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Contents

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8012-01, Session 1

Sofradir latest developments for infrared space detectors

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Sofradir is one of the leading companies that develop and produce infrared detectors. Space applications have become a significant activity and Sofradir relies now on 20 years of experience in development and production of MCT infrared detectors of 2nd and 3rd generation for space applications. Thanks to its capabilities and experience, Sofradir is now able to offer high reliability infrared detectors for space applications. These detectors cover various kinds of applications like hyperspectral observation, earth observations for meteorological or scientific purpose and science experiments. In this paper, we present a review of latest Sofradir's development for infrared space applications. A presentation of Sofradir infrared detectors answering hyperspectral needs from visible up to VLWIR waveband will be made. In addition a particular emphasis will be placed on the different programs currently running, with a presentation of the associated results as they relate to performances and qualifications for space use.

8012-02, Session 1

First flights of a new airborne thermal infrared imaging spectrometer with high area coverage

J. L. Hall, R. H. Boucher, D. J. Gutierrez, S. J. Hansel, B. P. Kasper, E. R. Keim, N. M. Moreno, M. L. Polak, M. G. Sivjee, D. M. Tratt, D. W. Warren, The Aerospace Corp. (United States)

A new, high-performance airborne thermal infrared imaging spectrometer, “Mako”, has recently completed its first engineering flights. The Mako sensor incorporates a novel spectrometer design which uses a convex diffraction grating in conjunction with a Dyson lens and operates at f/1.25. The instrument collects data in 128 spectral channels between 7.5 - 13.5 microns. The high optical throughput coupled with a fast-framing focal plane array permits large whiskbroom scans while maintaining low noise (< 0.1K NEDT), resulting in swath widths up to +/- 45 degrees at pixel resolutions of just 0.5 mrad. The sensor package sits on a commercial gyro-stabilized camera platform, and this has enabled additional collection strategies using pitch control of the sensor gimbal mirror, to either stare at targets or do multiple looks. The sensor was designed to fly on a Twin Otter aircraft, and it has been tested to altitudes of 12,000 ft MSL thus far. After successful initial check-out flights we devoted the final two days of the test period to science missions. The first flight was a day-time mission to California's Central Valley, where ammonia emissions from dairy farming and agriculture are abundant. The small-pixel, large area coverage of the new sensor is crucial in determining the contribution of localized sources of ammonia to the large pixel detections by NASA and ESA satellite sensors. The second science outing was a night-time flight to the Salton Sea region in California's Imperial Valley, where geothermal activity is pervasive. These flights have highlighted the significant capabilities of this new sensor.

8012-03, Session 1

SCD's uncooled detectors and video engines for a wide-range of applications

R. Frenkel, U. Mizrahi, L. Bikov, A. Giladi, N. Shiloah, S. Elkind, T. Czyzewski, R. Gazit, I. Kogan, S. Maayani, A. Amsterdam, I. Vaserman, O. Duman, Y. Hirsh, F. Schapiro, SCD Semiconductor Devices (Israel); A. Tuito, Israel Ministry of Defense (Israel)

Over the last decade SCD has established a state of the art small pitch VOx µ-Bolometer product line. Due to its overall size, weight and power advantages the uncooled technology is penetrating a large range of systems such as thermal weapon sights (TWS), driver vision enhancers (DVE) and digitally fused goggles (DENVG). In addition to a large variety of detectors, SCD has also recently introduced a modular video engine with open architecture. With minor modifications this engine can support both 25µm and 17µm pitch 384*288, 640*480 arrays.

In this paper we will describe the versatile range of applications supported by the products: From SWAP wide FOV/short range systems based on 17µm pitch technology, to very high sensitivity narrow FOV/ long range systems based on the 25µm pitch. These latter systems are already approaching the performance of traditional cooled 1D LWIR arrays. Along with detailed radiometric measurement results we will also incorporate supporting TRM3 system level calculations.

8012-04, Session 1

The new megapixel thermal imager family

J. Fritze, M. O. Münzberg, Carl Zeiss Optronics GmbH (Germany)

For long ranging imaging in high performing electro-optical systems visible cameras with HDTV resolution (1920x1080) are becoming the standard sensor for observation purposes during day. During night and for thermal imaging, significant reduced resolution has to be accepted over along period of time due to non-availability of adequate infrared detectors. In the meantime standard detectors with 1280x1024 are available on the market which provide at least SXGA resolution. ATTICA M is the newest member of Carl Zeiss Optronics ATTICA family of cooled thermal imagers, which uses an infrared detector with 1280x1024 pixels. ATTICA M can operate with a variety of infrared detectors either based on InSb or MCT as a detector material. ATTICA M is form and fit to the well known ATTICA Z and ATTICA P which is integrated in several military platforms in series production and can consequently be used to upgrade the related platforms. In detail three variants with different zoom optics covering the field of view range between 1,4° - 30° are available for a large scope of applications, on land, on the sea or in the air.

A newly developed video electronic is capable to operate the Megapixel detector as well as future dual band thermal imager detectors as soon as they are available on the market. The features and options are discussed as well as the performances compared to the current thermal imager generation.

8012-06, Session 1

A family of handheld thermal imagers

L. Sogno, Qioptiq S.A.S. (France); J. L. Fontanella, Thales Optronique S.A. (France)

TBDThe history of Sophie is a continuous evolution through world premiere and highly innovative improvements, starting in 1996 with the invention of the compact high performance hand held TI by Thales, to

cover now the full range of applications for defence thermal imagers.

In 1996 Thales produced the first hand held thermal imager for the dirty battlefield, which was a world premiere in term of weight, detection range, and price.

The second step in the evolution of Sophie included a large set of improvements such as image stabilization, or the possibility to locate the target in absolute coordinate, storage images, or the target location in stabilized mode.

The last step covers new applications such as survey and peace kipping, and taking advantage of the use of the 3-5 µm waveband increase the range detection, reduce the weight and the production cost. New features have been implemented, such as video storage, eye safe laser range finding, colour TV imager, GPS or x6 zoom.

8012-07, Session 1

New applications with a SWIR imager employing extended wavelengths

G. A. Tidhar, Optigo Directorate IAI-ELTA (Israel)

Recently, technological achievements have allowed SWIR imagers to operate at wavelength beyond the lattice-matched InGaAs:InP cutoff. A leading application in the SWIR band - Night vision, requires very low dark current levels, whereas the dark current increases as the cutoff wavelength increases. We demonstrate imaging applications made possible by utilization of dark current reduction, and the physics of background and objects radiance. A newly built imager is presented

8012-08, Session 2

Blast investigation by fast multispectral radiometric analysis

A. D. Devir, Y. Bushlin, I. Mendelewicz, A. B. Lessin, M. Y. Engel, IARD Sensing Solutions Ltd. (Israel)

Knowledge regarding the processes involved in blasts and detonations is required in various applications, e.g. missile interception, fire ball generation, final ballistics and IED identification. Blasts and detonations release large amount of energy in short time duration, some of this energy is released as intense radiation in the optical spectral bands. This paper proposes to measure the radiation released during the blast by fast multispectral radiometer at appropriately chosen different spectral bands simultaneously. These spectral bands provide extensive information on the physical and chemical processes that govern the blast through the time-dependences of molecular and aerosol components of the detonation products. Multi-spectral blast measurements are performed in the visible, SWIR and MWIR spectral ranges. Analysis of the cross-correlation between the measured multi-spectral signals gives the time dependence of the temperature, aerosol and gas composition of the blast. Farther analysis of the development of these quantities in time may indicate on the order of the detonation and amount and type of explosive materials. Examples of analysis of measured explosions are presented to demonstrate the power of the suggested fast multispectral radiometric analysis approach.

8012-09, Session 2

Open path FTIR detection of threat chemicals in air and on surfaces

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A remote infrared spectroscopy (RIRS) detection system was developed using a mid infrared (MIR) and near infrared (NIR) Fourier Transform interferometer, an infrared telescope and a cryocooled wide band, MCT detector. The system was used alone in passive mode IR emission measurements and was also coupled to a telescope enabled NIR-MIR thermal source for active mode measurements. Samples highly energetic compounds (HEM), chemical agent simulant (CWAS), toxic industrial compounds (TIC) in the gas phase and on metal surfaces as thin films and as solid phase samples were detected. Experiments in gaseous phase and on metal surfaces were carried out in passive and active modes. Experiments in solid phase were carried out in passive mode only. The analyzed samples were placed at different standoff distances: 1, 3, 8, 14, up to a maximum of 50 m. Different temperatures were used in the standoff detection system. Statistical treatments were applied to the recorded spectra and discriminant analysis was done to the recorded spectra from gas phase sample and on metal surface sample. Principal component analysis and cluster analysis were made to the emission spectra from solid phase samples. Limit of detection for the distances of 20-30 m were 50 µg/cm2 for TNT and RDX, using three times the signal to noise ratio (SNR) in passive mode.

8012-152, Session 2

Scene understanding and task optimisation using multimodal imaging sensors and context: a real-time implementation

B. Connor, I. Carrie, Thales Optronics Ltd. (United Kingdom); J. Letham, N. M. Robertson, Heriot-Watt Univ. (United Kingdom)

The aim of this paper is to describe the progress and results of an imaging system designed to optimise the performance of human operator tasks through exploitation of multimodal sensors and scene context. The performance of tasks such as surveillance, target detection and situational awareness is dependent on the scene content, the sensors available and the algorithms deployed. Intelligent analysis of the scene into contextual regions allows specific algorithms to be optimised and appropriate sensors to be selected, thereby increasing the performance of the operator's tasks. For example, a detection task could involve thermal imaging for detecting cars within a road region and visual multispectral cameras for detecting people within a forest region. Both situations require context-specific algorithms which will adapt as the scene changes. The contextual regions include road, sky and vegetation, and the dynamic detection of each region utilises different sensor modalities. For example, the system comprises Thales Optronics' high-resolution long wave infrared polarimeter and a four-band visible-near IR multispectral system. The polarimeter is useful for detecting strongly polarising regions, such as roads, whereas the multispectral system can be used to discriminate vegetation. The contextual concept is required to utilise other non-imaging sensors such as GPS and acoustic, although the system described in this paper contains only imaging sensors. The paper will describe the overall system concept and a real-time imaging demonstrator using GPUs, which will be used for future demonstrations of the context-specific processing. The real-time system simultaneously displays and processes all sensor inputs and allows the operator to combine them in order to highlight areas in each region. Simulations of the context-specific scene analysis will be described using sensor data from a moving vehicle in a rural environment. The results will be compared to ground truth measurements and ROC curves will be shown to illustrate the performance of a detection system with and without context.

8012-11, Session 3

Simultaneous multispectral framing infrared camera using an embedded diffractive optical lenslet array

M. Hinnrichs, Pacific Advanced Technology, Inc. (United States)

Using diffractive optical lenses configured in an array and placed

in close proximity to the focal plane array will enable a small compact simultaneous multispectral imaging camera. The number of simultaneously imaged spectral bins is determined by the number of individually configured lenslets in the array. Each lenslet images at a different wavelength. Using the lenslet array with dual-band focal plane arrays will increase the number of simultaneous spectral images by a factor of two by exploiting multiple diffraction orders.

The paper will present various designs for different applications and different spectral regions from visible to long-wave infrared. There will also be a discussion of how the co-registered spectral images in each frame will enable real-time processing of spectral/image detection algorithms by logic implemented in FPGA's embedded in a camera.

This approach to spectral imaging has applications in the detection of chemical agents in both aerosolized form and as a liquid on a surface. It also can be applied to weaponized biological agent detection and IED detection in various forms from manufacturing to deployment and post detection in the forensic process. It also can be applied to missile seekers and missile warning sensors.

8012-12, Session 3

Infrared-based early warning system for bird strike prevention at Frankfurt airport

M. O. Münzberg, H. Vogel, A. Schilling, M. Welk, Carl Zeiss Optronics GmbH (Germany); H. Cramer, J. Schlosshauer, FusionSystems GmbH (Germany)

In aviation bird strike is a high risk especially during take-off and landing. The repair costs and the Aircraft On Ground (AOG) time after bird strikes are high and serious accidents occurred in the past. In case of crossing a bird migration route the risk is even increased. Because flock of migratory birds mostly have a constant route, flight height and velocity, early warning is possible with a thermal imaging system.

In 2008 a feasibility study was finished for the Frankfurt airport and published in the SPIE proceedings 2009. The study showed that bird migration can be measured with thermal imagers with sufficient accuracy. In 2009 the proposed system was selected to monitor the landing corridor of the new runway Northwest of the Frankfurt airport.

The bird crossing of the runway corridor is measured with in total 3 observation towers located at the river Main which is used for orientation by the birds. Each tower carries an early warning system which consists of two pairs of stereoscopic thermal imaging cameras. The mid wavelength range (3 - 5 µm) cameras feature high geometrical (640 x 512 pixel) and thermal resolution (< 20 mK). A stereoscopic pair measures the swarm size, direction of flight and velocity in real time and with high accuracy. From these results an early warning is derived under all relevant weather conditions during day, night and twilight and the hazard level of the flock estimated together with the possible collision times is calculated.

The fixed focus cameras are thermally compensated and designed for ultra low distortion. Each stereoscopic pair is aligned in the sub-pixel range and is controlled by a reference beam to ensure that the alignment is preserved under all environmental conditions and over a very long time. The technical system concept is discussed.

8012-13, Session 3

Time-varying phase diversity turbulence compensation

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

For visual identification purposes over large distances it is crucial to compensate visual artifacts due to atmospheric turbulence. In this paper we propose a new method to compensate the visual effects of turbulence, which makes identification possible over larger distances. Our method is based on applying phase diversity imaging by adaptive optics in free-running mode (without feedback loop), which enables us to compensate turbulence for multiple isoplanatic angles. Given several known wave front aberrations, locally the optimal wave front aberration is estimated and thus the optimal - turbulence free - image is known. In this paper we show with results on simulated data that our method performs well under different conditions and its advantages over existing methods.

8012-14, Session 4

Focal plane generation of multi-resolution and multi-scale image representation for low-power vision applications

J. Fernández-Berni, R. A. Carmona-Galán, L. Carranza-González, IMSE-CNM (Spain); A. Zarandy, Computer and Automation Research Institute (Hungary); Á. B. Rodríguez-Vázquez, IMSE-CNM (Spain)

Early vision stages represent a considerably heavy computational load. A huge amount of data needs to be processed under strict timing and power requirements. Conventional architectures usually fail to adhere to the specifications in many application fields, especially when autonomous vision-enabled devices are to be implemented, like in lightweight UAVs, robotics or WSNs. A bioinspired architectural approach can be employed consisting in a hierarchical division of the processing chain, conveying the highest computational demand to the focal plane. There, distributed processing elements, concurrent with the photosensitive devices, influence the image capture and generate a pre-processed representation of the scene that still contains all the necessary information. These focal-plane operators are implemented by analog building blocks, which may individually be a little imprecise, but render the appropriate image processing. The biological inspiration is manifold; a highly demanding computational task is implemented by an aggregate of simple elements, with moderate accuracy and speed, but energy efficient.

As a proof of concept, we have developed a 176x144-pixel smart CMOS imager that delivers lighter but enriched representations of the scene. Each pixel of the array contains a photosensor and some switches and weighted paths allowing reconfigurable resolution and spatial filtering and supporting an energy-based image representation. These functionalities greatly simplify the operation of the subsequent digital processor implementing the high level logic of the vision algorithm. The resulting figures, 5.6mW@30fps, permit the integration of the smart image sensor with a wireless interface module (Imote2 of Memsic Corp.) for the development of vision-enabled WSN applications.

8012-15, Session 4

Advanced multi-function infrared detector with on-chip processing

L. Langof, D. Nussinson, E. Ilan, S. Elkind, R. Dobromislin, I. Nevo, F. Khinich, M. Labilov, Z. Calahorra, S. Vaserman, T. Markovitz, SCD Semiconductor Devices (Israel); O. Manela, Elbit Systems Electro-Optics El-Op Ltd. (Israel)

Modern electro-optical systems contain several components such as thermal imager, laser designator, laser range finder, etc. The demand for compact systems with low power consumption and low cost can be addressed by incorporating some of the traditional system abilities into the IR detector. We present SNIR, a new type of detector, which consists of a Readout Integrated Circuit (ROIC) with advanced on-chip signal processing. The ROIC is bump-bonded to a 640x512 InSb detector array of 15µm pitch. SNIR digital ROIC can be operated in either of four different modes of operation. The first operation mode is standard thermal imaging, which has typical functionalities and performance for MWIR detector. The second operation mode is a dual-function mode that includes both standard thermal imaging and information on Asynchronous Laser Pulse Detection (ALPD) for each pixel. The detection probability of a laser pulse was significantly increased by integrating a dedicated in-pixel circuit for identifying a fast signal temporal profile. Since each pixel has internal processing to identify laser pulses, we can also measure the elapsed time between a trigger to the detection of a laser pulse. This yields a third mode of operation in which the detector is synchronized to a laser and becomes a Two-dimensional Laser Range Finder (TLRF). The forth operation mode is dedicated to Low Noise Imaging (LNIM) for the SWIR band, where the IR radiation signal is low in both passive or active imaging. We review some of the predicted and measured results for the different modes of operation, both at the detector level and at the system level.

8012-18, Session 4

Analysis and simulation of CTIA-based pixel reset noise

D. A. Van Blerkom, Forza Silicon Corp. (United States)

This paper describes an approach for accurately simulating the reset noise of CTIA-based pixels. Using a circuit simulator to find the reset noise of a CTIA based pixel is not straightforward, due to the noise sampling and charge re-distribution after the reset switch opens. This often leads to an equation-based analysis of the pixel noise, which is inadequate for actual design work and incompatible with a mixed-signal design flow for advanced ROIC designs.

In a CTIA-based ROIC, the start of pixel integration is defined by the opening of the CTIA reset switch. The opening of this switch down-converts the wideband noise of the circuit to DC, and the charge is then redistributed by the CTIA to create an output reset noise. This reset noise can be removed by correlated double sampling (CDS). However, it is important to understand the magnitude of the reset noise in order to evaluate the effectiveness of the CDS scheme. CDS can be performed either in the pixel, or externally in the analog or digital domains. The specifications of the signal chain depend on the amount of reset noise and the degree of cancellation required.

Simulation of the reset noise in SPICE is not straightforward, since the charge is redistributed after the switch opens, and the noise on the two capacitors is correlated and cannot be treated independently. We describe a simulation technique that gives accurate estimates of the pixel reset noise, and verify the results using Spectre-RF.

8012-19, Session 4

Calibration method for division of focal plane polarimeters in the optical and near-infrared regime

T. York, V. Gruev, Washington Univ. in St. Louis (United States)

Advances in nanofabrication allow for the creation of metallic nanowires acting as linear polarizers in the visible and near infrared regime. The monolithic integration of silicon detectors and pixilated nanowire metallic polarization filters allows for an efficient realization of high resolution polarization imaging sensors. These silicon sensors, known as division of focal plane polarimeters, capture polarization information of the imaged environment from ~400nm to 1050nm wavelength. The performance of the polarization sensor can be degraded by both irregularities in the fabrication of the nanowires and possible misalignment errors during the final deposition of the optical nanowire filters on the surface of the imaging sensor. In addition, electronic offsets due to the readout circuitry, electronic crosstalk, and optical crosstalk will also negatively affect the quality of the polarization information. Partial compensation for many of these post-fabrication errors can be accomplished through the use of a camera calibration routine. This paper will describe one such routine, and show how its application can increase the quality of measurements in both the degree of linear polarization and angle of polarization in the visible spectrum. The imaging array of the division of focal plane polarimeter is segmented into two by two blocks of superpixels. The calibration method chooses one of the four pixels as a reference, and then a gain and offset for each of the remaining three is computed based on this reference. The output is a calibration matrix for each pixel in the image array.

8012-157, Session 4

Hexagonal sampling in the infrared domain: an introduction to array set addressing

N. I. Rummelt, Air Force Research Lab. (United States); G. L. Barrows, Centeye, Inc. (United States); M. A. Massie, Nova Sensors (United States)

No abstract available

8012-20, Session 5

Thermo-electrically cooled shortwave infrared and longwave infrared dual-band quantum-dot photodetector

J. N. Vaillancourt, Applied NanoFemto Technologies (United States); X. Lu, Univ. of Massachusetts Lowell (United States)

In this paper, we report a SWIR (900nm-1700nm) and LWIR (7.5um-10um) dual-band QDIP in a standard TO-66 package. Photodetectivities of 4x108 cmHz1/2/W and 1.4x107 cmHz1/2/W have been achieved at 270K for the SWIR and the LWIR bands, respectively. High photoresponsivities of 1.6A/W and 0.025A/W have also been demonstrated at 270K for the SWIR and the LWIR bands, respectively.

8012-21, Session 5

Design of broadband QWIPs

V. Guériaux, A. Nedelcu, A. Coulibaly, L. Dua, N. Brière de l'Isle, V. Trinité, X. Marcadet, Alcatel-Thales III-V Lab. (France)

One of the key features of quantum well infrared photodetectors is the narrow absorption band. This inherently narrow spectral response has been proven to be an excellent asset to enhance the contrast in thermal images. Yet, some applications, as the infrared spectroscopy, require broadband detection. Several approaches have been used to get a broadband response with QWIPs. In particular, superlattices and digital graded barriers in the active layers have been proposed to get transitions between minibands in the first case and multiple transitions in the second case. A number of authors reported stacked and interlaced designs using regular QWIPs.

However, most of these detectors exhibit strong spectral changes with the bias voltage. Moreover, in this paper, we show that conventional design approaches lead to a systematic extinction of longer wavelengths when the detector operates above BLIP temperature. We investigate both numerically and experimentally the underlying origins of these spectral changes. Several active layers have been grown, processed and characterized. Finally we propose a specific design which leads to a spectral shape quasi-independent on the operating temperature or applied bias.

8012-22, Session 5

Performance of the QWIP focal plane arrays for NASA's Landsat Data Continuity Mission

M. D. Jhabvala, NASA Goddard Space Flight Ctr. (United States); K. Choi, U.S. Army Research Lab. (United States); A. Waczynski, A. T. La, NASA Goddard Space Flight Ctr. (United States); M.

Sundaram, QmagiQ, LLC (United States); E. M. Costard, Thales Research & Technology (France); C. A. Jhabvala, E. Kan, D. M. Kahle, R. Folz, NASA Goddard Space Flight Ctr. (United States); N. Boehm, M. Hickey, Global Science & Technology, Inc. (United States); J. Sun, U.S. Army Research Lab. (United States); T. Adachi, Catholic Univ. of America (United States); N. P. Costen, L. A. Hess, Munz Engineering Inc. (United States); H. Facoetti, Alcatel-Thales III-V Lab. (France); M. Montanaro, Sigma Space Corp. (United States)

The focal plane assembly for the Thermal Infrared Sensor (TIRS) instrument on NASA's Landsat Data Continuity Mission (LDCM) consists of three 512 x 640 GaAs Quantum Well Infrared Photodetector (QWIP) arrays. The three arrays are precisely mounted and aligned on a silicon carrier substrate to provide a continuous viewing swath of 1850 pixels in two spectral bands defined by filters placed in close proximity to the detector surfaces. The QWIP arrays are hybridized to Indigo ISC9803 readout integrated circuits (ROICs). An overview of the focal plane assembly will be described including the construction and test requirements of the focal plane. A variety of QWIP arrays were evaluated and all were found to be suitable. The final discriminating parameter was the spectral uniformity of individual pixels relative to each other. The performance of the fully assembled, NASA flight-qualified, focal plane assembly with an emphasis on the spectral characteristics of the detector arrays will be reviewed. Both the grating-based and the corrugated QWIP designs will be described and data presented on each technology.

8012-23, Session 5

Electromagnetic modeling of C-QWIP FPA pixels

K. Choi, U.S. Army Research Lab. (United States); M. D. Jhabvala, NASA Goddard Space Flight Ctr. (United States); D. P. Forrai, L-3 Communications Cincinnati Electronics (United States); A. Waczynski, NASA Goddard Space Flight Ctr. (United States); J. Sun, U.S. Army Research Lab. (United States); R. A. Jones, L-3 Communications Cincinnati Electronics (United States)

Rigorous electromagnetic field simulations are applied to calculate the external quantum efficiency of various QWIP pixel geometries with thinned substrates. We found that for a 24 x 24 x 1.5 micron3 cross grating-QWIP, the QE is peaked at 13.0, 11.0 and 8.4 microns, insensitive to the grating periods. These peaks are identified as the first three harmonic resonances associated with the pixel resonant cavity. The corresponding QE are 9.2, 11.3, and 3.34%, respectively. When the pixel is reduced to 18 x 18 x 1.5 mircon3, the first harmonic peak is shifted to 12.0 microns with a 10.2% QE, and the second harmonic peak is shifted to 9.6 microns with a 6.7% QE. For a regular prism-shaped corrugated-QWIP with a 25 micron pitch, the QE oscillates about its classical value of 24.5% within the calculated wavelength range of 3 to 12 microns. A peaked value of 35% occurs at 8.6 microns. For pyramid-shaped C-QWIPs, the maximum QE is 42% and for cone-shaped C-QWIPs, it is 35%. In the presence of an anti-reflection coating, the oscillation amplitude diminishes and the average value generally rises to near its peak value. The simulation results are compared with the existing data on grating-QWIP FPAs and prism-shaped C-QWIP FPAs and show agreement for both.

8012-24, Session 6

Update on III-V superlattice material characterization and FPA performance

M. Z. Tidrow, U.S. Army Night Vision & Electronic Sensors Directorate (United States); L. Zheng, Institute for Defense Analyses (United States); S. Bandara, L. Aitcheson, N. Supola, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Type II strained layer superlattice (SLS) technology has shown great potential as an alternative infrared material for future military sensing systems. Significant progress has been made in single detector designs and FPA performance. Along with the FPA development, SLS material studies are carried out on the Shockley-Reed-Hall lifetime, lifetime killing defects and mechanisms. The results of the study provide deep understanding and insights of the material physics. In this presentation, we will give an overview of recent progress made in the SLS technology including material characterizations, device designs, defect studies and FPA performance.

8012-25, Session 6

Recent advances in high-performance antimonide-based superlattice FPAs

M. Razeghi, Northwestern Univ. (United States)

Infrared detection technologies are now entering the third generations with more and more demanding requirements for higher device performance, higher operating temperature, higher resolution, multiple color detectors as well as better yield and lower manufacturing/operating cost. With unique advantages and significant progress achieved in recent years, Type II antimonide based superlattices (T2SL) are making firm steps toward the new era of focal plane arrays.

In this talk, we will present the four research themes towards the third generation imagers based on T2SL at the Center for Quantum Devices. High performance LWIR mega pixel focal plane arrays (FPAs) are demonstrated at 80K with an NEdT of 23.6 mK using a f/2 optics, an integration time of 0.13 ms and a 300K background. MWIR and LWIR FPAs on non-native GaAs substrates are demonstrated as a proof of concept for the cost reduction and mass production of this technology. In the MWIR regime, progresses have been made to elevate the operating temperature of the device, in order to avoid the burden of liquid nitrogen cooling. We have demonstrated a quantum efficiency above 50%, and a detectivity of 7x1011 cm.Hz1/2/W at 150K for 5 m cut-off single element devices. Progress on LWIR/LWIR dual color FPAs as well as novel approaches for FPA fabrication will also be discussed.

8012-26, Session 6

Current developments for type-II superlattice imaging systems

F. Rutz, R. H. Rehm, M. Walther, M. Masur, A. Wörl, J. Schmitz, M. Wauro, J. Niemasz, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); R. Scheibner, J. Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

InAs/GaSb-based type-II superlattice (SL) photodiodes have considerably gained interest as high-performance infrared (IR) detectors. Beside the excellent properties of SLs, like the relatively high effective electron mass suppressing tunneling currents, the low Auger recombination rate, and a high quantum efficiency, the bandgap can be widely adjusted within the IR spectral range from 3 - 30 µm depending on layer thickness rather than on composition. SL growth and process technology has shown a tremendous progress during the last years. Fully integrated SL cameras have been demonstrated by several groups worldwide.

The Fraunhofer Institute for Applied Solid State Physics (IAF) works together with AIM Infrarot-Module GmbH on the fabrication of SL camera modules. A mature, molecular beam epitaxy based growth process and a reproducible III/V-process technology has been set up to facilitate fabrication of bispectral InAs/GaSb SL detector arrays for the mid-IR spectral range between 3-5 µm. As the world's first third generation IR detector based on dual-color InAs/GaSb SL technology, the development at Fraunhofer IAF is an important milestone in IR detector technology. The research and development activities at Fraunhofer IAF continue in order to raise the quantum efficiency with thicker absorber layers, to increase the spatial resolution using a smaller pixel pitch, and to extend the spectral range. In order to improve pixel yield, much effort is put in improving and monitoring the quality of the substrate and the epilayers. This talk will give an insight in the current status of SL IR detector properties and performance as well as fabrication aspects of the SL technology.

8012-27, Session 6

Performance optimization of long-wave infrared detectors based on InAs/GaSb strained layer superlattices

E. A. Plis, N. Gautam, S. A. Myers, M. N. Kutty, B. Klein, M. Naydenkov, S. Krishna, Ctr. for High Technology Materials (United States)

Photodetectors operating in the long-wave infrared (LWIR, 8-14 um) spectral band could be potentially useful for a wide variety of military and civil applications. The basic material properties of type-II InAs/GaSb strained layer superlattices (SLSs) provide a prospective benefit in the realization of high performance IR photodetectors with cut-off wavelengths in the LWIR range. In particular, InAs/GaSb SLS are theorized to have suppressed Auger recombination relative to the bulk mercury-cadmium-telluride (MCT) material leading to improved temperature operation limits. In addition, normal incidence absorption is permitted in type-II SLSs, contributing to high quantum efficiencies. Whereas SLS detectors are expected to demonstrate lower dark current with respect to MCT detectors operating in the same wavelength range due to a larger effective mass (~ 0.040m0 for SLS and ~0.0088m0 for MCT), which has not yet been experimentally shown. The dark current density demonstrated by SLS LWIR detectors is at least two orders of magnitude higher than that routinely achieved by MCTs.

The performance of LWIR SLS detectors may be significantly improved by optimization of SLS crystalline quality. Parameters to optimize include, but are not limited to, V/III ratios for the main constituent layers (InAs and GaSb), substrate temperature, and type of interface between the SLS layers.

In this paper, we report on optimization of InAs/GaSb SLS LWIR detector performance achieved by the optimization of MBE growth parameters. Dependence of detector dark current density and specific detectivity on change in interface type and V/III flux ratio (Sb/Ga and As/In) will be discussed.

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8012-28, Session 6

Effects of the phonon energy and carrier concentration on the carrier lifetime in LWIR and MWIR type-2 SLS and MCT materials for IR photodetector technology

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Shockley-Read-Hall (SRH), radiative and Auger recombination processes in n- and p-type GaSb-InAs Strained Layer Superlattices are compared to those in n-type MCT. The carrier lifetime values up to 32 ns in LWIR SLS, 75 ns in MWIR SLS and 1 us in LWIR MCT at T=77 K were measured by the optical modulation response technique from the dependences of the minority carrier lifetimes on excess carrier concentration. The significant difference in the carrier lifetime is partially explained by the large difference in LO phonon energy in Type-2 SLS and MCT. The background carrier concentration was determined from the dependences of PL intensity and carrier lifetime on excitation backed by measurements of the period of Shubnikov-de-Haas oscillations. The radiative recombination coefficients for the SLS materials were calculated using the measured fundamental absorption spectra and the lateral and vertical effective masses. The latter were obtained from cyclotron resonance measurements in the Faraday and Voight configurations.

Experimental data confirmed that in Type-2 SLS materials with the background doping concentration level of 10^16 1/cm^3 the carrier lifetime is defined by the SRH processes rather than Auger recombination. A low photon state density justified the minor role of the radiative recombination. A rapid change of the carrier lifetime with excess carrier concentration in low doped LWIR SLS materials versus relatively slow change in moderately doped structures indicated the important role of population of the acceptor-like mid-gap states in the SRH processes.

8012-29, Session 7

Dual-band response from InAs/GaSb strained layer superlattice detectors with nBn design

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Multicolor detectors are desirable in a variety of infrared (IR) applications related to remote sensing and object identification. Detectors based on mercury cadmium telluride (MCT) and interband transitions (quantum well infrared detectors, QWIPs) have been the dominant technologies for such applications. MCT detectors have the high quantum efficiency but are plagued by large tunneling currents limiting due to their low effective mass and the lack of spatial uniformity over large areas decreases the yield for large format focal plane arrays. QWIPs, on the other hand, are very uniform but have low quantum efficiency and large dark current.

SLS based detectors have been a subject of active research in the recent past and exploit a type-II bandstructure that exists in the InAs/GaSb system. This is theoretically predicted to lead to a decrease in the dark current due to reduced tunneling and lower Auger recombination rates. By optimizing the oscillator strength in this material system, a large quantum efficiency and responsivity can be obtained. The dual-color camera operating in mid-wave IR (MWIR) region ("blue channel", low-temperature 50 % cut-off wavelength (lambda 50% cut-off) of 4 um / "red channel" (lambda 50% cut-off = 5 um) has been recently demonstrated by IAF. Dual-color single element detectors operating in MWIR and LWIR bands (lambda 50% cut-off of ~ 4.5 um and ~ 8 um at 77K) have been demonstrated by UNM in 2006.

In this paper, we report on dual-band InAs/GaSb SLS detectors with nBn design operating in MWIR/LWIR spectral bands (lambda 50% cut-off ~ 5.5 um and 10.0 um). The detailed temperature dependent optical and electrical characterization of these devices was undertaken. The responsivity and specific detectivity were equal to 1.6 A/W and 1.2 x 10^11 Jones (77 K, + 1 V) for MWIR absorber; 1.2 A/W and 1.2 x 10^10 Jones (77 K, -1V) for LWIR absorber. The details of dual-band detector performance will be discussed in the presentation.

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8012-30, Session 7

Minority carrier vertical transport in InAs/GaSb type-II strained layer superlattices for infrared focal plane array applications

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InAs/GaSb type-II strained layer superlattices have attracted significant attention due to their promising properties for detection of infrared

radiation. Their performance is predicted to be superior over HgCdTe due to suppressed tunneling currents and reduced Auger 7 recombination rates. In the typical focal plane array pixel configuration it is the vertical (along the growth direction) mobility of minority carriers which is relevant to the detector performance. In this paper we report on vertical mobility of carriers measured in p-doped InAs/GaSb superlattice with nominally 10µm cut-off wavelength. Since the Hall Effect technique is not applicable for vertical transport measurements, magnetoresistance approach has been used instead. The magnetoresistance data obtained at (4 -320)K and (0-12)T temperature and magnetic field ranges, respectively, have been analysed using mobility spectrum technique and multi-carrier fitting procedure. Two carriers have been identified with mobility at 67K of 550cm2/Vs and 2000cm2/Vs, respectively. Their mobility at room temperature is 220cm2/Vs and 1640cm2/Vs respectively. Above 50K concentration of both carriers shows thermal activation with activation energy of 50meV matching expected energy gap of the material. Below 50K concentration of low mobility carriers saturates at 1x1012cm-3 while the high mobility carrier shows no saturation. At 67K the concentrations are at the level of low 1012cm-3 reflecting the number of carriers available for tunnelling through barriers rather than concentration in classic sense. Although magnetoresistance data does not allow for carrier type identification, the behaviour of high and low mobility carriers is consistent with minority electrons and majority holes, respectively, in p-type material.

8012-31, Session 7

Noise performance analysis of MWIR InAs/GaSb superlattice pin photodiodes

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We report on the full electro-optical characterization of MWIR InAs/GaSb superlattice pin photodiodes. Our results include dark current, spectral response, quantum efficiency measurements and a detailed study of dark current noise. A dedicated test bench was developed to perform these noise measurements. Our experimental results show that, up to -250mV, the noise of the detectors under test is limited by the theoretical Schottky contribution. The 1/f noise remains small. Realistic detectivity values (using measured noise values instead of a theoretical Johnson-limited noise) are deduced from our measurements. The comparison of noise measurements obtained on different detectors allows us, for example, to compare the performances of symmetrical and asymmetrical structures.

8012-32, Session 7

Low-temperature noise measurements of an InAs/GaSb-based nBn MWIR detector

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Recent experiments on conventional p-on-n and n-on-p Type II superlattices (SLS) infrared detectors still indicate larger than theoretically predicted dark current densities, despite the well known suppression of the Auger recombination mechanism. Rather, dark current in SLS is thought to still be limited by trap-assisted tunneling in the depletion region and surface leakage currents resulting from lack of fully passivated mesa sidewalls. An emerging infrared detector technology utilizing a unipolar, single-band barrier design, the so-called nBn architecture, potentially suppresses these remaining noise current mechanisms. In this report, measurements of the noise current spectral density of a mid-wave infrared nBn detector, composed of a type-II InAs/GaSb strain layer superlattice (SLS) absorber (n) and contact (n) layers with an AlGaSb barrier (B), under low-temperature, low-background conditions are presented. Here, noise was measured using a transimpedance amplifier incorporating a dewar-mounted feedback resistor RF and source-follower MOSFET, both held at 77 K. This configuration confines high detector impedance issues to the dewar, minimizes Johnson noise due to the electronics, and enhances bandwidth by reducing stray capacitance. Features of the detector's noise spectra at different bias and temperatures are examined.

8012-33, Session 7

Scaling up antimonide wafer production: innovation and challenges for epitaxy ready GaSb and InSb substrates

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In this paper we describe the volume manufacture of GaSb and InSb substrates that are used in the epitaxial growth of advanced III-V infrared detector structures. Results will be presented on the crystal growth of 2", 3" and 4" GaSb ingots grown by the Czochralski method. The evolution of crystal growth production techniques will be discussed with material quality comparisons made between ingots produced on current format production pullers, and crystals that are being developed by Wafer Technology using techniques that are more commonly found in the of 'volume' manufacture of other III-V materials such as GaAs and InP. This work will also present results for surface quality assessments of epitaxy ready GaSb substrates processed on multiwafer polishing platforms and will describe the challenges and innovation required to deliver high consistency substrate finishing for large diameter substrate types. An appraisal will be given of the challenges required to deliver 6" diameter antimonide substrates and how current production technologies can be successfully scaled to deliver this product and so support the development of next generation infrared imaging technologies.

8012-34, Session 7

Fabrication and performance of InAs/GaSb superlattice LWIR detectors

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We describe our recent efforts in developing InAs/GaSb strained-layer superlattices for LWIR and dual-band infrared detectors on the MDA-funded FastFPA program. InAs/GaSb superlattice wafers were received from epi vendors, trusted entities, and internal resources. For LWIR single-color devices, dark current densities at 78K of Jd = 2x10-5 A/cm2 for large-area diodes (λCO=10 µm) are demonstrated for JPL-grown structures. For dual-band detectors, we review modeling and experimental data for LWIR-LWIR structures based on barrier-based device architectures, and demonstrate 78K Jd = 1.8x10-4 A/cm2 for the longer band (λCO=10.5 µm). The measured dark currents for both the single-color and dual-band structures are within 10x of the HgCdTe performance trendline for the respective device. We also present characterization data including quantum efficiency, NEI, and NETD for simple heretojunction LWIR FPAs. Baseline LWIR FPAs utilized a p-on-n architecture compatible with commercially available ISC9705 ROICs. Progress in fabricating FPAs that incorporate more advanced designs with the n-on-p architecture will also be presented. Finally, we review our efforts to improve FPA quantum efficiency by removing the GaSb substrate using a high-selectivity dry etch process.

8012-35, Session 7

Performance analysis of symmetrical and asymmetrical InAs/GaSb superlattice pin photodiode

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Symmetric and asymmetric mid-wavelength infrared (MWIR) InAs/GaSb superlattice pin photodiode were fabricated by MBE on p-type GaSb substrate and characterized as a function of temperature. The symmetric SL structure was made of 8 InAs monolayers (MLs) and 8 GaSb MLs and exhibits at 80K a cut-off wavelength (c) of 4.5μm, while the asymmetric SL design was composed of 7.5 InAs MLs and 3.5 GaSb MLs for c = 5.5μm at 80K.

Several electro-optical characterizations including dark current, noise measurements, capacitance-voltage measurements, spectral response and quantum efficiency were performed on single detectors in the temperature range [77K-300K]. Complementary Hall measurements were made on specific non-intentionally doped InAs/GaSb SL samples to extract residual carrier concentration at low and high temperature.

Results obtained were compared and analyzed in order to define optimized SL structure design for the high operating temperature in the MWIR domain.

8012-36, Session 7

Superlattice barrier infrared detector development at the Jet Propulsion Laboratory

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We report our recent efforts in achieving state-of-the-art performance in superlattice based infrared photodetectors using the barrier infrared detector (BIRD) architecture. We used photoluminescence measurements for evaluating detector material and studied the influence of the material quality on the intensity of the photoluminescence. We performed direct noise measurements of the superlattice detectors and demonstrated that while intrinsic 1/f noise is absent in superlattice heterodiode, side-wall leakage current can become a source of strong frequency-dependent noise. We developed an effective dry etching process for these complex antimonide-based superlattices that enabled us to fabricate single pixel devices as well as large format focal plane arrays. We describe the demonstration of a 1024 x 1024 pixel long-wavelength infrared focal plane array based the complementary barrier infrared detector (CBIRD) design. An 11.5 μm cutoff focal plane without antireflection coating has yielded noise equivalent differential temperature of 53 mK at operating temperature of 80 K, with 300 K background and cold-stop.

8012-37, Session 8

Toward 17μm pitch heterogeneously integrated Si/SiGe quantum well bolometer focal plane arrays

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Most of today's commercial solutions for un-cooled IR imaging sensors are based on resistive bolometers using either Vanadium oxide (VOx) or amorphous Silicon (a-Si). Despite the long history for both materials, market penetration outside high-end applications is still limited. By allowing actors in adjacent fields, such as those from the MEMS industry, to enter the market, this situation could change. This requires, however, that technologies fitting their tools and processes are developed. Heterogeneous integration of Si/SiGe quantum well bolometers on standard CMOS read out circuits is one approach that could easily be adopted by the MEMS industry. Due to its mono crystalline nature, the Si/SiGe thermistor material has excellent noise properties that result in a state-of-the-art signal-to-noise ratio. The material is also stable at temperatures well above 450°C which offers great flexibility for both sensor integration and novel vacuum packaging concepts.

We have previously reported on heterogeneous integration of Si/SiGe quantum well bolometers with pitches of 40μm x 40μm and 25μm x 25μm. The technology scales well with small pixel pitches and in this paper, we will report on our work on developing the heterogeneous integration technology for Si/SiGe QW bolometers with a pixel pitch of 17μm x 17μm. We will present details of the bolometer design and the integration process along with manufactured bolometer test structures. We also will discuss the manufacturing challenges that we have experienced.

8012-38, Session 8

Experimental LWIR spectral characterization of wavelength selective microbolometers

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Past work has discussed the microfabrication process of wavelength selective germanium dielectric supported microbolometers. Here we will present experimental long wave infrared spectral response characterization of dielectric coated Salisbury screens suitable for use in microbolometer focal plane arrays. We have demonstrated a micro fabricated germanium dielectric support structure layer that replaces the usual silicon nitride structural layer in microbolometers. The fabricated microbolometers consist of a chromium resistive sheet as an absorber layer above a germanium dielectric/air gap/ interference structure. In order to produce wavelength selective narrowband absorption, the general design rules for germanium dielectric supported microbolometers show that the thickness of air gap should be a half wavelength thick and the optical thickness of germanium layer a quarter dielectric wavelength thick. This structure is also air gap tunable; i.e., by varying only air gap thickness, the center wavelength of absorption curve is shifted. To characterize the spectral responses of the fabricated microbolometers, FTIR microscope measurements have been made on a number of the different devices, including 50μm x 50μm pixels. We show that the fabricated germanium dielectric supported microbolometer structuctures are able to produce excellent tunable narrowband absorption in LWIR band, and experimentally show efficient three color LWIR spectral response using three wavelength selective pixels. This research was supported by US Army RDECOM-ARDEC Contract No. W15QKN-05-C-0449.

8012-39, Session 8

Infrared phased-array sensor

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Infrared (IR) dipole antenna-coupled metal-oxide-metal (MOM) tunnel diodes provide a unique detection mechanism that allows for determination of the polarization and wavelength of an optical field. By integrating the MOM diode into a phased-array antenna, the angle of arrival and degree of coherence of received IR radiation can also be determined. The angular response characteristics of IR dipole antennas are determined by boundary conditions imposed by the surrounding dielectric or conductive environment on the radiated fields. To explore the influence of the substrate configuration, single dipole antennas are fabricated on both planar and hemispherical lens substrates. Measurements demonstrate that the angular response can be tailored by the thickness of the electrical isolation stand-off layer on which the detector is fabricated and/or the inclusion of a ground plane. Directional detection of IR radiation is achieved with a pair of dipole antennas coupled to a MOM diode through a coplanar strip transmission line.

The direction of maximum angular response is altered by varying the position of the diode along the transmission line connecting the antenna elements. By fabricating the devices on a quarter-wavelength layer above a ground plane, narrow beam widths of 35° full width at half maximum and reception angles of ± 50° are achievable with minimal side lobe contributions. The two-element phased array can also be used to assess the degree of coherence of a partially coherent source. With the illumination source held fixed, the spatial coherence function is measured by varying the separation of the antenna elements.

8012-40, Session 8

High-speed uncooled MWIR hostile fire indication sensor

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Hostile fire indication (HFI) systems require high-resolution sensor operation at extremely high speeds to capture hostile fire events, including rocket-propelled grenades, anti-aircraft artillery, heavy machine guns, anti-tank guided missiles and small arms. HFI must also be conducted in a waveband with large available signal and low background clutter, in particular the mid-wavelength infrared (MWIR). The shortcoming of current HFI sensors in the MWIR is the bandwidth of the sensor is not sufficient to achieve the required frame rate at the high sensor resolution. Furthermore, current HFI sensors require cryogenic cooling that contributes to size, weight, and power (SWAP) in aircraft-mounted applications where these factors are at a premium. Based on its uncooled photomechanical infrared imaging technology, Agiltron has developed a low-SWAP, high-speed MWIR HFI sensor that breaks the bandwidth bottleneck typical of current infrared sensors. This accomplishment is made possible by using a commercial-off-the-shelf, high-performance visible imager as the readout integrated circuit and physically separating this visible imager from the MWIR-optimized photomechanical sensor chip. With this approach, we have achieved high-resolution operation of our MWIR HFI sensor at 1000 fps, which is unprecedented for an uncooled infrared sensor. We have field tested our MWIR HFI sensor for detecting all hostile fire events mentioned above at several test ranges under a wide range of environmental conditions. The field testing results will be presented.

8012-41, Session 9

Uncooled detector development at Raytheon

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ABSTRACT

At the 2010 meeting of the SPIE Defense, Security and Sensing Symposium, Raytheon reported on the status of their efforts to establish a high rate uncooled detector manufacturing capability. At that time we had just finished the transition of the 640x480 - 25um product to our 200mm wafer fab line at Freescale semiconductor and established an automated packaging and test capability.

Over the past year we have continued to build on that foundation. In this paper we will report on this year's progress in completing the transition of our 25um product line to Freescale semiconductor. Included will be the 320x240 product transition and a summary of SPC and defectivity data from one year's production.

Looking beyond 25um, we have completed the transition of our 17um product line to Freescale, with test results being available for both the 640x480 and 1024x768 format arrays. Additionally, we will report on initial test results from the Tailwind program, which is developing a 2048x1536 - 17um uncooled sensor. Data to be reported includes the establishment of subfield stitching at a high rate commercial fab, combined with initial probe and package level performance data.

With 17um transitioned to production, Raytheon has started work on the next generation of uncooled detectors by further shrinking the pixel to <17um. While these efforts are in their infancy, we will review our development strategy and program plan.

8012-42, Session 9

Development of Terahertz focal plane arrays and handy video camera

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Since pixel structure of vanadium oxide microbolometer infrared focal plane array (IRFPA) was modified for detection of Terahertz (THz) radiation1), the authors have evaluated wavelength dependence of NEP (Noise Equivalent Power) for 320x240 THz-FPA, developed THz imagers including handy THz camera (F/1 optics) and obtained THz imageries2)-4). The handy THz camera they developed was found very efficient for alignment of complicated THz generation optics, label-free detection of reaction of small molecules with protein, art conservation science5) and so forth.

In this paper, the authors describe a couple of new pixel structures of THz-FPAs with 320x240 format and 23.5μm pixel pitch to further improve NEP. One of them is unique in that high resistivity Silicon plate coated with anti-reflection layer is put at a distance of half of wavelength of interest, (e.g., 100μm wavelength), beyond thermal isolation structure and this structure improves NEP by a factor of 2 - 4 for specified wavelength6). This structure is very effective for active THz imaging, in combination with usage of both quantum cascade laser (QCL) and lock-in thermo technique. This paper also describes effectiveness of the loch-in thermo technique.

As to broad band THz imaging, another pixel structure is fabricated, which offers larger absorption than the previous1). The THz-FPA with this structure is incorporated into handy THz camera (F/0.8) and THz imageries are obtained.

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8012-43, Session 9

VGA 17 µm development for compact, low-power systems

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The high level of accumulated expertise by ULIS and CEA/LETI on uncooled microbolometers made from amorphous silicon enables ULIS to develop VGA IRFPA formats with 17μm pixel-pitch to build up the currently available product catalog.

This detector keeps all the innovations developed on the 25 μm pixel-pitch ROIC (detector configuration by serial link, low power consumption and wide electrical dynamic range. The specific appeal of this unit lies in the high spatial resolution it provides. The reduction of the pixel-pitch turns this TEC-less VGA array into a product well adapted for high

resolution and compact systems.

Electro-optical performances of this IRFPA are presented as well recent performance improvement. 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. Solar exposure is also taken into account and shows that amorphous silicon is very well adapted to sustain high intensity exposure. This technology node associated with advanced packaging technique paves the way to compact low power system.

8012-44, Session 9

Modular, open architecture uncooled video engines based on a DSP processor

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The market demand for low SWaP (Size, Weigh and Power) uncooled engines keeps growing. Low SWaP is especially critical in battery-operated applications such as goggles and Thermal Weapon Sights. A new approach for the design of the engines was implemented by SCD to optimize size and power consumption at system level.

The new approach described in the paper, consists of:

1. A modular hardware design that allows the customer to define the exact level of integration needed for his system

2. An “open architecture” based on the OMAP DSP that allows the integrator to take advantage of unused hardware (FPGA) and software (DSP) resources, for implementation of additional algorithms or functionality.

The approach was successfully implemented on the first generation of 25µm pitch detectors, and more recently on the new, 640 x 480, 17 µm pitch.

8012-45, Session 9

Development of new SOI diode structure for beyond 17 µm pixel pitch SOI diode uncooled IRFPAs

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Scalable new SOI diode structure has been proposed and developed for beyond 17µm pixel pitch mega-pixel-class SOI diode uncooled IRFPAs. Conventionally, each p+n vertical diode is formed between a p+ diffusion and an n-body in each SOI active area, and 8-10 diodes are serially connected with interconnections. In the proposed new structure, we employ two kinds of diodes, namely, p+n and n+p vertical diodes. First, two regions of an n-body and a p-body are prepared in an SOI active area. In the n-body, a p+ diffusion is formed apart from the n-body /p-body boundary. In the p-body, an n+ diffusion is formed apart from the boundary. In this way, a p+n vertical diode and an n+p vertical diode are formed together in an SOI active area. Moreover, a contact hole, which is formed in touch with both n- and p-bodies, electrically connects these two kinds of diodes. With this new structure, we have realized remarkable reduction of the diode area. It leads to significant increase of the diode series number in a pixel, which increases infrared responsivity of the pixel. As a result, designing a 15µm pixel pitch IRFPA with the new structure, 12 series diodes can be arranged in a pixel, although 10 series diodes have been used even in the case of our 25µm pitch generation pixel.

To confirm the ability of the new diodes, test elements of 12-17µm pitch pixels were fabricated and evaluated. Furthermore, the fabrication of 17µm pixel pitch 320x240 IRFPAs with the new diodes was carried out and their favorable FPA operations were successfully verified.

In conclusion, the proposed and developed new SOI diode technology is very promising for beyond 17µm pixel pitch mega-pixel-class uncooled IRFPAs.

8012-46, Session 9

Improvements of a digital 25 µm pixel-pitch uncooled amorphous silicon TEC-less VGA IRFPA with massively parallel Sigma-Delta-ADC readout

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This paper presents the improvements of an advanced digital VGA-IRFPA developed by Fraunhofer-IMS. The uncooled IRFPA is designed for thermal imaging applications in the LWIR (8 .. 14µm) range with a full-frame frequency of 30 Hz and a high sensitivity with NETD < 100 mK @ f/1. The microbolometer with a pixel-pitch of 25µm consists of amorphous silicon as the sensing layer. The structure of the microbolometer has been optimised for a better performance compared to the 1st generation IRFPA. The thermal isolation has been doubled by increasing the length and by decreasing the width of the legs. To increase the fill-factor the contact areas have been reduced. The microbolometers are read out by a novel readout architecture which utilizes massively parallel on-chip Sigma-Delta-ADCs. This results in a direct digital conversion of the resistance change of the microbolometer induced by incident infrared radiation. Two different solutions for the vacuum package have been developed. To reduce production costs a chip-scale-package is used. This vacuum package consists of an IR-transparent window with antireflection coating and a soldering frame which is fixed by a wafer-to-chip process directly on top of the read substrate. An alternative solution based on the use of a standard ceramic package as a vacuum package. This packaging solution is used for high performance applications. The IRFPAs are completely fabricated at Fraunhofer-IMS on 8” CMOS wafers with an additional surface micromachining process. In this paper the architecture of the readout electronics, the packaging, and the electro-optical performance characterization are presented.

8012-47, Session 9

Scale down of p-n junction diodes of an uncooled IR-FPA for improvement of the sensitivity and thermal time response by 0.13 µm CMOS technology

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We have developed 22um pitch and 320 x 240 pixel uncooled infrared radiation focal plane arrays(IR-FPAs) with silicon single crystal p-n junction diodes by 0.13um CMOS technology and bulk-micromachining.

Generally, uncooled IR-FPAs have trade-off relation between sensitivity and thermal time response, which requires thermal conductance of supporting legs and thermal capacitance of the thermal cells to be small enough simultaneously. Thin metal wiring, therefore, were fabricated on the diodes and in the supporting legs, and etched back the upper structures just above them. The fabricated IR-FPA showed thermal time response of 16msec without degradation of its sensitivity.

IR absorption rate of the thin metal wiring area on diodes showed about half of the other areas. To increase the sensitivity of thermal cell, diode

size should be scaled down without degradation of performances, and non-device area, including supporting legs area, should be extended as much as possible.

Sub-micron slits which were negligible small compared to incident IR wavelength were formed in the cell to reduce only thermal capacitance with no degradation of thermal conductance and IR absorption rate.

Even though the sensitivity, dV/dT, decreased slightly with respect to diode size, the diodes with width of 0.8um showed several percents reduction, which corresponds the size of 20% compared to previous one. The sensitivity of fabricated IR-FPAs showed a substantial improvement without any additional IR absorbing structure.

8012-49, Session 9

Pixel level packaging for uncooled IRFPA

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Cost reduction of IRFPA is of importance to address high volume camera market. In this approach, CEA-LETI has developed in 2008 an on-chip packaging technology dedicated to microbolometers. Since the last 30 months, the pressure under the developped microcap is constant and stable with a value of 0.5 mbar. In order to reduce this down to 10-3 mbar, the one used for nominal IRFPA operation, thin film advanced getters have been studied. The most important point is that these getters are also used in a way that they should exhibit electrical, optical and patternable properties. Moreover these getters should be functional after microbolometer process. First results show that several thin film getters of different metallurgical composition can be used for this application. Then, a new technological innovative pixel level packaging, based on the first 2008 one, and with the addition of the advanced thin film getter is under development at CEA-LETI. Compared to the previous studies, optimized exhaust structure, new sacrificial layer etching, advanced getters addition, and anti-reflecting coating have been addressed. The new exhaust structure is optimized to allow an easy and quite fast sacrificial layer removing. The new sacrificial layer etching have been developed without any impact for both microbolometer and advanced getters.

8012-150, Session 9

1024 x 768 XGA uncooled camera core achieves new levels of performance in a small package

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An uncooled XGA camera core has been developed for multiple applications including soldier-borne thermal imaging, fixed mount surveillance and airborne reconnaissance. The goal of the XGA camera is to increase detection range without sacrificing field of view in order to realize longer standoff distances. The design challenge was to achieve high performance while optimizing for size, weight, and power (SWAP). A SWAP-optimized design has been achieved with a combination of low power electronic designs incorporating field programmable gate arrays (FPGAs) and unique calibration methods. Frame rates of 30 Hz (XGA) and 60 Hz (VGA) have been achieved. The uncooled XGA core is based on a new advanced technology 17µm pitch, 1024 x 768, high performance amorphous silicon (A-Si) microbolometer array which results in a significant improvement in image resolution and detection range. Despite an array size that is smaller than some existing VGA systems, the exceptional resolution performance is achieved as a result of a two and a half times increase in the number of pixels. Maintaining the array size has permitted the camera core size to be maintained while resolution performance has significantly increased without compromising sensitivity. The result is a camera core with true high definition (XGA format) and exceptional sensitivity that delivers far better detection range and angle-of-view performance than previous uncooled solutions in a comparable housing size to previous uncooled camera core generations.

8012-50, Session 10

Wide-area infrared surveillance: performance requirements and technology needs

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The emergence of asymmetric and terrorist threats as a prime focus of military operations is placing high demands on airborne reconnaissance, surveillance, and targeting systems. When placed within the context of a complex, urban landscape, a need arises for advanced electro-optical and infrared (EO/IR) sensing techniques to deal with the combination of small, diverse, and elusive targets and broad area, complex, and highly structured regions of interest. One particular research emphasis within the Air Force Research Laboratory (AFRL) has been toward the development of wide area IR surveillance capabilities that can continuously image city-sized areas with sufficient fidelity to detect and track individual personnel, or dismounts, in order to monitor their activity and ultimately assess their intent. This research has involved infrared signature phenomenology investigations of dismount activity to understand performance requirements, prototype infrared sensor system development to assess current technology capabilities, and enabling sensor component research to provide the necessary future advancements. This presentation will provide a summary of this on-going research, with a specific focus on establishing the technical requirements for dismount detection and tracking and the future infrared technology advances that will likely be required in order to address this challenging need.

8012-51, Session 11

Comparison of ion beam and magnetron sputtered vanadium oxide thin films for uncooled IR imaging

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Uncooled Infrared (IR) focal plane arrays are an enabling technology for both military and commercial high sensitivity night vision cameras. The IR imaging is accomplished using MEMS microbolometers fabricated on read-out integrated circuits (ROIC's) and depends critically on the material used to absorb the incoming IR radiation. Thus, suitable detector materials must exhibit a large temperature coefficient of resistance (TCR) and low noise characteristics to efficiently detect IR photons while also maintaining compatibility with standard IC processing. The most commonly used material in uncooled infrared imaging detectors is vanadium oxide deposited by reactive ion beam sputtering. Here we present a comparison of vanadium oxide thin films grown via commercial reactive ion beam sputtering to films grown using reactive pulsed DC magnetron sputtering. Films deposited using both methods were optically and structurally characterized using Raman spectroscopy, transmission electron microscopy, atomic force microscopy, grazing incidence X-ray diffraction and Rutherford backscattering spectroscopy. Electrical properties of the films were also measured and were found to be very sensitive to the deposition conditions used. The ion beam sputtered films were determined to contain twinned FCC VOx nanocrystals with sub-nanometer scale twin spacing, in the form of large 10-20 nm wide columnar/conical grains. In contrast, the un-biased magnetron sputtered films consisted of equiax grains of FCC VOx (5-10 nm) encapsulated in an amorphous matrix. Subtle differences in composition and structure could also be determined from the Raman spectra of the films. These differences in microstructure and composition were then correlated to the measured resistivities and TCRs of the films.

8012-52, Session 11

Performance improvement in amorphous silicon-based uncooled microbolometers through pixel design and materials development

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Uncooled amorphous silicon microbolometers have been established as a field-worthy technology for a broad range of applications where performance and form factor are paramount such as soldier-borne systems. Recent developments in both bolometer materials and pixel design at L-3 in the 17µm pixel node have further advanced the state of the art. In this paper, pixel design improvements involving thermal isolation and fill factor optimization to enhance NETD sensitivity will be discussed. Increasing the a-Si material temperature coefficient of resistance (TCR) has the impact of improving NETD sensitivity without increasing thermal time constant (TTC), leading to a further improvement in the NETD*TTC product. By tuning the amorphous silicon thin-film microstructure using hydrogen dilution during deposition, films with high TCR have been developed. The electrical properties of these films have been shown to be stable even after thermal cycling to temperatures greater than 300C enabling wafer level vacuum packaging currently performed at L-3 to reduce the size and weight of the vacuum packaged unit. Through appropriate selection of hydrogen dilution conditions during deposition, amorphous silicon on the order of -4% TCR has been integrated into the L-3 microbolometer manufacturing flow. By combining pixel design enhancements with improvements to amorphous silicon thin-film technology, L-3's amorphous silicon microbolometer technology will continue to provide the performance required to meet the needs to tomorrow's war-fighter.

8012-53, Session 11

Uncooled infrared detectors toward smaller pixel pitch with newly proposed pixel structure

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To realize an uncooled infrared (IR) focal plane array (FPA) with a narrower pixel pitch (17 um), the authors propose a new pixel structure consisting of a diaphragm and beams, which are arranged in different level. Upper level consists of the diaphragm, having VOx bolometer and IR absorber layers, and two connection parts, supporting the diaphragm with narrowed area. Lower level consists of the two beams that one edge connects to the connection part of upper level and the other edge connects to electrical contact pads on a silicon (Si) readout integrated circuit (ROIC). This pixel structure is featured by arranging the beams just below the diaphragms of adjacent pixels but not own pixel.

To verify the effect of the new pixel structure, the test devices have been fabricated on the ROIC for the uncooled IRFPA with 320 x 240 pixels of 23.5 um pitch (HX0830)1). The test devices have the uncooled IR detectors with the narrow pixel pitch of 12um, 15um, and 17um, which are processed in the imaging area. The results showed characteristics (thermal time constant: 15msec@12um, 26msec@15um, 23msec@17um / NETD : 63.1mK@12um, 49.8mK@15um, 39.6mK@17um) , which were nearly equal to the practical performance. It is expected that, with the newly proposed pixel structure, uncooled IRFPA with the narrower pixel pitch can achieve high performance.

References

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8012-54, Session 11

Uncooled VO_x infrared sensor development and application

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This paper provides an overview of the recent DRS VOx uncooled focal plane array (UFPA), sensor electronics, and camera development activities. Presently, DRS UFPAs consist of 25 µm and 17 µm pixel pitch detectors in 320x240 and 640x480 formats. Under the Army NVESD sponsored 17 µm Large Format Uncooled FPA Development program and internal project, DRS has developed a 17 µm pitch 1024x768 UFPA product (U8000). The 17 µm pixel pitch UFPAs provide sensor systems with significant size, weight, and power (SWaP) savings as well as cost advantage over the 25 µm pixel pitch counterparts. There is a growing demand to transition current products to the 17 µm pixel technologies. For example, next generation military systems such as thermal weapon sights (TWS), digitally fused enhanced night vision goggles (ENVG(D)), driver viewer enhancers (DVE-FOS) and unmanned aerial vehicle (UAV) infrared (IR) surveillance sensors all called for the 17 µm pixel technologies. To meet the market demand, DRS has improved its production facilities to accommodate 17 µm pixel detector manufacturing. In conjunction, DRS has also developed a family of signal processing electronics based on a new FPGA architecture for various sensor modules and cameras that can be incorporated for commercial OEM products as well as DoD weapon systems. Under the DARPA funded DUDE program, DRS and Goodrich Sensor Unlimited, Inc are jointly developing a single, integrated two-color, detector by combining the VOx microbolometer (8-14 µm) and InGaAs (0.7 -1.6 µm) detectors into a single focal plane array. Design and fabrication of the dual-mode ROIC have been completed and fabrication of the DUDE detectors is now underway.

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8012-55, Session 12

Dual-band imaging technology on indium gallium arsenide focal plane arrays

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While InGaAs-based SWIR imaging technology has been improved dramatically over the past 10 years, the motivation remains to reduce Size Weight and Power (SWaP) for applications in Intelligence Surveillance and Reconnaissance (ISR). Goodrich ISR Systems, Princeton (Sensors Unlimited, Inc.) has continued to improve detector sensitivity. Additionally, SUI is working jointly with DRS-RSTA to develop innovative techniques for manufacturing dual-band focal planes to provide next generation technology for not only reducing SWaP for SWIR imagers, but also to combine imaging solutions for providing a single imager for SW+LW imaging solutions. Such developments are targeted at reducing system SWaP, cost and complexity for imaging payloads on board UASs as well as soldier deployed systems like weapon sights. Our motivation is to demonstrate capability in providing superior image quality in fused LWIR and SWIR imaging systems, while reducing the total system SWaP and cost by enabling Short Wave and Thermal imaging in a single uncooled imager.

Under DARPA MTO awarded programs, a LW bolometer (DRS-RSTA) is fabricated on a Short Wave (SW) InGaAs Vis-SWIR (SUI-Goodrich) Imager. The combined imager is a dual-band Sensor-Chip Assembly which is capable of imaging in VIS-SWIR + LW. Both DRS and Goodrich have developed materials and process enhancements to support these dual-band platform investigations. The two imagers are confocal and coaxial with respect to the incident image plane. Initial work has completed a single ROIC capable of running both imagers. The team

has hybridized InGaAs Focal planes at waferscale to support bolometer fabrication onto the SW array.

8012-56, Session 12

Toward a single-chip TECless/NUCless InGaAs SWIR camera with 120 dB intrinsic operation dynamic range

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This paper describes a single-chip InGaAs SWIR camera with more than 120dB intrinsic in-pixel operational dynamic range with an innovative CMOS ROIC technology, MAGIC technology, invented and patented by New Imaging Technologies. An 320x256-pixel InGaAs 25um pitch photodiode array, designed and fabricated by 3-5Lab, has been hybridized on this new generation CMOS ROIC. With NIT's MAGIC technology, the sensor's output follows a precise logarithmic law in function of incoming photo flux and gives instant operational dynamic range better than 120dB. Thanks to on-chip TV encoder, a complete CCIR SWIR camera has been realized with neither TEC nor NUC. The measured RMS noise and FPN noise from the prototype sensor in dark conditions are 0.4mV and 0.27mV with a signal excursion of 300mV over the 120dB dynamic range. The NEI has been measured to be 3,71E+09 ph/s/cm2 with 92 equivalent noise photons. The characterization of this new generation single-chip InGaAs SWIR is still on the way and the detailed results will be presented with a demonstrating camera at the conference.

8012-57, Session 12

Recent advances in SWIR MEMS-based tuneable Fabry-Pérot microspectrometers

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Recent advances in the development of MEMS-based infrared microspectrometers at The University of Western Australia will be presented. Initially, the research was focused on monolithic approaches allowing fabrication of on-pixel Fabry-Pérot tuneable filters directly on HgCdTe infrared focal plane arrays. Due to the limited thermal budget of HgCdTe, a technology based on low temperature deposited thin-film silicon nitride was used. The fabricated tuneable Fabry-Pérot filters consisting of three layer Ge/SiO Bragg mirrors demonstrated the tuning range from 1.6µm to 2.4µm with tuning voltages < 25V, and tuning speeds of 50kHz. Their FWHM, of the order of 100nm, was limited by the three layer mirror design and stress related bowing and tilting of the top mirror. In addition, the low temperature silicon nitride was found to be sensitive to environmental exposure, resulting in a slow drift of the filter characteristics.

In order to address these problems a different approach has been adopted recently. Detectors and filters are fabricated separately and then hybridized. As a consequence, the temperature limit has been removed resulting in highly stable silicon nitride films deposited by PECVD at 2000C. The FWHM was reduced to the theoretical minimum of ~50nm using stress-balancing layers. Recently, FWHM has been improved dramatically by introducing five layer mirrors with the mid-range value less than 30nm (theoretically predicted ~17nm for an ideal cavity). As will be demonstrated by the detailed analysis of the top mirror surface profiles this difference results from minor mirror imperfections.

8012-58, Session 12

Analytic modeling and explanation of ultra-low noise in dense SWIR detector arrays

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InGaAs-based focal plane arrays (FPAs) are unrivaled as an uncooled SWIR detector technology. Moreover, while InGaAs FPAs merge two different semiconductors, the scalability of their manufacturing process creates a volume-cost structure equivalent to their microbolometer counterparts-making InGaAs valuable for low-cost, low-power SWIR and fused infrared applications. The key to the adoption of InGaAs is low dark current, and refinements in device design, growth and processing have been steadily decreasing this current. Prior analytical models of InGaAs devices have worked somewhat for large pitch diodes over small voltage ranges, but have proven inaccurate at predicting the ultimate performance limits of device arrays as pixel pitch shrinks.

By going to first-principles, we have developed an improved analytic model for tight-pitch p-i-n diodes which fits empirical data well. Model components include diffusion, bulk generation-recombination, interface generation-recombination, defect-assisted shunt, and tunneling. To validate the model, we have taken data on devices with a variety of active area sizes and pixel pitches over both temperature and a wide voltage range. By fitting each contributor, the model clarifies such things as how tight pitch arrays suppress diffusion current and why bulk generation-recombination is not a limiting factor in today's devices. We can thus explain our experimental 1280 x 1024 arrays with dark currents of 1nA/cm2 at 20C and our smaller arrays with <0.1nA/cm2 7C. Based on the correspondence of our models to the empirical data, we believe that further refinements of device design can lead to another order of magnitude decrease in dark currents.

8012-59, Session 12

Modeling of the electrical characteristics of SWIR/MWIR InGaAs/GaAsSb type-II MQW photodiodes

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This paper reports the results of modeling of the electrical characteristics of SWIR/MWIR p-i-n photodiodes with type II InGaAs/GaAsSb multiple quantum wells (MQWs) as the absorption region. Bulk based model with the effective band gap of the type-II quantum well structure has been used in modeling of the experimental data. We investigated the dark current contributing mechanisms that are limiting the electrical performance of the diode. The quantitative simulation of the I-V characteristics shows, that the 200K to 290K performance of InGaAs/GaAsSb photodiodes is dominated by generation-recombination processes at the small reverse bias (-5V~0V). Above -10V, the trap-assisted tunneling current and direct tunneling current begin to dominate.

8012-60, Session 12

MOVPE grown InGaAs/GaAsSb type II quantum well photodiode for SWIR focal plane array

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Low cost, low dark current photodiodes (PDs) in the short wavelength infrared (SWIR) region up to 2.5µm are expected for many applications such as environmental gas detection and bio-diagnostics. HgCdTe (MCT) is predominantly used for infrared imaging applications.

However, MCT is expensive and its application has been restricted mainly military and scientific use. Recently, InGaAs/GaAsSb type II quantum well structures are considered as an attractive material system for realizing low dark current PDs owing to lattice-matching to InP substrate. In the previous work, we reported PDs with InGaAs/GaAsSb quantum wells grown by molecular beam epitaxy (MBE). In this report, we describe successful operation of pin-PDs with InGaAs/GaAsSb quantum wells

grown by metal-organic vapor phase epitaxy (MOVPE).

MOVPE method is well-known to have good uniformity which leads to mass-production of focal plane array.

Planer type pin-PDs with InGaAs/GaAsSb quantum well absorption layer were successfully fabricated for the first time. The p-n junction was formed in the absorption layer by the selective diffusion of zinc. InGaAs layer which was adopted as a layer for adjusting concentration distribution of zinc were grown on quantum wells. Electrical and optical characteristics of PDs such as well number dependence and temperature dependence of dark current and responsivity, were investigated. Dark current of 1.3mA/cm2 at room temperature, which has better uniformity compared to those of MBE sample, and responsivity of 0.5A/W in SWIR region were obtained.

This result means that planer photodiode using MOVPE grown InGaAs/GaAsSb type II quantum wells is a promising candidate for consumer applications.

8012-61, Session 12

InGaAs focal plane arrays for low-light-level SWIR imaging

M. H. MacDougal, J. Geske, J. Wang, D. Follman, J. Manzo, Aerius Photonics, LLC (United States); J. Getty, Raytheon Vision Systems (United States)

Aerius Photonics specializes in low dark current, high operability large InGaAs detector arrays. Aerius will show imagery from large 1280x1024 arrays exhibiting low light level imaging. Also, Aerius will show 640x512 InGaAs FPAs with wavelength sensitivity below 800 nm. The dark current data will show that Aerius is achieving better than 2 nA/cm2 at 20°C. Furthermore, Aerius will show results of a special mode of their detector (non-destructive reads) to reduce the read noise by a factor 2. In addition, Aerius will show imagery under different conditions including low light as well as daytime imagery. Aerius has developed VCSEL arrays that provide speckle-free illumination to augment scenes with no available photons. Aerius will show imagery from their FPA using the illuminators.

8012-62, Session 12

IR CMOS: ultrafast laser-enhanced silicon detection

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

SiOnyx has developed a novel ultrafast laser silicon processing technology for CMOS sensors that will extend spectral sensitivity into the near/shortwave infrared (NIR/SWIR) and enable a full performance digital night vision capability comparable to that of current image-intensifier based night vision goggles. The process is compatible with established CMOS manufacturing infrastructure and has the promise of much lower cost than competing approaches. SiOnyx has validated enhanced photodetectors manufactured on 8" CMOS silicon wafers. The measured thin layer quantum efficiency is 30x that of incumbent imaging sensors at the critical YAG laser 1064 nm node. The spectral sensitivity is from 400 to 1200 nm with high QE (>50%) in the NIR spectrum enabling silicon based nightvision. SiOnyx has extended this capability to pixel arrays that validate this technology for imaging applications. Pixel performance metrics will be discussed.

8012-63, Session 13

Somewhere under the rainbow: the visible to far infrared imaging lens

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This paper will explore the challenges associated with the design of optical imaging system that span the visible to far infrared portion of the electromagnetic spectrum. The work will focus on the refractive approach and will discuss advantages and disadvantages compared to solutions of an all reflective nature. A total optical solution (one lens for a multi-spectral camera) as well as the classic common aperture (one lens for two cameras) solutions, will be discussed. The keystone of this presentation will be StingRay's own solution dubbed the SuperBand Optic TM, which enables achromatic imaging over exceedingly wide spectral bands.

8012-64, Session 13

Refractive lens design for simultaneous SWIR and LWIR imaging

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Infrared detector technology has progressed to include many fused wavebands. This has been driven by the need of military systems to image over diverse spectrums. Imaging systems can now operate in both the short wave infrared (SWIR) as well as the long wave infrared (LWIR). Reflective optics seems like a natural solution to such a large waveband, but they will have more restrictive size and field of view constraints. This paper will demonstrate the steps to achieve a Petzval lens with fast aperture and moderate field that is apochromatic in the SWIR and has low axial color in the LWIR. The lens achieves a high resolution solution in terms of modulation transfer function (MTF).

8012-65, Session 13

Compact dual field of view SWIR/MWIR optical system

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This paper discusses the design and development of a dual field of view, all-refractive infrared optical system that images the mid-wave infrared (MWIR) light in one field of view and the narrow band short wave infrared (SWIR) light in the second field of view onto the same detector. The narrow field of view images the SWIR radiation at a slow f/number of 10.0, while the wide field of view images the MWIR radiation at f/1.9. The field of view is changed via a single lens that changes its axial position within the lens, resulting in an axial zoom and an overall magnification change of 6X. The change in focal length and f/number at the same time enables an increased focal length without having to increase the aperture size by the ratio of the focal length change. The large field of view change is achieved by both the motion of the lens, and the use of the spectral properties of the materials that change with wavelength. The change in spectral bands is accomplished via the use of a spectral filter wheel.

8012-66, Session 13

Optical design of compact multichannel and all-reflective system for infrared imaging

M. Wang, F. Châteauneuf, C. Proulx, INO (Canada)

In space IR optics, to achieve better observation of ground target, a common aperture all-reflective telescope, working at fast focal-ratio with multi-channel to cover different waveband and wide field-of-view, is a most wanted optical system. The remarkable imaging properties of the fast focal-ratio, flat-field, anastigmatic, rotationally symmetric Schwarzschild telescope have been well recognized historically, but suffer strong central obscuration and limited FOV in the conventional axis-symmetric design. Our solution is to use an eccentric system evolved from the Schwarzschild axially symmetric system, adding a tertiary off-axis mirror, to optimize the off-axis performance with the appropriate system parameters and specs, as required by most space IR optical systems.

The optical design system consists of a convex primary mirror (M1) and two concave secondary (M2 or in convex shape) and tertiary mirrors (M3), both of which have their size larger than that of the primary. The entrance pupil of the system is located after the M1. The wedged dichroic filters can be used after the tertiary mirror to achieve a separation of multi-spectral channels. In this kind design the mirrors with optimized aspherical shapes, which are all in even-asphere warped up to 10th asphericities, are used for achieving the final image quality. The final corrected wavefront in the system can result in the good optical performance for the encircled energy of better than 80% per pixel for all channels, working at F/1.66 to cover a wide FOV up to 27.70 (H) x 48.70 (V). The extra-broadband, including MWIR and LWIR up to 60 um, can be fully covered by this design. Multiple focal-plane-arrays (FPAs) can be used with respect to different spectral channels.

8012-67, Session 13

Advanced manufacturing technologies for reduced cost and weight in portable, ruggedized, VIS-IR, multi-mode optical systems, for land, sea, and air

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Homeland security systems, special forces, unmanned aerial vehicles (UAV), and marine patrols require low cost, high performance, multi-mode VIS-IR optical systems to identify and neutralize potential threats that often arise at long ranges and under poor visibility conditions. Long range and wide spectral performance requirements favor reflective optical system design solutions. The limited field of view of such designs can be significantly enhanced by the use of catadioptric optical solutions that utilize molded or diamond point machined VIS-IR lenses downstream from reflective objective optics. A common optical aperture that services multiple modes of field of view, operating wavelength, and includes laser ranging and spotting, provides the highest utility and is most ideal for size and weight. Such a design also requires fast, highly aspheric, reflective, refractive, and sometimes diffractive surfaces using high performance and aggressively light-weighted materials that demand the finest of manufacturing technologies. Visible wavelength performance sets the bar for component optical surface irregularity on the order of 20 nm RMS and surface finishes less than 3nm RMS. Aluminum mirrors and structures can also be precision machined to yield “snap together alignment” or limited compensation assembly approaches to reduce cost and enhance interchangeability.

Diamond point turning, die cast mirror substrates and structures, computerized optical polishing, mirror replication, lens molding and other advanced manufacturing technologies can all be used to minimize the cost of this type of optical equipment. This paper discusses the tradeoffs among materials and processes selection for catadioptric, multi-mode systems that are under development for a variety of DoD and Homeland Security applications. Several examples are profiled to illuminate the confluence of applicable design and manufacturing technologies.

8012-68, Session 13

Toward infrared DDCA with an imaging function

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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 array (FPA) with micro-sized pixels, this miniaturisation will become feasible with the integration of optical functions in the detector area. In the field of cooled infrared imaging system, 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 an imagery function can be added to the dewar by simply integrating a single meniscus inside the cold shield. An infrared system with a wide field of view and high throughput is thus obtained without adding optics outside the dewar. The additional mass of the optic is sufficiently small to be compatible with the cryogenic environment of the DDCA. The temperature stabilization of the optic and the reduction of the background radiation are the main advantages of this system. The performance of this camera will be discussed and several evolutions of this camera will be introduced too.

8012-69, Session 13

Compact designs of hyper- or multispectral imagers compatible with the detector dewar

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There is an emerging demand for compact IR instruments, imagers and/or spectrometers, integrated on ground or air vehicles for security and surveillance applications. The goal of this study is to design handheld devices, compatible with the classic packaging of a cooled infrared focal plane array, called an IR detector dewar-cooler assembly (IDDCA). We have recently shown that dewar-level integration of optics is a promising way to develop compact IR cameras. Indeed, the integration of optics into the dewar leads to simple and entirely cooled optical architectures dedicated to imaging applications with large-field of views.

Here, we review the optical elements we could add in those devices to make a hyper- or multispectral imager. Among them, we find specific focal-plane arrays with a built-in spectrometry function, plasmonic filters combined with a multichannel optical design, and birefringent interferometers. Several optical architectures will be detailed with first experimental results.

8012-71, Session 13

Challenges, constraints, and results of lens design for 17 micron-bolometer-FPAs in 8-12 micron waveband

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In the 8-12 micron waveband Focal Plane Arrays (FPA) are available with a 17 micron pixel pitch in different arrays sizes (e.g. 512 x 480 pixels and 320 x 240 pixels) and with excellent electrical properties. Many applications become possible using this new type of IR-detector which will become the future standard in uncooled technology.

Lenses with an F-number faster than f/1.4 minimize the diffraction impact on the spatial resolution and guarantee a high thermal resolution for uncooled cameras. Both effects will be quantified. The distinction between Traditional F-number (TF) and Radiometric F-number (RF) is discussed.

Lenses with different focal lengths are required for applications in a variety of markets. They are classified by their horizontal field of view. Respecting the requirements for high volume markets, several two lens solutions will be discussed. A commonly accepted parameter of spatial resolution is the MTF at the Nyquist frequency of the detector (here 30cy/mm). This parameter of resolution will be presented versus field of view and versus temperature. Wide Angle and Super Wide Angle lenses are susceptible to low relative illumination in the corner of the detector. Measures to reduce this drop to an acceptable value are presented.

8012-110, Session 13

Increasing dynamic range of cameras with Dynamic Sunlight Filter (DSF)

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Todays battlefield has imaging systems everywhere, from simple observation and up to very sophisticate warning and offensive systems, with cameras integrated in almost all systems. Since the direction of viewing is not always known and can be in certain cases in toward the sun, events of camera blinding are very likely to occur. Regulating optical power levels within cameras, requires today an electronic feedback control or offline data processing, which introduces complex and expensive systems. When regulation of light power fails, blooming effect is created. When light passes the lens of a digital camera and is captured by the CCD it is converted into an electrical charge. There is a limit to how much charge each pixel or photosite can store. Excessive charge in a photosite will overflow to its neighboring pixels causing an effect, which is called blooming. Manufacturers try to eliminate this effect by "anti-blooming gates" which can be compared to vertical drainage channels running beside each row of photosites. These allow the overflowing charge to flow away without affecting surrounding pixels. Though these anti-blooming gates are fairly successful at avoiding the problem, there are exposure situations where blooming can still occurs. Sometimes the blooming is such that data is lost and cannot be recovered by any sophisticated software.

The need for a better light control was the trigger for our effort in developing a family of products that are able to control and regulate light, in a passive way, all based on our already proven principles of Optical Power Control (OPC) using nanotechnology and nanostructure optics. Most of our OPC past applications were controlling laser optical power for various optical systems and applications. We developed the Dynamic Attenuator for the Telecom market, a device for limiting and regulating the optical power propagating in an optical telecom network. In this area we have also developed the Optical Fuse that protects the optical network from over power and optical spikes. Based on similar nanotechnology we developed the Wideband Protection Filter (WPF), which is designed to protect sensors as well as the human eye, from high power lasers impinging into optical systems, such as sights, binoculars, cameras etc.

In this paper we report on the Dynamic Sunlight Filter (DSF), which is a passive solution dedicated to sunlight overpower, controlling and regulating applications. In the normal state, when incident light is below a predefined level the DSF is highly transparent, light just passes through it. As the light level is increased and gets more intense, such as in the case of morning sun, or the headlights of an approaching car facing the rear-view mirror, the DSF transmission decreases accordingly, eventually reaching a darkened state. The darkening effect is selective and is limited only to the intense light areas in the image. This process is reversible and the filter returns to its transparent state once the intensity of light decreases to its normal level.

We demonstrate our DSF functioning when introduced as an add-on module to a SWIR camera, and as an integrated near the sensor itself. We present new experimental results including attenuation values, time response and imaging improvement as function of DSF type.

8012-72, Session 14

Influence of Spinel head window thickness on the performance characteristics of a submarine, panoramic, infrared imaging system

J. M. Nichols, J. R. Waterman, S. S. Bayya, I. D. Aggarwal, J. S. Sanghera, U.S. Naval Research Lab. (United States)

This work explores the influence of head window thickness on the performance of a mid-wave infrared, panoramic periscope imager. Our focus is on transparent spinel ceramic as the head window material. Spinel is an attractive material for IR applications due to its good strength and transmission properties (visible through mid-wave). However, there is some degradation in spinel transmission near the high end of the mid-wave band (~5μm) as the head window thickness increases. In this work we predict the relationship between head window thickness and imager performance, as quantified by the Noise Equivalent Temperature Difference, and compare these predictions to values estimated from experimental data. The imager used in this study is a compact, catadioptric, camera that provides a 360deg. horizontal azimuth by -10deg. to +30deg. elevation field of view and uses a 2048 x 2048, 15μm pitch InSb detector.

8012-73, Session 14

Development of the automatic focus control unit (AFCU) for the Mobile InfraRed Telescope (MIRT)

J. S. Allen, U. S. Dept of Defense (United States)

This paper discusses the design, testing, and fielding of the Automatic Focus Control Unit for the Mobile Infra-Red Telescope at White Sands Missile Range. The paper also discusses the usefulness of the MIRT when collecting Missile Defense Agency (MDA) programs such PAC-III, THAAD, and SM-3. The Distant Object Attitude Measurement System (DOAMS) is a tracking telescope with a dual 'over/under' lens configuration that supports a 5.0-meter effective focal length (efl) visible lens on the top and 2.5-meter efl visible lens on the bottom, when originally delivered from the factory. The DOAMS hardware was manufactured by the Contraves Corporation (now Brashear L.P.) of Pittsburgh, PA in the late 1970s and early 80s. The lens configurations are Catadoptric, meaning that they are a Casagrainian-type configuration, with a focus assembly between the secondary and focal plane. The two lens tubes are approximately 6 feet long, and two feet in diameter. Two of White Sands Missile Range's five DOAMS telescopes have been mobilized. The quality of the visible images collected by the DOAMS over the years has been disappointing, due in large part to the large apertures of the lenses (subject to the effects of turbulence) and the original veiling-glare specification that necessitated over 20 reflective and refractive surfaces in the lens train.

8012-74, Session 15

Development of miniature moving magnet cryocooler

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High performance IR systems need to have more than just excellent E/O performance but also need to be competitive in its SWAP (size weight and power) characteristics. SWAP of IR imagers is predominated by the employed cryocooler. Therefore compact high performance cryocoolers with high MTTF life are needed.

For highest MTTF life AIM developed its Flexure Bearing Moving Magnet product family "SF". Such coolers achieve more than 20000h MTTF with Stirling type expander and more than 5yrs MTTF life with Pulse Tube coldfinger (like for Space applications).

To keep the high lifetime potential but to significantly improve SWAP AIM is developing its SX type cooler family.

The new SX040 cooler incorporates a high efficient dual piston Moving Magnet driving mechanism resulting in very compact compressor of less than 100mm length. The cooler high lifetime is also achieved by placing the coils outside the helium vessel as usual for moving magnet motors.

The mating ¼" expander is compact as well with less than 63mm length. This allows a total dewar length from optical window to expander warm end of less than 100mm even for large cold shields. The cooler is optimized for HOT detectors with operating temperatures of 95K and above.

In a next step a smaller version with single piston and balancer is foreseen.

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

8012-75, Session 15

Micro cryogenic coolers for IR imaging

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We have demonstrated one of the smallest Joule Thomson micro cryogenic coolers (MCC) utilizing a hollow fiber-based heat exchanger. The design, fabrication, assembly, and testing are described. With mixed refrigerants optimized for a 16:1 pressure ratio, we have demonstrated a 140 K stable temperature and 76 K transient temperature at the cold head for a heat load around 10mW. The cold head's dimension was only 2 mm x 2 mm x 1.2 mm and the heat exchanger was only 25 mm in length, 0.61 mm in diameter.

With this success, we are encouraged to explore applications for IR imaging over the temperature range of 80 K to 200 K. Specifically, we have studied three issues: a) manufacturability, b) heat lift and c) miniaturization. It is a challenge to assemble the hollow fiber-based heat exchanger. Therefore, we have to replace it by a planar heat exchanger fabricated using batch, thin film processes. The 10 mW heat lift is not large enough for most IR imaging applications, so we have to scale the configuration for heat lifts up to about 100 mW. The compressor used for the cold-head demonstration was a large laboratory model, but in parallel we have conducted investigations of micro-compressors for use with the MCC. We will present these new approaches supported by experimental or numerical results. For cold-end temperatures of 140 K to 200 K we have designed mixed-refrigerants that operate efficiently at pressure ratios of only 4:1, which simplifies the design of micro-compressors. More importantly, we have identified a unique window of opportunity for Joule Thomson MCCs. At 200 K the efficiencies of such MCCs are 10X better than those of thermoelectric coolers, and the sizes of such MCCs are 10X smaller than those of Stirling coolers. In fact, a path has been identified to develop a fully integrated, cm-scaled MCC. Such small MCCs may stimulate novel applications for future IR imaging.

8012-76, Session 15

Adaptation of the low-cost and low-power tactical split Stirling cryogenic cooler for aerospace applications

A. Veprik, S. Zechtzer, N. Pundak, RICOR-Cryogenic & Vacuum Systems (Israel); C. S. Kirkconnell, J. Freeman, Iris Technology Corp. (United States); S. V. Riabzev, EADS Astrium Ltd. (United Kingdom)

Cryogenic coolers are often used in modern spacecraft in conjunction with sensitive electronics and sensors for military, commercial and scientific instrumentation. The typical requirements associated with their use in a space mission are power efficiency, ultra-low vibration export, proven reliability, ability to survive launch vibration/shock and long-term exposure to space radiation.

A long standing paradigm of using exclusively “space heritage” equipment is a best known practice aiming at delivering high reliability components for the critical and quite expensive space missions.

The recent trend of developing mini and micro satellites for the relatively inexpensive missions has spurred attempts to adapt leading-edge tactical cryogenic coolers for suitability in the space environment. The primary emphasis has been on reducing cost, weight and size. The above conservative “space heritage” practice results in using oversized, overweight and indeed overpriced cryogenic coolers for these applications; this is unacceptable for space agencies now operating within tough monetary and time budgets.

The authors are disclosing some theoretical and practical aspects of a collaborative effort to develop a space qualified cryogenic refrigerator system based on the tactical cooler model Ricor K527 technology and the Iris radiation hardened Low Cost Cryocooler Electronics (LCCE). The K27 / LCCE solution is ideal for applications where cost, size, weight, power consumption, vibration export, reliability and time to spacecraft integration are of concern.

8012-77, Session 15

Low-vibration microminiature tactical split Stirling cryogenic cooler for infrared aerospace applications

A. Veprik, S. Zechtzer, N. Pundak, RICOR-Cryogenic & Vacuum Systems (Israel); C. S. Kirkconnel, J. Freeman, Iris Technology Corp. (United States); S. V. Riabzev, EADS Astrium Ltd. (United Kingdom)

The cryogenically cooled infrared space-borne instrumentation is usually susceptive to the cryocooler induced vibration, the major portion of which is contained at the driving frequency; the relatively low power higher-order harmonics typically manifest themselves through excitation of the lightly damped structural resonances in the optical benches or support structures.

Attenuation of the above vibration export over the typical wide frequency range is normally accomplished by using the principle of momentum cancellation under supervision of dedicated feed-forward DSP controller, where the error signals are delivered by the vibration sensors (accelerometers or load cells). It is widely acceptable across the industry to use dual-piston compressor design approach, where one of the compressors is used as an active counter-balancer with regards to the second one. The attenuation of vibration export originated from the expander portion of the cryogenic cooler is normally achieved by using the auxiliary active counter-balancer. This results in oversized, overweight and indeed overpriced cryogenic coolers with spoiled electromechanical performances and reliability.

The authors are advocating the purely passive approach utilizing the principle of tuned dynamic absorber for suppressing vibration export at the driving frequency and low frequency vibration isolator for attenuating the vibrational force transmission over the typical high frequency range and decoupling of the object of vibration protection from the entire system.

The outcomes of theoretical prediction are fully supported by experimental testing using the full-scale technology demonstrator which was built on the base of Ricor model K527 split Stirling cryogenic cooler.

8012-78, Session 15

FLIR submicro cooler IDCA

U. Binnun, FLIR Systems, Inc. (United States)

A new miniature fully integrated IDCA has been developed and tested and released to manufacturing by FLIR Systems Inc-Boston.

This module contains several new technologies and design features in terms of the cooling engine thermodynamic cycle, mechanical package, configuration, cooling capacity per unit volume, audible noise signature, reliability, field serviceability, shelf life, input power, cool down and more.

We will present the design concept, performance tests, thermo-dynamic cycle improvements, specific system applications, jitter tests, reliability test data and MTBF analysis and more.

Few imaging modules will be demonstrated as well.

8012-79, Session 15

Release for production if the most compact microcooler in the Thales cryogenic rotary monobloc range

J. Martin, S. Freche, R. J. Griot, T. Benschop, Thales Cryogénie S.A. (France)

Thales Cryogenics has an extensive background in developing and manufacturing Stirling rotary integral (Monobloc) coolers for military applications. Up to now, this cooler range was based on three coolers named RM2, RM3 and RM4.

Due to specific market demands a new type of cooler has recently been developed in the Rotary Monobloc range (RM): the RM1. This cooler has been designed for applications where a low cooling power and a high efficiency are required and is particularly suitable for cooling components with a low heat load at intermediate temperature (90 to 120K) while allowing short cool down time. Cooling down to 77K remains possible but is restricted in available cooling capacity. The RM1 shows high compactness and is the smallest and lightest cooler of the RM product range. A special feature has been implemented in cold finger and displacer design to lower accuracy of dimensional and geometrical requirement for the associated dewar well leading to significant cost reduction for the user.

In this paper, an overview of performance parameters (cooldown time, input power in temperature regulation mode, maximum cooling power, coefficient of performance) is given depending on test conditions and compared to the performance of the RM2 which is the most popular product in the Thales Cryogenics RM range.

The RM1 cooler has been extensively qualified for use in various thermal and mechanical environments. Life time tests have been carried out on a sample batch of 9 coolers tested according to Thales Cryogenics standard accelerated life time test profile A20 (running continuously 24/7, at a rate close to maximum rotation speed in representative dewar and real cryogenic condition). The qualification results are reported and the evolution of performances over time in life tests are also presented.

8012-80, Session 15

1/5 W linear cryocooler for infrared applications

M. Squires, Cobham Mission Systems (United States)

The new LC1070 cryocooler is one of the smallest coolers designed by Cobham Mission Systems to date. The cryocooler uses a 0.260 inch diameter coldfinger from the Cobham LC1056 cryocooler with an entirely new linear moving coil compressor. The compressor envelope is a 1.36 inch diameter, 4.493 inch long cylinder.

The cryocooler design benefits from system and component level simulation using commercially available software such as Sage, MATLAB, and ANSYS. Sage was used to determine the required volumes, areas, piston mass, spring rates, charge pressure, etc. of the compressor, and to model the overall system performance. ANSYS was used in the design of the magnetic circuits and to design the structural members of the housing. MATLAB was used with Sage data to estimate cooldown times. Information on the modeling and design process is presented.

The cryocooler is estimated to hold a 200 mW heat load at less than 77 K with less than 18 W electrical input power at an ambient temperature of 23 °C. Cooldown time from 300 K to 77 K with a 19 g copper mass is estimated to be less than 4.5 minutes.

8012-81, Session 15

Lifetime testing results and diagnostic performance prediction of linear coolers at Thales Cryogenics

H. van der Weijden, Thales Cryogenics B.V. (Netherlands)

Thales Cryogenics (TCBV) has an extensive background in delivering long life cryogenic coolers for military, civil and space programs. During the last years many technical improvements have increased the lifetime of coolers resulting in significantly higher MTTF's. Lifetime endurance tests are used to validate these performance increases. The status of these tests will be presented, together with recent advances in statistical representation of these tests.

MTTF figures indicate the statistical average lifetimes for a large population of coolers. However, for the user of IR camera's and spectrometers a detailed view on the performance of an individual cooler and the possible impact of its performance degradation during its lifetime is very important. Thales Cryogenics is developing Cooler Diagnostic Software (CDS), which can be implemented in the firmware of its DSP based cooler drive electronics. With this implemented software the monitoring of the main cooler parameters during the lifetime in the equipment will be possible, including the prediction of the expected cooler performance availability. Based on this software it will be possible to analyze the status of the cooler inside the equipment and, supported by the lifetime knowledge at Thales Cryogenics, make essential choices on the maintenance of equipment and the replacement of coolers.

In the paper, we will give an overview of potential situations in which such a predictive algorithm can be used. We will present the required interaction with future users to make an optimal interaction and interpretation of the data generated possible.

8012-82, Session 15

RICOR's new development of a highly reliable integral rotary cooler - engineering and reliability aspects

A. Filis, Z. Porat, RICOR-Cryogenic & Vacuum Systems (Israel)

The growing demand for EO applications that work around the clock 24hr/7days a week, such as in border surveillance systems, emphasizes the need for a highly reliable cryocooler having increased operational availability and decreased integrated system Life Cycle (ILS) cost. In order to meet this need RICOR has developed a new rotary Stirling cryocooler, model K508N, intended to double the K508's operating MTTF achieving 20,000 operating MTTF hours.

The K508N employs RICOR's latest mechanical design technologies such as optimized bearings and greases, bearings preloading, advanced seals, laser welded cold finger and robust design structure with increased natural frequency compared to the K508 model.

The cooler enhanced MTTF was demonstrated by a Validation and Verification (V&V) plan comprising analytical means and a comparative accelerated life test between the standard K508 and the K508N models. Particularly, point estimate and confidence interval for the MTTF improvement factor where calculated periodically during and after the test. The (V&V) effort revealed that the K508N meets its MTTF design goal. The paper will focus on the technical and engineering aspects of the new design. In addition it will discuss the market needs and expectations, investigate the reliability data of the present reference K508 model; and report the accelerate life test data and the statistical analysis methodology as well as its underlying assumptions and results.

8012-83, Session 16

High-operating temperature MWIR photon detectors based on type II InAs/GaSb superlattice

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Recent efforts have been paid to elevate the operating temperature of Type II superlattice Mid Infrared photon detectors. Using M-structure superlattice, novel device architectures have been developed, resulting to significant improvement of the device performances. In this talk, we will compare different photodetector architectures and discuss the optimization scheme which leads to almost one order of magnitude of improvement to the electrical performance. At 150K, single element detectors exhibit a quantum efficiency above 50%, and a specific detectivity of 7x1011 cm.Hz1/2/W. BLIP operation with a 300K background and 2 FOV can be reached with an operating temperature up to 180K. High quality focal plane arrays were demonstrated with a noise equivalent temperature of 10mK at 77K. Uncooled camera is capable to capture hot objects such as soldering iron.

8012-84, Session 16

MWIR InAsSb XBn detector arrays operating at 150 K

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We report on the progress of XBn detector development at SCD. The project is aimed at developing a high operating temperature (~150K) mid-wave infrared detector array, based on InAsSb/AlSbAs device elements with an XBn architecture. The essential principle of this architecture is to suppress the Generation-Recombination contribution to the dark current by ensuring that the depletion region of the device is contained inside a large bandgap barrier layer (BL) and excluded from the narrow bandgap active layer (AL). The band profile of the XBn device leads to effective blocking of electron transport across the BL while maintaining a free path for the holes, thus assuring a high internal quantum efficiency (QE) for a device with an n-type AL. The BL is doped n-type to avoid the need for high doping in the AL, thereby preventing an unwanted blue-shift of the device cut-off wavelength due to the Moss Burstein effect. Our devices exhibit a very large minority carrier lifetime (~700ns), leading to a very low dark current of <10-6A cm-2 at 150K, which is essentially diffusion limited. In flip-chip devices with an InAsSb AL thickness of 3 micron, the external QE at 3.5 micron is ~70% and the cut-off wavelength is 4.1 micron. In a 5x5 array with 30 micron pixels, we demonstrate BLIP operation at f/3 and 150K, with a uniformity of ~10% in dark current and ~0.5% in QE. XBn Focal Plane Arrays (FPAs) have been coupled to SCD's Blue Fairy 320x256/30 micron CMOS Read-Out Integrated Circuit. The electro-optical characteristics of the XBn FPAs at 150K are reported, and examples of images are presented

8012-85, Session 16

InAsSb detectors for visible to MWIR high-operating temperature applications

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The Photon-Trap Structures for Quantum Advanced Detectors (PT-SQUAD) program requires MWIR detectors at 200 K. One of the ambitious requirements is to obtain high (> 80 %) quantum efficiency over the visible to MWIR spectral range while reducing dark diffusion current in the detector via reducing the volume fill ratio (VFR) of the detector while optimizing absorption. Electromagnetic simulations show that an innovative architecture using pyramids as photon trapping structures provide a photon trapping mechanism by refractive-index-matching at the tapered air/semiconductor interface, thus minimizing the reflection and maximizing absorption to > 90 % over the entire visible to MWIR spectral range. InAsSb with bandgap appropriate to obtaining a cutoff wavelength ~ 4.3 um is chosen as the absorber layer. An added benefit of reducing VFR using pyramids is that no AR-coating is required.

Compound-barrier (CB) detector test structures with alloy composition of the InAsSb absorber layer adjusted to achieve 200 K cutoff wavelength of 4.3 μm (InAsSb lattice-matched to GaSb). The dark current density was observed to be within a factor of 3 of the HgCdTe standard. 64 x 64 focal plane arrays with variable area detectors are currently under fabrication. Response and noise data will be acquired following fabrication of the arrays. Response data as a function of wavelength will be compared to the electromagnetic modeling to determine if the broadband absorption predictions match observations. Detector data as a function of temperature will test the efficacy of reduced VFR on detector dark diffusion current.

8012-86, Session 16

Use of unipolar barriers to block dark currents in infrared detectors

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Unipolar barriers are heterostructures that block the flow of one carrier type and pass the other carrier type. Unipolar barriers can be inserted into the epitaxial structures of otherwise-conventional IR detectors to achieve dramatic suppression of certain types of dark current components. We use InAs-based materials to demonstrate these unipolar barrier IR detector concepts, but they can also be implemented in most other common IR detector semiconductor material systems, such as InAsSb, strained layer superlattices, and HgCdTe. In this presentation, we present experimental results that quantify suppression of dark currents in InAs-based unipolar barrier IR detectors.

We have inserted unipolar barriers into photoconductors thereby creating nBn detectors, which suppress surface leakage and Shockley-Read-Hall currents by at least six orders of magnitude, down to undetectable levels. Additionally, we have inserted unipolar barriers into photodiodes, suppressing (again, usually to undetectable levels) surface leakage, Shockley-Read-Hall current, band-to-band tunneling currents, and trap-assisted tunneling currents. As a result of this dark current suppression, unipolar barrier photodiodes exhibit RoA values, which are six orders of magnitude greater than those of conventional photodiodes.

Finally, we present a general description of the use of unipolar barriers, showing explicitly which types of dark currents can be blocked and which types of dark currents cannot be blocked. The description relies on the spatial makeup of the dark current components, relative to that of the photocurrent. Surface leakage currents and depletion layer currents can be blocked; diffusion currents cannot be blocked.

8012-87, Session 16

Development of interband cascade infrared photodetectors

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Interband cascade (IC) infrared (IR) photodetectors (ICIPs) are a new type of detector based on quantum-engineered InAs/GaSb/AlSb

heterostructures. They combine the features of conventional interband photodiodes with the discrete nature of quantum-well IR photodetectors (QWIPs). The operation of ICIPs takes advantage of fast intersubband relaxation and interband tunneling for carrier transport, and relatively slow interband transitions (long lifetime) for photon generation. As such, ICIPs can be optimized for specific application requirements, such as higher operation temperature or lower noise. Many advanced detector structures such as complementary electron and hole barrier layers are already incorporated in ICIPs. Our initial effort has led to the demonstration of ICIPs with low noise and photovoltaic operation in the mid-IR wavelength region. Even with a relatively thin absorber (~1.5 μm), a quantum efficiency exceeding 20% (at 5 μm) has been achieved at temperatures up to 320 K. The background-limited performance temperature at 2π field of view is as high as 126 K. At 300 K and 5 μm, the Johnson-limited D* is 4.2x10^8 Jones. Using an IC laser structure, we also observed clear photon current response with cutoff wavelength beyond 7 μm at temperatures up to 260 K. We will discuss unique features of ICIPs and report our recent effort in the development of ICIPs.

8012-88, Session 16

High-operating temperature IR-modules with reduced pitch for SWaP sensitive applications

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

Low Size, Weight and Power (SWaP) are the most critical requirements for portable thermal imagers like weapon sights or handheld observations devices. On the other hand due to current asymmetrical conflicts there are high requirements for the e/o performance of these devices providing the ability to distinguish between combatants and non-combatants or identify persons from a photo ID in adequate ranges. Despite of all the success with uncooled technology, such requirements usually still require cooled detectors.

AIM has developed a family of thermal weapon sights called HuntIR and RangIR based on high performance cooled IR-modules which are used e.g. in the infantryman of the future program of the German army (IdZ). The specific capability of these devices is a high ID range >1500m for tank targets being suitable in use as thermal sights for .50 cal rifles like the G82, fire control units for the 40mm AGL or for night observation. While such ranges sound far beyond the operational needs in urban operations, the a.m. specific needs of asymmetric warfare require sometimes even more range performance.

As a key component to keep performance while reducing SWaP AIM is developing for a follow-on sight family a new cooled MCT IR-module with reduced pitch of 12μm operating at a temperature >120K. The module will provide full TV format with 640x480 elements sensitive in the MWIR spectral band. A low power electronics provides the additional functions like image correction and dynamic reduction as well as power management of the components. In a modular approach the sight can be used as a high performance clip-on for snipers with additional modules for laser range finding and oculars for observation or stand-alone targeting.

The paper will show recent results of AIM IR-modules operating a higher operation temperature and the impact of design regarding the IR-module itself and the thermal sight making use of it.

8012-89, Session 16

HOT infrared detectors using MCT technology

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Cooled IR technologies are challenged for answering new system needs like the reduction of power consumption. This reduction is requested in new IR system design in particular for cooled IR detection. The goal is to reduce system sizes, to increase system autonomies and reliabilities and globally to reduce system costs. One of the key drivers for cooled systems is the cooler and the operating temperature. As far as operating temperature is concerned, Sofradir and CEA-LETI LIR put a lot of efforts to increase the operating temperature of IR MCT detectors. The n/p and p/n MCT technologies are improved to operate at high temperature with good performances and particularly with low rate of defective pixels. These detectors operate in the MW blue band, MW and LW. In addition complex structures like nBn structures are developed to go further in the high operating temperature. Results are presented and discussed.

8012-90, Session 16

High-operating temperature (HOT) broadband quantum-dot infrared photodetector (QDIP)

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In this paper, a high operating temperature (HOT) broadband InAs/GaAs quantum dot (QD) infrared photodetector (QDIP) is reported. The QDIP covers a wide detection spectrum range from 3 μm to 10 μm. A large photoresponsivity of 1.2 A/W at a low bias voltage of 0.5V and a high peak specific photodetectivity D* of 1.2×108 cmHz1/2/W were obtained at a high operating temperature of 298 K.

8012-91, Session 16

Digital 640x512/15 μm InSb detector for high-frame rate, high-sensitivity, and low-power applications

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PelicanD is a new digital 640x512/15micron InSb detector developed by SCD to serve several applications. The Readout Integrated Circuit (ROIC) has a digital output which can be calibrated to a signal resolution in the range of 13-15 bit. Besides the digital output the detector has some additional advantages over other MWIR detectors of the same format. The high frequency of data output, which supports full image frame rate of above 300Hz, is very useful in systems that track fast evolving events such as Missile Warning Systems (MWS), Missile Seekers and some Thermographic applications. Another important characteristic of the detector is related to an operation mode with relatively low readout noise. This mode of operation is especially beneficial in applications where the background radiation is low such as in long range surveillance systems. For imaging systems where very high sensitivity is required, the ROIC can be coupled to epi-InSb detector array and have a dark current at 77K that is lower by a factor of 15 with respect to standard InSb. Alternatively, PelicanD with epi-InSb can be operated at 95K with standard dark current and sensitivity. Such elevated operation temperature enables the use of cryogenic coolers of relatively low size, weight and power for applications such as Hand-held cameras, miniature gimbaled systems, and light UAVs. In this work we present in details the characteristic performance of the new detector and its applications.

8012-92, Session 17

Ion implantation study of Be in InSb for the fabrication of IR detectors

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InSb-based MWIR photodetectors are most commonly doped by thermal diffusion because it is economical and repeatable. However, thermal

diffusion has limitations when it comes to fabricating more complicated doping profiles such as avalanche photodetector structures. These structures require separate absorption and multiplication (SAM) regions, with high and low doping concentrations at specific depths below the surface. While they can be attained with epitaxially grown layers, a detector technology based on bulk-InSb has significant advantages. Ion implantation offers one alternative to achieve PIN and SAM-APD structures on bulk InSb substrates. However, there are limitations to the structures that can be achieved with ion implantation, and to date very little has been reported on the accuracy of ion implantation models for InSb.

In this paper we will present experimental and modeling results of various ion implantation profiles of beryllium in n-type InSb substrates. We utilize SRIM modeling software to design the doping profiles. These results are then compared to measured values obtained from SIMS analysis of the detector structures. The effects of annealing on the doping profile are also investigated. We also present the photodetector performance parameters and how they could be further improved by tailoring the implantation profile. Because these are bulk detectors rather than grown, they can be fabricated cheaply and be easily integrated into existing InSb detector array production lines.

8012-93, Session 17

New developments in HgCdTe APDs and ladar receivers

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

No abstract available

8012-94, Session 18

Design and development of 256x256 linear mode low-noise avalanche photodiode arrays

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A larger format photodiode array is always desirable for many LADAR imaging applications. However, as the array format increases, the laser power or the lens aperture has to increase to maintain the same flux per pixel thus increasing the size, weight and power of the imaging system. In order to avoid this negative impact, it is essential to improve the pixel sensitivity. The sensitivity of a short wavelength infrared linear-mode avalanche photodiode (APD) is a delicate balance of quantum efficiency, usable gain, excess noise factor, capacitance, and dark current of APD as well as the input equivalent noise of the amplifier. By using InAlAs as a multiplication layer in an InP-based APD, the ionization coefficient ratio, k, is reduced from 0.40 (InP) to 0.22, and the excess noise is reduced by about 50%. An additional improvement in excess noise of 25% was achieved by employing an impact-ionization-engineering structure with a k value of 0.15. Compared with the traditional InP structure, about 30% reduction in the noise-equivalent power with the following amplifier can be achieved. Spectrolab demonstrated 30-um mesa APD pixels with a dark current less than 10 nA and a capacitance of 60 fF at gain of 10. APD gain uniformity determines the usable gain of most pixels in an array, which is critical to focal plane array sensitivity. By fine tuning the material growth and device process, a break-down-voltage standard deviation of 0.1 V and gain of 30 on individual pixels were demonstrated in our 256x256 linear-mode APD arrays.

8012-95, Session 18

A 320x256 HgCdTe avalanche photodiode focal plane array for passive and active 2D and 3D imaging

E. De Borniol, J. Rothman, F. Guellec, P. Castelein, G. L. Destéfanis, CEA Leti-MINATEC (France)

CEA-Leti has developed a 30µm pitch 320x256 FPA dedicated to active imaging. Each pixel of the readout IC (ROIC) can perform time-of-flight (TOF) measurement in addition to 2D intensity imaging from a single emitted laser pulse. The FPA consist of this ROIC hybridized to an HgCdTe avalanche photodiode (APD) array. A prototype of flash laser radar system based on this FPA has been developed. The source used to illuminate the observed scene is a 1.57µm eye safe laser producing 8ns pulses.

This paper describes the readout IC pixel architecture and the experimental setup used to test the FPA. We report the electro-optical performances and calibration results obtained during laboratory tests. The linearity, the noise and residual fixed pattern noise are evaluated. The range correction to be applied as a function of the laser pulse return intensity has been evaluated. We also report results of 3D imaging field trials made with this prototype flash laser radar system.

8012-96, Session 19

Remembering Philippe Tribolet

P. Bensussan, SOFRADIR (France)

No abstract available

8012-97, Session 19

Large format high-operability SWIR and MWIR focal plane array performance and capabilities

J. W. Bangs, Raytheon Vision Systems (United States)

Large format detector arrays responsive to the 1-7µm wavelength range are available for advanced imaging applications with a straightforward growth path to an 8k×8k infrared focal plane array (FPA). This paper describes arrays 1.5 to 4 Mega-pixel infrared HgCdTe developed by Raytheon Vision Systems for demanding higher performance applications. These detector arrays have 1024 x 1536 and 2048 x 2048 formats with detector pixel size scaled down to 10 to 15 µm to minimize overall sensor size, with low cost capability achieved by fabrication on 6-inch diameter HgCdTe/Si wafers. Performance data will be provided on both the detector and ROIC noise and detector low dark current, high quantum efficiency and optical fill factor, and uniformity of typical SWIR and MWIR FPAs. MWIR HgCdTe/Si 2k×2k FPAs have been made with over 99.9% operability to a full range of stringent performance specs. This paper will provide detailed FPA performance capability for small pitch large format for HgCdTe/Si detector arrays fabricated at RVS and describe our readiness to provide multi mega pixel infrared FPAs for current and future wide FOV high-resolution systems.

8012-98, Session 19

MCT IR detectors in France

G. L. Destéfanis, CEA Leti-MINATEC (France); P. Tribolet, M. Vuillermet, SOFRADIR (France)

This talk will describe the status of MCT IR technology in France at Leti and Sofradir. This concerns first evolution of crystal growth of large CZT for substrates, and MCT epilayers grown by LPE and MBE. A focus will be made on extrinsic doping of MCT with Indium and Arsenic for device fabrication.

Evolution of detector technology will also be considered for detectors that operate from NIR/SWIR to VLWIR, moving from an n on p vacancy doped technology to a fully extrinsically doped p on n device architecture.

Last results on 3rd generation detectors such as multicolor FPAs, HOT

Return to Contents

detectors and 2D or 3D FPAs that use MCT APD will also be described.

Moving to larger FPAs, pixel pitch reduction become mandatory and technology evolution to achieve this goal will be presented.

Then, cost reduction achievement through more compact systems that operate at higher temperature and/or integrate optical functions inside the cryostat will also be considered

8012-99, Session 19

Latest detector developments with HgCdTe grown by MOVPE on GaAs substrates

C. D. Maxey, P. Abbott, L. G. Hipwood, C. L. Jones, P. Knowles, J. P. Price, SELEX Galileo Infrared Ltd. (United Kingdom)

This paper describes the current state of the art HgCdTe grown by metal-organic vapour phase epitaxy on GaAs substrates, and progress in the development of dual-band (MW / LW) infrared detectors. In previous papers, we have described full-TV dual-band arrays of 640 x 512 pixels on 24µm and 20µm pitches. The latest development is a 20µm pitch 860 x 480 pixel array in 'wide screen' 16:9 format, incorporating a new ROIC designed in 0.35µm CMOS.

The detector can be operated in multiple imaging modes: dedicated LW or MW, or both LW and MW wavebands per frame. The ROIC includes stable on-chip voltage references, a serial digital control interface, and supports integrate-then-read, integrate-while-read, binning, and windowing readout modes.

8012-100, Session 19

The development of 3rd gen IR detectors at AIM

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AIMs production of 2nd Gen infrared detectors is based on LPE MCT layers and n on p planar technique covering the spectral range from VIS-NIR to VLWIR and delivering high performance state-of-the art IR devices. 3rd Gen IR modules - dual-color (DC), dual-band (DB), and large format 2-dimensional arrays - require a more sophisticated production technique such as MBE and mesa technique, which can satisfy the rising demand for increasingly complex device structures and low cost detectors, respectively.

The DC devices of AIM are based on MBE-grown InAs/GaSb type II superlattices which have been developed by the Fraunhofer Institute, IAF. The 384x288 DC detector with 40 µm pitch combines the simultaneous integration of two colors (3-4 µm, 4-5 µm) in the MWIR range in one pixel. In accordance with the AIM roadmap, the qualification of production is currently in progress, the start of production is scheduled for mid 2011.

For DB MW/LW detectors, MCT MBE on CdZnTe substrates is the technology of choice for AIM. The basic MBE growth of MCT multilayer structures was developed in cooperation with IAF. Dedicated for production of DB devices, AIM has installed an additional growth chamber connected to the existing MBE system. The basic approach for the mesa structured 640x512 DB FPA at 20 µm pitch is backside illumination with extrinsic Indium doping for the MW layer and Boron implantation for the LW layer.

Another benefit of MBE technology is the growth of MCT layers on alternate substrates which permits cost-effective production of large format arrays in the MWIR, due to its high homogeneity and yield. Currently, AIM develops the MBE growth of MWIR MCT on GaAs for megapixel detectors (1280x1024, 15 µm pitch). Promising first results were achieved for 640x512, 15 µm pitch PV arrays.

The paper will present the development status and latest results of the above-mentioned 3rd Gen Focal Plane Arrays and IDCAs.

8012-101, Session 19

Infrared dual-color and dual-band detectors for next generation

Y. Reibel, F. Chabuel, D. Billon-Lanfrey, SOFRADIR (France); J. Baylet, P. Ballet, G. L. Destéfanis, CEA Leti-MINATEC (France)

The development of dual-color and dual-band infrared detectors has been the core of research and technological improvements for the last ten years at CEA-LETI and Sofradir: the semi planar structure uses a proven standard process with robust reproducibility, leading to low-risk and an facilitated ramp-up to production This makes it the natural choice for the third generation FPA proposed by Sofradir.

The fabrication of dual-band MCT detectors is reaching maturity: ALTAIR 24µm-pitch arrays in TV format is available, showing median NETD around 18mK with operability over 99.5%. Lately, thanks to improvements in the production process, ALTAIR with 20µm pixel pitch has been launched.

This new technology widens perspectives and opens new horizons of applications such as dual mode capability providing both SAL and IR operations for more robust target engagement or compact dual color detection with wide-angle integrated optics for missile warning system.

8012-102, Session 19

Electro-optical characteristics of a p^+n long-wavelength HgCdTe photodiode limited by Auger intrinsic carrier recombination for T>40K

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

D. Donetsky et al.1, recently reported photoluminescence decay (PLD) data for a n-type material of long wavelength Hg1-xCd xTe grown on CdZnTe, with x= 0.22, λcut-off = 10.76 µm at 78K with a doping level Nd =1015cm-3. Analysis of the data resulted in a Shockley Read Hall minority carrier lifetime of ≈ 1-2 µs suggesting recombination through traps as a limiting recombination mechanism in P+n devices, where n is the absorbing layer. The work reported here is a detail analysis of the current versus voltage versus temperature data of individual P+n photodiodes built on the same wafer with focus to establish correlations between minority carrier lifetimes measured using PLD and photoconductive decay (PCD) and minority carrier lifetimes obtained from analyses of the dominant limiting currents. The major finding is that over a temperature range from 78K down to ≈ 40K, the currents can be mostly explained by Auger (e-e) carrier recombination processes with no evidence of SRH recombination through states in the forbidden energy gap. The absence of space charge (GR) currents at 50K suggests SRH lifetimes > 30 µs. The material- device model parameters, x= 0.22, Nd=1015 cm-3, n- layer thickness = 9 µm, Auger overlap coefficient F1F2= 0.15, explain the current versus voltage data over the temperature range from 78K to 40K. From the analysis of variable area devices the diffusion length at 80K is calculated to be 23 µm. For T ≤ 40K trap assisted tunneling is the dominant current in reverse bias. Forward bias currents are dominated by diffusion currents of origin in the n- layer. The lifetime measured by the PCD method is in agreement with what is expected for the Auger lifetime ~ 2 µs and with the lifetime obtained from device analysis at 78K; deviations are observed at lower temperatures where the functional dependence on temperature tends to a constant, suggesting trapping and de trapping effects. Not explained at this time are the differences in minority carrier lifetime measured by PLD and PCD. Analysis of the PLD excess carrier lifetime data suggests flaws situated near the conduction band edge, above the Fermi level, these states are likely not localized and thus may not be limiting the recombination processes.

1. D. Donetsky, G.Belenky, S. Svensson and S. Suchalkin, Minority carrier lifetime in type-2 InAs-GaSb strained- layer superlattices and bulk HgCdTe materials, Appl. Phys. Lett. 97, 052108 (2010)

8012-148, Session 19

On the role of dislocations in influencing the electrical properties of HgCdTe photodiodes

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Dislocations in the base material are known to influence the electrical properties of semiconductor diodes - (a) by acting as a shunt operating in parallel to the diode impedance, the dislocations intersecting the junction are relevant in this context though, and (b) by acting as regions of high recombination and degradation of carrier lifetime. The above effects of dislocations influencing the electrical and photo-electric characteristics of HgCdTe have been widely discussed in published literature. However, there is yet another unexplored aspect of the dislocations, that has not attracted the attention of any of the investigators, that is the band gap narrowing/widening induced by the intense stress field around dislocation core. Preliminary estimations show that the band gap narrowing due to the tensile region of the stress field along the dislocations in HgCdTe is high enough to cause significant band gap narrowing in low band gap HgCdTe. The average band gap lowering in the tensile region around a 60° dislocation in HgCdTe can be expressed as of ~ 0.11 (b/r) eV, where b is the magnitude of the Burgers vector and r is the radial distance from the dislocation core. The extent of this lower band gap region is expected to be of the order of a few Burgers vectors only. It is proposed that this band gap narrowing in the immediate vicinity of dislocations may be responsible for soft breakdown of HgCdTe diodes under reverse bias condition.

8012-103, Session 20

Dual-band antireflection coatings on 3rd Gen lenses

T. D. Rahmlow, Jr., J. E. Lazo-Wasem, Rugate Technologies, Inc. (United States); J. N. Vizgaitis, J. Flanagan-Hyde, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Use of a dual band FPA necessitates an optical system that is capable of imaging both mid wave infrared (MWIR) and long wave infrared (LWIR) spectral bands simultaneously. Such optical system can have up to 10 lenses, (20 surfaces that require antireflection (AR) coatings) which, if 95% transmitting in each band, will result in overall throughput of just under 60% . With 99% transmitting in each band, overall throughput would be just over 90%, a relative improvement of 50%. An earlier paper presented dual band antireflection designs, as well as early fabrication attempts on plano Ge, ZnSe, ZnS, AMTIR-1, and CaF2 windows . This paper presents results of prototype coating fabrication on ZnSe, Ge, and BaF2 lenses that comprise a 7 lens set. The measured performance of the individual elements is used to model overall system performance. The elements were incorporated into an optical assembly and measured overall imager performance is analyzed and presented.

8012-104, Session 20

Infrared hybrid glass-polymer optics: combining the thermal stability of glass with low manufacturing cost of polymers

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Development of infrared detector technology brought to the market high performance infrared cameras for demanding thermal imaging applications in the shortwave, mid-wave and long-wave spectral bands. There is a vast demand on high performance imaging optics for infrared cameras in a variety of markets and applications. Low manufacturing cost, thermal stability, impact resistance are some unbeatable characteristics of infrared application hybrid glass-polymer optics. The hybrid solutions offer thermal stability of glass with low manufacturing cost of polymers reducing component cost, weight, complicity of the design and alignment while enhancing the appeal of the products. Narrow choice of polymer materials is compensated by utilizing sophisticated optical surfaces and prescriptions.

The unique solution presented in this paper is the fast high performance diffraction limited imaging Hybrid Glass-Polymer lens for infrared application. The low number of components, light weight, the thermal stability, and low manufacturing cost makes this lens desirable for multiple applications. The listed advantages are not achievable when polymers or glass optics are used as stand-alone.

The author demonstrates that integration of polymer and glass for Infrared application offers high resolution and diffraction limited image quality with stable thermal performance, significantly reduces cost, weight, and complexity.

The author will describe the design and analysis process of combining glass and polymer optics in Infrared spectral range for a variety of challenging applications such as fast optics with low F/#, wide field of view lenses or systems, free form optics, etc.

8012-105, Session 20

Emerging results for producing low-scatter EN clad and bare Al mirrors: enabling technology for new tactical instruments

K. G. Carrigan, J. Daniel, J. B. Barentine, T. B. Hull, L-3 Communications Tinsley Labs. Inc. (United States)

Processes have been developed at L-3 Integrated Optical Systems Tinsley Operations that are now producing mirrors that exhibit very low microroughness surfaces on bare electroless nickel (EN); three to as much as ten times better than prior industry practice. Coupled with Tinsley's single point diamond turning methods, designers may now consider metal substrate approaches leading to high-performing, low-scatter mirrors. Advantages include aggressive optical forms, excellent thermal continuity (important for cooled systems), and potentially significant cost savings from traditional glass fabrications used to reach these scatter levels. Parameters will be presented. Also emerging results on unclad post polishing of bare aluminum will be presented.

8012-123, Poster Session

Technical and market trends for microbolometers for thermography and night vision

E. Mounier, Yole Développement (France)

Initially developed for the military market by US defense companies, use of uncooled infrared (IR) cameras in commercial applications has been growing over the last ten years. In the infrared spectrum, Long Wave Infrared (LWIR) is the most commonly used wavelength (8-12 microns). Thermography and a variety of vision enhancement applications are the main growth markets for uncooled IR cameras. Camera prices have been significantly reduced in the thermography business, which has allowed expansion of the use of IR cameras to maintenance engineers and building inspectors.

This camera cost reduction will continue through 2015 in the thermography business and will also be a strong factor in the vision market (also called night vision or vision enhancement) with the growth of the security/surveillance and automotive markets.

Driven by the continued cost reductions, the volumes of camera sold will triple by 2015 from more than 200,000 cameras today to more than 700,000 units, meaning + 25 % annual growth rate.

Microbolometers are the dominant uncooled IR detector technology with more than 95 % of the market in 2010. More than 75 % of the production is based in USA but this landscape will change in the next five years:

many new players (Sensonor, Faun Infrared, Bosch...), focusing only on selling detectors, often in Europe, will enter on the market place with aggressive price strategies.

The following technical trends make detector cost reduction possible: wafer Level Packaging and even Pixel Level Packaging, smaller pixel size, 3D integration.

8012-124, Poster Session

100mm diameter GaSb substrates with extended IR wavelength for advanced space-based applications

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A key component for stealth defense enhancement is the development of megapixel strain layer superlattice (SLS) structures on GaSb substrate based infrared focal plane arrays (IRFPAs) for use in war fighter support and protection. A significant aspect inhibiting widespread military and commercial application of large format SLS on GaSb substrate IRFPAs is the size of the starting substrates. In June 2009, the Czochralski method for producing GaSb substrates has resulted in the world's first 100mm (4") GaSb boules. The 100mm GaSb substrates can be ultra-low doped (n~4-9x1015/cm3) for extended IR wavelength transparency. A plethora of changes to the manufacturing process is required for larger diameter GaSb growth and manufacturing, especially for substrate polishing. In this study, we examined the surface quality of the larger diameter GaSb as a function of the polishing process. Interferometry was used to analyze free standing (non-vacuum hold) wafer flatness and surfscan data was analyzed for surface haze of the 100mm GaSb batches. Atomic force microscopy (AFM) as a function of pre-MBE and post-MBE was examined. Strain layer Superlattice material suitability was examined by x-ray diffraction (XRD) and successful 400 period Complimentary Barrier Infrared Detector (CBIRD) epitaxial structure growth. The low 0.3-0.4nm Ra AFM roughness values, the high intensity XRD peaks measuring ~6.6nm in periodicity, the low FWHM SLo = 15.48 arsec, and the successful CBIRD epi growth suggest that the longer final surface polish time provides the 100mm GaSb with a desirable low UHV thermal desorption character and excellent surface crystallinity for advanced IRFPA applications.

8012-125, Poster Session

A high fill-factor high-SNR CMOS image sensor for IR camera applications

V. Shenoy, D. McBride, S. Jung, H. Moon, The Univ. of Texas at Arlington (United States)

In infrared imaging systems, high dynamic range (DR) is required to increase the charge storage capacity. However, high DR imaging is challenging since the system must be able to capture scenes which have large variations in irradiance due to object temperatures. Thus, to achieve high DR infrared imaging system, high signal to noise ratio (SNR) readout integrated circuits (ROICs) is critical. Several design trade-offs are required in a high SNR ROIC design including noise, frame rate, power per unit cell, and unit cell area.

In this work, a high-fill factor/high SNR ROIC unit cell designed using TSMC 0.18 um CMOS process is presented. The ROIC array uses a single reference photo diode, and it is routed to each unit cell in the array using current mirrors to subtract the dark current for high SNR. The achieved average SNR is 80 dB and the fill factor is 28%. The proposed circuit is significantly smaller than other circuits that perform dark current subtraction because less circuitry is used in the unit cell. The proposed circuit uses only two transistors and one resistor in each unit cell to suppress the dark current. The size of the circuit in the layout is 25 x 25 µm2. With this new unit cell and routing approach, the size of the unit cell is reduced by 300% compared to other high SNR circuits. The maximum power required per unit pixel is 500nW, which is considerably less than that of existing high SNR ROICs.

8012-126, Poster Session

A self-protecting uncooled microbolometer structure for uncooled microbolometer

Y. Jo, I. Kwon, D. S. Kim, H. B. Shim, H. C. Lee, KAIST (Korea, Republic of)

During the microbolometer operation, it occasionally happens that the detector views very high temperature scenes such as sun during the daylight or flames in very close distance. Detector temperature increase can be so high that bolometer material may experience annealing effect by viewing such high temperature scenes. Thus, microbolometers are required to stand a high temperature that can cause device damage.

In this paper, a bimaterial leg integrated microbolometer structure will be proposed. The bimaterial is an extra leg which is separated from the signal transfer legs and it bents downward and snaps on the substrate when the microbolometer's temperature reaches to critical temperature. Then, the temperature of the microbolometer is decreased as the heat is transferred to the substrate.

By snapping the bimaterial leg down onto the substrate, microbolometer's thermal conductance is temporarily increased 10 times higher than that of normal state and thermal damage of the bolometer material can be prevented effectively.

8012-127, Poster Session

Electric characteristic of nickel oxide film for the mirobolometer

Y. S. Lee, Kyungpook Univ. (Korea, Republic of); D. S. Kim, KAIST (Korea, Republic of); J. H. Kim, Kyungpook Univ. (Korea, Republic of); H. C. Lee, KAIST (Korea, Republic of)

1. Formation of Nickel oxide film and its evaluation of bolometric properties: We used two methods that can make a nickel oxide films; heat treatment of nickel metal and reactively sputtering. The nickel oxide film obtained from heat treatment of nickel has a high TCR(above -3.2/°C) and a relatively high 1/f noise. But the nickel oxide films obtained from reactively sputtering has a wide range of resistivity as condition of sputter parameters. Acquired TCR was varied with a range from -1.4%/°C to -3.45%/°C as function of resistivity. and a 1/f nosie parameter k was low as 8.5×10-13 at TCR of -1.75%/°C. This result as a bolometric material shows a performance between VOx and a-Si. And it means that nickel oxide films can be applicable to microbolometer.

2. Analysis of nickel oxide films: Acquired nickel oxide fimls were analyzed from XRD, RBS, AFM and XPS methods. We certified that a resistivity variation results from nonstiochiometric property of nickel and oxygen atoms. A resistivity is decreased as a deficiency of nickel is increased.

3. Application of infrared sensor: We conducted a optic simulation and bolometer structure calculation for predicting the performance of a microbolometer with nickel oxide films. Through result of calculation of microbolometer for 50 ×50 , we verified that a low NETD(noise equivalent temperature difference) below 50mK can be obtained.

8012-128, Poster Session

Non-cryogenically cooled amorphous/polycrystalline InSb and InAs0.3Sb0.7 films for long-wavelength infrared detection

T. W. C. Zens, Massachusetts Institute of Technology (United States) and Air Force Institute of Technology (United States); A. J. Drehman, Air Force Research Lab. (United States); P. Becla, A. M. Agarwal, L. C. Kimerling, Massachusetts Institute of Technology (United States)

The structural, electronic, and optical properties of amorphous InSb and InAs0.3Sb0.7 films deposited by RF sputtering on glass, Al2O3, CdZnTe, and CaF2 substrates have been studied as they relate to Mid and Long Wavelength Infrared (MWIR and LWIR) detection. Depositions at elevated substrate temperature and pressure of <10 mTorr Ar show an emergence of crystalline grains with strong X-ray diffraction peaks at the (111) and (220) orientations. Electronically the amorphous InSb and InAs0.3Sb0.7 films deposited at 300K show hopping conduction with resistance in InSb ranging from 44 to 1.1E8 Ω-cm at 300K and 84K respectively. Optical analysis of these films using Fourier Transform Infrared Spectroscopy (FTIR) show that the absorption of these films has an Urbach tail the equation of which differs in InSb compared to InAs0.3Sb0.7 films. Amorphous InSb and InAs0.3Sb0.7 films showed thermal responsivity in excess of 100V/W for a range of wavelengths between 8 and 10 m for 6µm thick TEC cooled films held at -40C. The maxima and minima of the responsivity are shown to correspond to the interference fringes in the film. The response is highly substrate dependent and compares favorably to other thermal detectors.

8012-129, Poster Session

Design of multiple demeaning filters for small target detection in infrared imageries

W. Choi, J. Lee, A. Heo, D. Park, KAIST (Korea, Republic of)

In this paper, we propose multiple demeaning filters for small target detection in infrared (IR) imageries. The demeaning filter is a promising method which detects a small object by removing background components with a mean filter. The main factors in designing of demeaning filters are two kinds of demeaning methods and the window size of demeaning filters. We compare two demeaning methods: sliding window method and grid method. And we analyze the trade-off between the window size and performance of the demeaning filters, and present its limitation. To overcome the drawback of the conventional demeaning filter, multiple demeaning filters with various sizes of filters is considered. The proposed method not only has the advantage of detecting a small object in the dense-clutter environment, but also can be performed with low complexity by using the integral image. Experimental results demonstrate the robustness and stability of the proposed multiple demeaning filters with low computational complexity compared with the conventional methods.

8012-130, Poster Session

Image processing module for high-speed thermal camera with cooled detector

H. Madura, G. Bieszczad, T. Sosnowski, M. Kastek, T. Orzanowski, Military Univ. of Technology (Poland)

Infrared cameras are used in various military applications for early detection and observation. In applications where very fast image acquisition is needed the so called cooled detectors are used. Cooled detectors are a kind of detectors that demands cryogenic cooling, but in return provide exceptional performance and temperature sensitivity with low integration times. These features predestinate cooled detectors for special purposes like airborne systems, where fast and precise infrared radiation measurement is needed. Modern infrared cooled detector arrays like HgCdTe Epsilon detector from Sofradir with spectral range of 3.5 µm-5 µm can provide high frame rate reaching 140 Hz with full frame readout. Increasing frame rates of cooled infrared detectors demands fast and efficient image processing modules for necessary operations like nonuniformity correction, bad pixel replacement and visualization. For that kind of detector array a fast image processing module was developed. The module is made of two separate FPGA modules and configuration processor. One FPGA was responsible for infrared data processing, and was performing nonuniformity correction, bad pixel repleacement, linear and nonlinear filtering in spatial domain and dynamic range compression. Second FPGA was responsible for interfacing infrared data stream to standard video interfaces. It was responsible for framerate conversion, image scalling and interpolation, and controlling ASICs for video interface realization. Both FPGAs use several external resources like SRAM and DRAM memories. The input interface was developed to connect with Epsilink board which is a standard proximity board provided by Sofradir for this kind of detector. The image processing chain is capable of performing real-time processing on data stream of volume up to about 40 Megapixels per second.

8012-131, Poster Session

Design of ROIC based on switched capacitor TDI for MCT LWIR focal plane arrays

H. Kayahan, M. Yazici, O. Ceylan, Y. Gurbuz, Sabanci Univ. (Turkey)

Design and measurement of a silicon readout integrated circuit (ROIC) based on switched capacitor time delay integration (TDI) technique for LWIR HgCdTe Focal Plane is presented. ROIC incorporates time delay integration (TDI) functionality for scanning type of detector by using switched capacitor techniques with a supersampling rate of three, increasing SNR and the spatial resolution. ROIC, in terms of functionality, is capable of bidirectional scan, programmable integration time, 5 gain settings at the input and auto gain adjustment with pixel deselection capability. Programming can be done parallel or serially with test mode functionality. ROIC can handle up to 3.75V dynamic range with the load being 25pF capacitive, output settling time is less than 80 nsec. This low power ROIC consumes less than 100mw. Moreover, input referred noise is less than 750 rms electrons. Simulations and measurements are done in both room temperature and cryogenic temperatures. In order to measure and simulate chip without a detector, process and temperature invariant current source block that imitate detector currents are designed as well. The manufacturing technology is 0.35µm, double poly-Si, four-metal (3 metals and 1 top metal) 5V CMOS process.

8012-132, Poster Session

Suppression of saturation based on low histogram for uncooled infrared detector

C. Park, Samsung Thales Co., Ltd. (Korea, Republic of)

In this paper, we propose suppression of saturation for protection of radiation against a high energy such as sunlight in un-cooled infrared (UCIR) system. If the sunlight radiates the UCIR system, the detector of it has damaged. This case can be recovered it by material of detector but difficult return to one's former state. Therefore, this happen the performance problem of it. Proposed method measures the output power a cell per line of the detector and analyzes a low histogram of image. The electronic board of the system controls the detector. Experimental result, the proposed method shows which undamaged the detector.

8012-133, Poster Session

Interpolation methods for division of focal plane polarimeters

S. Gao, V. Gruev, Washington Univ. in St. Louis (United States)

This paper will present different imaging interpolation methods using in the division of focal plane polarization imaging sensor-- a CCD based sensor (1-Mega pixels, 20 fps operating from 400nm to 1050nm wavelength) with aluminum nanowire polarization filters, then we will discuss the performance differences among these methods. Unlike the three-channel RGB Bayer pattern used in the color filter array (CFA) of the single color image sensor, a four angle-element (0°,45°,90°,135°) based pattern is applied to the high performance polarization sensor that we built. The "super pixel" composed by the four single angle elements is used to generate the low resolution polarization images (intensity, degree of linear polarization and angle of polarization), which need to be interpolated to achieve viewable image quality. Based on the arithmetic algorithms and polarization imaging sensor characteristics, we developed three linear interpolation methods (bi-linear, bi-cubic, bi-cubic spline) and two edge detection based interpolation methods (one first order and one second order derivative based) for our polarization imaging sensor. Several testing polarization images, with rich edge areas and sharp angle of polarization transition regions, will be used to evaluate the performance of different interpolation methods. The edge transition speed, mean square error and the comparison of image quality, such as image fidelity and interpolating artifacts, will be set as the main benchmarks for evaluation. Our purpose is to find an efficient and high-quality interpolation method for our polarization sensor, and set up effective benchmarks of image quality and correctness testing for polarization sensor design.

8012-134, Poster Session

MWIR continuous zoom with large zoom range

M. C. Sanson, J. Cornell, B. P. Roy, S. Herbert, K. Woodard, Corning Incorporated (United States)

A thermal imaging zoom system has been developed for the mid wave infrared band with greater than 30X zoom range. The zoom system provides continuous changes in the field of view from the narrow field of view to the wide field of view. Athermalization was also a key feature included in the design. An active thermal compensation approach is being used to cover a broad thermal range. A preloaded rail approach is used to maintain boresight and vibration requirements. The final optical layout and mechanical design resulted in a system suitable for tactical and other harsh environments. The current design is very compact for the extremely large zoom range but, the lens layout also provides adequate space for folding. In this way the zoom system can be easily configured for applications with compact space claims such as small turrets or gimbals. The fundamental optical design has also been found to be capable of accommodating different camera formats (focal plane array size and F number).

8012-135, Poster Session

Apache Point Observatory (APO) notch filter design

J. S. Allen, U. S. Dept. of Defense (United States)

The Apache Point Observatory (APO) is a world class 3.5 meter reflective telescope used for astronomical observations situated on top of the Sacramento Mountains in southern New Mexico. In 1994 the Ballistic Missile Defense Organization (BMDO), now the Missile Defense Agency (MDA), established a requirement of the collection of high altitude intercept data for its Theatre High Altitude Air Defense (THAAD) missile program. Initiated by the White Sands Missile Range Instrumentation Development Directorate (WSMR/IDD), a cooperative agreement was established between APO and MDA. The Apache Point Observatory is the result of a consortium of universities, including New Mexico State University, pooling together resources to establish a world-class observatory using a 3.5 meter cassegrainian telescope with a tertiary mirror which has the ability to rotate in such a manner that the incoming light can be directed to one of nine instrument ports situated on the periphery of the instrument. WSMR has received permission to use on the these ports to collect data using an Amber ALIRT infra-red camera which collects light in the 1 to 5 micron region using a 512 Indium-Antimonide sensor focal plane array.

2. INTRODUCTION

The author used a Hewlett Packard 4570A Dynamic Signal Analyzer to measure the spectral content of resonance frequencies of APO's 3.5 meter telescope. Resonances are due to both physical and electromagnetic inputs to the control system. The purpose was to identify resonances which compromise the image quality of the telescope and design appropriate filters to correct the problem.

Active notch filters were chosen for this application for several reasons. First, a passive filter would require expensive inductors. Second, impedance matching problems were a concern. Third, because of the low frequencies of the resonances, a high Q filter was essential in the design due to the fact that the resonances are at or near the operational bandwidth (BW) of the instrument. Recall that Q is the quality factor of a filter that is a dimensionless parameter that describes how a resonator's bandwidth is relative to its center frequency. An active filter with a high Q filter gives a maximally flat response, which can only be achieved with a passive filter where Q is an anemic 0.707. Simulations indicate that even with an active filter with a Q as high as five, attenuation exceeds 20 decibel (dB) at the desired notch frequency. Finally, high Q passive filters have the very undesirable characteristic of being non-linear near the notched frequency.

8012-136, Poster Session

The advantages of using a digital temperature controller in a miniature Stirling cryogenic refrigerator

S. Ninburg, RICOR-Cryogenic & Vacuum Systems (Israel)

Modern Infra-Red (IR) night-vision thermal imagers for reconnaissance, surveillance, recognition and targeting rely mostly on Stirling-cycle cryogenic refrigerators thanks to their high thermodynamic efficiency. Traditionally, linear cryogenic refrigerators comprised analog temperature controllers for controlling the cold-tip temperature and controlling the desire frequency. These controllers usually consist operational amplifiers, comparators, resistors and capacitors. The fine-tuning of the pre-set cold-tip temperature and the desire cooler frequency where achieved by setting potentiometers to a certain resistance.

It is known that potentiometers are affected by environmental temperature variations, continuous exposure to extreme temperatures, and aging. Another aspect of using a potentiometer is the difficulty for the customer to change the pre-set cold tip temperature and frequency.

Using potentiometer to reach wide operation set point temperature means potentiometer with high resistance with less accuracy, means less accuracy set point.

Even without the use of potentiometers, the accuracy and stability of the analog components are not sufficient for the increasing requirements of advanced IR detectors at various environmental temperatures, loads, and input voltages.

Moreover, manufacturers of cryogenic refrigerators could improve the reliability and traceability of their products by adding various functions to the controllers.

A digital temperature controller that is based on a highly integrated flash MCU could serve both goals: improve the accuracy of the cold-tip temperature and accuracy of the desire frequency, and provide with extra features aimed at improving the functionality and reliability of the refrigerators.

This paper describes the various functions and advantages of the K527 Sine digital temperature controller that was developed in RICOR Vacuum and Cryogenic Systems.

8012-138, Poster Session

Performance of 4.0W/60K pulse tube cryocooler for large-scale long-wave infrared focal plane arrays

H. Dang, Shanghai Institute of Technical Physics (China)

The pulse tube cryocooler has been proven to be an enabling technology which provides high reliability, low-noise and long life cooling for the Infrared Focal Plane Arrays (IRFPAs). For the developing large-scale long wave IRFRA, the operating temperature is about 60 K and the required cooling power can be up to 4 W. A single-stage coaxial pulse tube cryocooler has been developed to meet the requirements. The coaxial configuration is choosen to achieve a compact system, and the inertance tube together with a gas reservoir serves as the only phase-shifting component. The inertance tube consists of two parts with different inner diameter and length to obtain desirable phase relationship. The cooler system adopts split arrangement and an Oxford-type linear compressor with dual-opposed piston configuration is connected to the cold finger with a flexible metallic tube. Both cold tip and warm flange integrated with fine slit heat exchanges fabricated with electro discharge machining technology to enhance heat exchange performance. The design and optimization of the cooler are based on the theoretical CFD model developed by the analyses of thermodynamic behaviors of gas parcels in the oscillating flow. The system design is described by focusing on the thermodynamic aspects, and the cooler performance is investigated and evaluated.

8012-139, Poster Session

Development of high-capacity pulse tube cryocoolers at 80K for infrared focal plane array applications

H. Dang, Shanghai Institute of Technical Physics (China)

With the rapid increase of the scale of the infrared focal plane arrays (IRFPAs), there is an urgent need for the cryocoolers which can provide large cooling power. The pulse tube cryocoolers (PTCs) with the merits like high reliability, low-noise and long life become ideal candidates. A series of single-stage high frequency PTCs with the capacity of over 10 W at 80 K have been developed to meet the cooling requirements of large-scale medium wave IRFPAs. Both the coaxial and in-line arrangements have been employed, while their refrigeration efficiencies and systematic complexity have been compared. The inertance tubes, which consist of two or three parts with different inner diameter and length, together with the gas reservoirs, are employed as the only phase-shift components for all the systems. The design and performance optimization approaches are discussed in detailed. And some key factors influencing the performance have been indentified.

8012-140, Poster Session

Stirling-cycle cooler reliability growth at L-3 CE

D. P. Arndt, D. Kuo, Q. Phan, L-3 Communications Cincinnati Electronics (United States)

L-3 CE has in place a continuous effort to evaluate and improve the lifetime of its cryocooler products. This effort includes analysis of both lab environment reliability tests and field data from shipped units. The purpose of this paper is to outline L-3 CE's life testing methodology and provide reliability data for L-3 CE cryocoolers, specifically for the 0.6-Watt Cooler (Model B602), 1.0-Watt Reduced Size, Weight, and Power (RSWAP) Cooler (Model B610), and the 1.5-Watt Cooler (Model B1500). Cooler performance characteristics such as cooldown time, refrigeration capacity, and input power are monitored throughout the life of the cooler. The data presented here updates previously reported data. Field data for the 1.0-Watt Cooler (Model B1000) is also presented.

8012-141, Poster Session

Characterization of quantum cascade laser-based emissivity monitor for CORSAIR

M. T. Lwin, Princeton Univ. (United States) and Utah State Univ., Energy Dynamic Lab. (United States); M. D. Wojcik, Utah State Univ., Energy Dynamic Lab. (United States)

Quantum Cascade Lasers (QCLs) have shown great potential in monitoring the concentrations of environmental toxins due to its advantages such as emission wavelength in mid-infrared region, frequency tunability, high output power, operating at room temperature or with thermoelectric cooler (TEC) and small size. However, the requirements of the precise laser temperature and driving current which are responsible for output power fluctuation and emission frequency draw back its usefulness in a sensor system. We present an integrated environment for temperature and laser driving current control in the QCL experiments. The experimental setup included a copper block heat-sink, TEC controller, TEC source and laser source control and an IR-detector with the software package for the PID feedback control, and LabVIEW based user interface. The LabVIEW virtual instrument (VI) drivers were used to create an application VI that would allow the user to set laser options such as waveform and amplitude of the QCL temperature and current to the laser, and use those options to pulse the laser at given wavelengths. Additionally, the PID feedback control was implemented in controlling temperature and the real time updates regarding the state of the laser such as temperature and activity were displayed. Once enabled, the VI auto-configures the PID control parameters based on ambient and laser operating temperatures. The QCL VIs that form the application's foundation greatly simplify the error handling and programming required for such an operation. These results were evaluated to define the accuracy of QCL output frequency and intensity in a chemical sensor system.

8012-142, Poster Session

Quantum cascade laser as a mid-infrared photovoltaic and photoconductive detector

X. Chen, D. Shyu, F. Choa, Univ. of Maryland, Baltimore County (United States); S. B. Trivedi, Brimrose Corp. of America (United States)

We report the operation of quantum cascade lasers (QCLs) as a mid-IR photo-detector under both photovoltaic and photoconductive modes. When operated at photoconductive mode, negative photo-conductance is observed at low bias current. The photo-conductance of the device changes from negative to positive when the bias is increased over transparency point. Both modes can be operated at low temperature and room temperature. These experiments are done using two QCLs with the same QC structure and lasing wavelength. In the photovoltaic mode, QCL1 is lasing and its power is coupled into QCL2 waveguide. The generated terminal voltage of QCL2 is proportional to the coupling power from QCL1. The measured response time is 20μs and the responsivity is 27.8μA/W. In photoconductive mode operations, QCL2 is initially at a low bias. The injected QCL1 photons generate a reverse current flow to reduce the bias current and produce the negative photo-conductance. The measured responsivity is 55.6μA/W. When the bias current is increased to pass the transparency point and gets close to the threshold, the photo-conductance changes from negative to positive. These interesting mid-IR detection characteristics of QCL gain material can help with the design and testing of mid-IR photonic integrated

Return to Contents

devices. For example, integrated coherent receivers and transceivers have been demonstrated at near-infrared range with benefits of reduced size, weight, and cost. The QC material detection capability can help to simplify device design and testing by inserting them at necessary locations to measure the coupling and waveguide loss and provide gain by increasing bias current.

8012-144, Poster Session

Different approximation for carrier statistic in non-parabolic MWIR HgCdTe photovoltaic devices

J. Wang, National Synchrotron Radiation Lab. (China) and Shanghai Institute of Technical Physics (China) and Univ. of Science and Technology of China (China); X. Chen, W. Hu, L. Wang, Y. Chen, W. Lu, Shanghai Institute of Technical Physics (China); F. Xu, National Synchrotron Radiation Lab. (China) and Univ. of Science and Technology of China (China)

HgCdTe (mercury cadmium telluride) has been proven to be one of the most ideal and highest performing materials for the fabrication of infrared detector due to the features of tunable band gap, high optical absorption and favorable inherent recombination mechanisms. The performance of HgCdTe infrared photo detectors is largely determined by the characteristics of Fermi level, which is sensitive to carrier concentration. Electron anole densities can be recomputed from the Fermi potential, and vice versa, using carrier statistic formula.

In this paper, we concentrate our attention on the comparison of different carrier statistic approximation. Simulations of current-voltage and photo-response characteristics of MWIR (middle wavelength infrared) HgCdTe photodiodes have been performed based on a self-consistent solution of the poisson's equation, the electron/hole continuity equations, and three generation-recombination processes as Auger, Shockley-Read-Hall, and optical generation recombination. Three different carrier density approximations are proposed to take account of the carrier degeneracy and the conduction band non-parabolic into the simulation of MWIR HgCdTe photovoltaic devices. By using the numerical simulation, the comparisons of I-V curve and photo-response are made with the carrier statistic by considering (1) parabolic conduction band approximation, (2) Bebb's non-parabolic expression, and (3) Harman's non-parabolic approximation.

The effect of the neglect of non-parabolic on the dark current mechanism is evaluated. It is found to lead to an enormous deviation in the simulation of HgCdTe device, especially for heavy doping. Comparing with Bebb's and Harman's approximation, the Harman's result underestimates the dark current, while the parabolic conduction band approximation significantly overestimates the dark current. In the simulation results of photo-response, the parabolic conduction band and Harman's approximation can lead to a response peak shift to short and long wave, respectively.

8012-145, Poster Session

Study of photosensitive area extension in HgCdTe photodiodes using scanning laser microscopy

Y. Chen, W. Hu, X. Chen, J. Wang, W. Lu, Shanghai Institute of Technical Physics (China)

HgCdTe is a well known narrow band semiconductor for infrared (IR) detectors which are widely used in military and aerospace industry, and many studies have been carried out on its performance. Laser-beam-induced-current (LBIC) measurements as a high-resolution, nondestructive optical characterization technique have been used to characterize photosensitive area extension induced by n-type inversion in HgCdTe photodiodes for typical n+-on-p HgCdTe photovoltaic IR detectors. The technique involves using a laser beam to scan through the p-n junction arrays, and induced current reflecting the electrical properties of the p-n junction arrays is collected from the remote contacts at both sides of the arrays.

In this paper, we report on the n-type inversion region extension in HgCdTe photodiodes at low temperature (87 K) comparing with that at room temperature (300 K). The type conversion regions were formed by B+ ion implantation on Hg-vacancy-doped p-type HgCdTe. The effect of temperature on n-type inversion region extension is investigated by considering the sign of the LBIC signal. It is well known that shallow donor level is readily formed through ion implantation, and its energy level is very close to conduction band. So the ionization energy is very small and the whole donor impurities almost ionize even at extreme low temperature. However, the acceptor like level formed by Hg vacancies locates about 10 meV just above the valence band, and acceptor impurities ionize partly due to freeze out effect at relative low temperature. Additionally, some carriers could freeze out in the localized acceptor level. This possibly causes the decreasing of p type carrier density with the drop of temperatures.

Our theoretical calculation of carrier concentration at low temperature shown that the hole concentration is far less than electron concentration in multi-doped HgCdTe, lead to p-to-n conversion near the junction area as temperature decreased. The n-type inversion region expanding is the result of p-to-n type conversion at low temperature.

8012-146, Poster Session

VPD PbSe technology fills the existing gap in uncooled, low-cost and fast IR imagers

R. Linares-Herrero, R. Gutiérrez, M. T. Montojo, A. Baldasano, New Infrared Technologies, Ltd. (Spain)

Uncooled Infrared imagers are today affordable and widely used in numerous applications. However they exist an important list of applications where they are not useful at all due to fundamental limitations in performance. Because their importance and interest, some of these applications present a wide margin of growing.

The paper reviews the actual panorama of uncooled IR imagers and presents the VPD PbSe as one of the most promising technologies for filling the existing gap in photonic uncooled IR imagers. Examples of applications and some experimental results are presented.

8012-153, Poster Session

A detailed analysis for the absorption coefficient of multilevel uncooled infrared detectors

S. E. Kucuk, Y. Tanrikulu, T. Akin, Middle East Technical Univ. (Turkey)

This paper introduces a detailed analysis on the calculation of the absorption coefficient of multilevel uncooled infrared detectors. A two-level 25µm pixel pitch infrared detector with a sandwich type resistor is divided into subregions consisting of different stacks of layers. The absorption coefficients of these different subregions are calculated individually by using the cascaded transmission line model, including the main body, arms, and the regions where the resistors are implenmented. Then, the total absorption coefficient of the detector is found by calculating the weighted average of these individual absorption coefficients, where the areas of subregions are taken into account. The absorption can be calculated as a function of the sacrificial and structural layer thicknesses together with the sheet resistance of the absorber layer to find the optimum value. However, the thermal conductance of the detector must be considered while adjusting the structural layer thickness. The proposed analysis also takes the thermal conductance into account in order not to compromise the overall detector performance.

8012-154, Poster Session

A 2-stage digital-to-analog converter for bias correction in uncooled microbolometer arrays

A. Toprak, M. Tepegoz, T. Akin, Middle East Technical Univ. (Turkey)

This paper introduces a detector biasing scheme proper for resistive microbolometer type uncooled thermal detector focal plane arrays (FPAs). The proposed scheme utilizes a 2-stage digital-to-analog converter (DAC) architecture where the first DAC stage generates the voltage interval that covers the bias voltage range of the overall FPA, while the second stage generates the high resolution analog voltages that are used to apply pixel-specific bias voltages. The second DAC stage output includes a resistive ladder type multi-level voltage generator (MLVG), which can be shared by multiple column readouts. The proposed scheme utilizes a single first stage DAC and a number of second stage DACs that can be optimized in terms of the specifications of the application. The proposed scheme provides high resolution bias correction with small silicon area coverage, low power dissipation, and low noise. Besides, this scheme is suitable for microbolometer FPAs with very different detector resistance ranges, since the bias correction voltage interval is adjustable by the first DAC stage. The proposed architecture is used to design a 5+5 bit, 2-stage DAC that can be used in a 640x480 microbolometer FPA where a standard 0.35 µm CMOS process is considered. The simulation results show that the circuit provides a detector current resolution of 130 nA when the architecture is optimized to cover a 80 kΩ nominal detector resistance with ±10% resistance nonuniformity. The designed circuit dissipates 7.5 mW with a single 5 V supply, and the noise contribution to the detector current is 30 pA for a 10 kHz electrical bandwidth.

8012-155, Poster Session

A thermal conductance optimization approach for uncooled microbolometers

S. U. Senveli, Y. Tanrikulu, T. Akin, Middle East Technical Univ. (Turkey)

This paper introduces an optimization approach of thermal conductance for single level uncooled microbolometer detectors. An efficient detector design is required due to the limited availability of silicon area per pixel, i.e., the pixel pitch, and due to the capabilities of the fabrication line. The trade-offs between physical parameters are studied to attain the best performance, including the thermal conductance, the thermal time constant, and the active area, where the main performance criterion has been chosen as the Noise Equivalent Temperature Difference (NETD). Theoretical formulations and FEM simulations are used to obtain the optimum design parameters, such as length and electrical resistance of support arms together with the pixel fill factor. Furthermore, a relatively more accurate method for measuring the thermal conductance, which takes into account the non-linear nature of the Temperature Coefficient of Resistance (TCR), has been introduced. With this method, it is possible to measure the thermal conductance in a large temperature range, which is required especially for high thermal resistance microbolometers, as they heat up rapidly in vacuum.

8012-147, Poster Session

Advanced manufacturing methods for chalcogenide molded optics

G. S. Cogburn, LightPath Technologies, Inc. (United States)

As Chalcogenide glass and Precision Molded Optics (PMO) have developed and matured to a point of being accepted as replacements for Germanium Single Point Diamond Turned (SPDT) optics; technological research is being dedicated to developing infrared PMO that can be used in a broader application base. These include laser arrays, large aperture molded chalcogenide optics, 90% clear aperture to outside diameter ratio and molded in mount infrared optics.

This paper presents applications for infrared laser arrays and the corresponding optics that must be closely mechanically mounted to avoid clipping the beams. Different molding and mounting techniques will be discussed to solve this issue which include; dicing chalcogenide optic lenses, outside diameter coatings to mount optics, molded in mount chalcogenide optics and molded cylindrical surfaced lenses. Accompanying the research and discussion of these techniques will be experiments, supporting data and molded chalcogenide glass lenses showing the results and application for each lens type.

8012-149, Poster Session

Impacts and mitigation strategies of sun exposure on uncooled microbolometer image sensors

D. A. Dorn, O. Herrera, C. Tesdahl, E. Shumard, A. Wang, Pelco Ft. Collins (United States)

This paper provides results from testing and analysis of sun exposure effects on amorphous silicon micrbolometers and vanadium oxide microbolometers. Gain and offset changes for each detector type is provided. Results from different sun exposure levels corresponding to different geographic locations and time of year are presented. Data associated with increasing exposure duration and number of exposures is presented. The time constants associated with the sun exposure effects are also provided. Potential mitigation processes and algorithms are explored reducing the impact on image quality. The effectiveness of mitigation processes and algorithms is presented.

8012-151, Poster Session

Characterization of SiGe-detector arrays for visible-NIR imaging sensor applications

A. K. Sood, E. J. Egerton, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); N. DiLello, J. L. Hoyt, Massachusetts Institute of Technology (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States); R. S. Balcerak, Raymond S. Balcerak, LLC (United States); T. G. Bramhall, U.S. Army Aviation and Missile Command (United States)

SiGe based focal plane arrays offer a low cost alternative for developing visible- near-infrared focal plane arrays that will cover the spectral band from 0.4 to 1.6 microns. The attractive features of SiGe based foal plane arrays take advantage of silicon based technology that promises small feature size, low dark current and compatibility with the low power silicon CMOS circuits for signal processing.

This paper will discuss performance characteristics for the SiGe based VIS-NIR detector arrays and improvements in dark current as a function of temperature for a variety of defense and commercial applications using small unit cell size. We will also compare performance with InGaAs, InSb, and HgCdTe IRFPA's. We will discuss electrical and optical properties of SiGe arrays at room temperature and as a function of temperature. We will also discuss future integration path for SiGe devices with other focal plane arrays for multicolor applications.

8012-156, Poster Session

Controlling the excited energy levels in quantum dots-in-a-well (DWELL) infrared photodetectors with confinement enhancing barriers

A. V. Barve, J. O. Kim, T. J. Rotter, S. Sengupta, J. A. Montoya, S. Krishna, The Univ. of New Mexico (United States)

Quantum dots-in-a-well (DWELL) detectors have been widely researched in recent years and have been used to fabricate state-of-the-art focal plane arrays. High temperature operation is very important in third generation infrared photodetectors, as it reduces the size, cost and complexity of a system. Low dark currents and high absorption coefficients are crucial to high operating temperature. In this report, we demonstrate the use of thin AlGaAs barrier layers around the DWELL structure to enhance the confinement of carriers in the excited energy level for bound to quasibound transitions. This approach combines the advantages of higher quantum efficiency and higher extraction efficiency for photoexcited electrons. AlGaAs barriers also reduce the dark current in the device. We report a systematic means for controlling the excited energy level in DWELL detectors. Thereby the peak wavelength of the device can be controlled, while maintaining the bound to quasibound nature of transitions. The excited energy level also controls the carrier capture process in the DWELL structure and thereby the photoconductive gain. We will present a detailed study of device design, fabrication and device characterizations for these high performance DWELL detectors.

8012-158, Poster Session

Erosion resistant anti-reflection coating for ZnSe, CZnS, chalcogenide and glass substrates

K. M. Khajurivala, Janos Technology, LLC (United States)

At present, Ge/Si components are used for MWIR and LIR assemblies. The exposed surface of these assemblies is coated with DLC films using several technologies to provide protection against rain, wind and blowing sand while also serving as the AR coating. The disadvantage is that Ge absorption increases at higher temperatures and also blocks the visible and NIR wavelengths below 2.0 micron. ZnSe, Cleartran and some Chalcogenide materials are alternate substrate material choices for multi-band Visible, NIR, MWIR systems with alignment or target acquisition capability in the visible spectrum and high temperature applications. DLC films do not adhere well to ZnSe which has resulted in DLC equivalent coatings or boron Phosphide films being used. The results presented herein are for a DLC AR coating applied on ZnS, ZnSe, Chalcogenide and Glass substrates using a combination of evaporation, IAD and sputtering technology and special tools. Also presented in this paper are high transmitting AR coatings on various chalcogenide materials for MWIR AND LWIR, Broad band AR for 7.5 to 14.0 micron spectral range, Dual Band AR coatings for MWIR and LWIR using a combination of evaporation, IAD and sputtering technologies which meet environmental and durability requirements of next generation optical components and assemblies. Measured data is compared with predicted theoretical performance for all aforementioned coatings.

8012-107, Session 21

A field spectral reflectometer to characterize surfaces in the infrared from the NIR to the LWIR

L. M. Moreau, H. A. Bourque, C. B. Roy, C. A. Vallieres, ABB Analytical Measurement (Canada)

ABB Bomem has recently designed a field-deployable reflectometer. That instrument measures the spectral reflectance of diffuse surfaces from 0.7 µm to 13.5 µm. Its spectral resolution is adjustable and can be as fine as 4 cm-1. The instrument is designed to be usable in the field. It is portable and battery-operated. In its simplest mode, the instrument is automated and can be operated by non-specialist personnel with minimal training.

The instrument is to be used to build a spectral database of different surfaces in various conditions (different humidity, temperature, texture, mixing, etc.) and in the presence of various interfering chemicals (oils, solvents, etc.).

The instrument has its own built-in infrared sources. The sources illuminate the ground area to be measured. The instrument has also two built-in reference diffusers: a Spectralon diffuser and an Infragold diffuser.

Overview of the instrument capabilities and test results will be presented.

8012-108, Session 21

Long-wave infrared (8 to 14 µm) hyperspectral imager based on an uncooled thermal camera and the traditional CI block interferometer

D. Cabib, M. Lavi, A. Gil, CI Systems (Israel) Ltd. (Israel)

Since the early '90's CI has been involved in the development of FTIR hyperspectral imagers based on a Sagnac or similar type of interferometer. CI also pioneered the commercialization of such hyperspectral imagers in those years. After having developed a visible version based on a CCD and a 3 to 5 micron infrared version based on a cooled InSb camera, it has now developed an LWIR version based on an uncooled infrared camera for the 8 to 14 microns range. The system has applications in gas cloud imaging among others. In this paper we will present the design and performance of the system.

8012-109, Session 21

Compact dewar and electronics for large-format infrared detectors

A. Manissadjian, S. Magli, E. Mallet, F. Barillot, SOFRADIR (France)

Infrared systems cameras trend is to require higher performance (thanks to higher resolution) and in parallel higher compactness for easier integration in systems.

The latest developments at SOFRADIR / France on HgCdTe (Mercury Cadmium Telluride / MCT) cooled IR staring detectors do show constant improvements regarding detector performances and compactness, by reducing the pixel pitch and optimizing their encapsulation.

Among the latest introduced detectors, the 15µm pixel pitch JUPITER HD-TV format (1280×1024) has to deal with challenging specifications regarding dewar compactness, low power consumption and reliability. Initially introduced four years ago in a large dewar with a more than 2kg split Stirling cooler compressor, it is now available in a new versatile compact dewar that is vacuum-maintenance-free over typical 18 years mission profiles, and that can be integrated with the different available Stirling coolers: K548 microcooler for light solution (less than 0.7 kg), K549 or LSF9548 for split cooler and/or higher reliability solution.

The IDDCAs are also required with simplified electrical interface enabling to shorten the system development time and to standardize the electronic boards definition with smaller volumes. Sofradir is therefore introducing MEGALINK, the new compact Command & Control Electronics compatible with most of the Sofradir IDDCAs. MEGALINK provides all necessary input biases and clocks to the FPAs, drives up to eight inputs, and digitizes and multiplexes them to provide a 14 bit output signal through a cameralink interface, in a surface smaller than a business card.

8012-111, Session 21

Integrated approach to optomechanical system development

T. E. Reney, R. L. Wiggins, L. E. Comstock, J. J. Santman, K. Woodard, Corning NetOptix (United States)

Over the past few decades of computer aided engineering growth there has been much more progress in increasing the power and capability of function specific engineering tools (e.g., optical design, finite element analysis, etc.) than in the integration of and communication between these tools. With only a few notable exceptions, such as FEA being imbedded into solid modeling, the communication method between the function specific tools continues to be dominated by translation to neutral data formats (e.g., IGES, STEP) and file transfer. There are a number of problems with this approach. The translation is a serial process where an engineer has to stop at some point in the design, make the neutral file, send that file to the next function, and wait for feedback. The translation through a neutral format is typically one way so the whole translation process has to be repeated when changes are required. Revision tracking of multiple files for each design iteration is both critical and a likely source of errors. Also, as with any translation, some information is always lost or corrupted in the process.

This paper describes some progress that has been made in more tightly integrating optical design, mechanical design, fabrication, and testing of optical systems. Tools have been developed that connect CODE V to SolidWorks (bidirectional), compensation of diamond turning CNC from interferometric data, slope analysis from interferometer and profilometer data, and other tools for wavefront error compensation, electronic nulls, and motor response analysis. Design, machining, testing and inspection efficiency gains are achieved through tools that consume mechanical solid models in their native format.

8012-112, Session 21

Classification of thermal face images using radial basis function neural network

M. K. Bhowmik, D. Bhattacharjee, D. K. Basu, Jadavpur Univ. (India)

In this paper we have investigated an approach to classify thermal face images for face recognition using feature extraction method and Radial Basis Function (RBF) neural network with a back propagation learning algorithm as classifier. The proposed feature extraction method is done in two steps. In first step line features are extracted from thermal polar images and feature vectors are constructed using these line. In the second step feature vectors thus obtained passes through principal component analysis (PCA) for the dimensionality reduction of feature vectors. Finally, the images projected into eigenspace are classified using a Radial Basis Function (RBF) neural network. In the experiments we have used Object Tracking and Classification beyond Visible Spectrum (OTCBVS) database. Experimental results show that the proposed approach significantly improves the verification and identification performance and the success rate is 100% (maximum) but on an average it is 94.44%.

8012-113, Session 21

The research on infrared small-target detection technology under complex background

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Small target detection and 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 detection. However, under complex backgrounds, such as clutter, varying illumination, and occlusion, the traditional detection 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 detection 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 detection algorithm to enhance the detection performance. The experimental results show that, compared with the traditional algorithm, the presented method greatly improves the accuracy and effectiveness of infrared target detection under complex scenes, and the results are satisfactory.

8012-17, Session 22

A look at non-uniformity correction in the spatial frequency domain

G. Raz, Y. Weiss, Elbit Systems Electro-Optics El-Op Ltd. (Israel)

The residual non uniformity of uncooled IR detectors is of major concern in the implementation of innovative IR systems. Several algorithms were developed during the recent decade in order to solve this problem. One of these algorithms, “Scene based non uniformity correction” (SBNUC), is based on the notion that for a moving thermal imager, close by pixels get over time similar distributions of scene radiation. Following this assumption, differences between the time collected histograms of pixels are due to non uniformity and can thus be corrected. However, pixels which are not in the closest proximity of each other need in general more time for their histograms to match. Moreover, depending on the imager motion characteristics, there can be additional temporal and spatial limitations. An efficient SBNUC algorithm must take the exact limitations into consideration.

In this work, after reviewing several techniques of non-uniformity correction, we look at the SBNUC spatial-temporal relations using the spatial frequency domain representation. This representation provides an effective point of view since distances in the image are naturally translated into different spatial frequencies. We show that a way to implement this correction by a recursive time filter incorporates spatial frequency dependence into the correction speed, allowing the spatial-temporal relation to be engineered easily into the correction process. Using several characteristic imager motion models we analyze the effect of the motion on the spatial-temporal relations for different SBNUC implementations and demonstrate how an optimal SBNUC process can be designed, for each motion model.

8012-114, Session 22

Further applications for mosaic pixel FPA technology

K. C. Liddiard, Electro-optic Sensor Design (Australia)

In previous papers to this SPIE forum the development of novel technology for next generation PIR security sensors has been described. This technology combines the mosaic pixel FPA concept with low cost optics and purpose-designed readout electronics to provide a higher performance and affordable alternative to current PIR sensor technology, including an imaging capability. Progressive development has resulted in increased performance and transition from conventional microbolometer fabrication to manufacture on 8 or 12 inch CMOS/MEMS fabrication lines.

A number of spin-off applications have been identified and are being actively investigated. These are considered in general; however in this paper two specific applications are highlighted: forest fire detection and high performance imaging FPA design. The former involves cheap expendable sensors which can detect approaching fire fronts and send

alarms with positional data via mobile phone or satellite link. The latter involves an alternative method to design and manufacture small pixel high performance IRFPA

8012-115, Session 22

Toward very high-resolution infrared camera core

L. Le Noc, B. Tremblay, L. Mercier, M. Morissette, J. Lambert, INO (Canada); D. Tang, Dept. of National Defence (Canada); A. Bergeron, INO (Canada)

In the recent years INO has worked actively toward very high resolution imagers. Recently INO proposed a 1280 x 960 pixel infrared camera core making use of a microscan system. The use of a microscan system allows doubling the resolution along each axis while reducing the efficient pixel pitch and consequently the aliasing effects.

With the availability of high resolution small pixel pitch FPA, such as the 1024 x 768 pixel, 17 um pixel pitch FPA from Ulis, this technology can push the efficient toward very high resolution, potentially 2048 x 1536 pixels.

With these pixel pitch dimensions, a new frontier is emerging. Using a microscan system with a 17 um pixel pitch FPA brings the efficient pixel pitch to 8.5 um approaching and sometimes exceeding the diffraction limits of the 8 to 12 um waveband. The questions that rise is how efficient are the FPAs and imaging systems at those wavelength near the diffraction limits. In this presentation, INO will review the capabilities and performances of a 1024 x 768 pixel uncooled infrared camera core. The results of the use of a microscan system with the FPA to provide a 2048 x 1536 pixel image will also be presented.

8012-116, Session 22

Development of integrated noncryogenic cooled carbon nanotube-based infrared focal plane array

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 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 carbon-based detectors are considered to be one of the most promising candidates to enhance the performance. Carbon nanotubes (CNTs) exhibit low dark current which allows CNTs to be employed as new nano IR sensing elements that cryogenic cooling is not required. This paper presents the development of noncryogenic cooled IR focal plane array (FPA) using CNTs. The FPA consists of an array of CNT-based IR detectors which can be fabricated by our nanomanufacturing processes. The processes include several key developments such as CNT selection, band gap engineering of CNTs and nano assembly etc. Each detector consists of an individual gate to modulate the doping level of the CNT channel, so the generated photocurrent can be maximized. The results indicate that CNTs are very sensitive of middle-wave IR signal at room temperature. Besides, a readout circuitry has been integrated with the CNT-based FPA to retrieve the photocurrents from the detectors. A differential input charge integrator current amplifier was designed to read the photocurrent precisely. The proposed readout circuitry allows sampling multiple signals of the CNT-based FPA at 2 kHz and this result suggests that they can be used in high throughput IR sensing applications.

8012-117, Session 23

New materials for uncooled IR imaging: nickel manganite thin films grown by spin spray

S. W. Ko, J. Li, E. C. Dickey, S. Trollier-McKinstry, T. N. Jackson, M. Lee, The Pennsylvania State Univ. (United States)

Ceramic thermistors like VOx, a-Si, and NiMn2O4 are used for thermal sensing applications such as microbolometers and infrared sensors. These materials should have high negative temperature coefficient of resistance (TCR), high sensitivity, and low noise for these applications. Nickel manganite films have large TCR (>-3%/K) and good environmental stability, so that the properties are robust during subsequent processing. To improve the ability to prepare manganite spinels on pre-existing circuitry, new techniques that enable low temperature depositions need to be developed. To address this, the spin spray technique was adopted in this work; this approach is both low cost and permits low process temperatures (<100°C). Spin spray deposition is accomplished using two dilute water-based solutions: a reaction solution and oxidizing solution. The reaction solution consists of metal salts like nickel chloride and manganese chloride while the oxidizing solution contains pH buffer, pH adjuster, and oxidizing agent. To grow films the solution was nebulized by a nitrogen carrier gas and sprayed onto a rotating silicon substrate with a 1μm thick SiO2 buffer layer. As deposited nickel manganite films were nanocrystalline spinel by TEM analysis. The temperature coefficient of resistance was around -3.6 %/K and activation energy was about 0.36eV. The doping of Zn increased crystallinity of as-deposited nickel manganite films but resistivity increased as well. In contrast, Cu doping allowed the electric resistivity to be tuned to less than 1000 Ω-cm.

8012-118, Session 23

Microstructural aspects of thin film vanadium oxide used for uncooled infrared imaging

B. D. Gauntt, O. M. Cabarcos, J. Li, H. A. Basantani, S. S. N. Bharadwaja, N. J. Podraza, T. N. Jackson, E. C. Dickey, C. Venkatasubramanian, The Pennsylvania State Univ. (United States); S. Antrazi, 4Wave Inc. (United States); D. L. Allara, M. W. Horn, The Pennsylvania State Univ. (United States)

Reactive pulsed DC sputtering was used to grow a systematic series of films with resistivity ranging from 1 × 10-3 to 6.8 × 104 Ohm cm and TCR varying from 0 to 4% K-1. Throughout the parameter space studied, a transition from amorphous to nano-crystalline growth was observed. Films in the range of interest for microbolometers, i.e. 1 × 10-3 to 10 Ohm cm, contained the FCC VOx (0.8 < x < 1.3) phase. Altering the sputtering energetics via substrate biasing resulted in highly-columnar, nano-twinned grains of FCC VOx, reminiscent of ion beam sputtered bolometer material. Both X-ray absorption and electron diffraction in the TEM confirmed the presence of a secondary, oxygen-rich amorphous phase. Micro-Raman spectroscopy was used as a probe to characterize the chemical composition and morphology of VOx thin films.. In general, Raman spectral results from amorphous films show a broad feature around ~890 cm-1, while spectra from nanocrystalline films exhibit the “amorphous” feature and a second broad feature at ~320 cm-1. The resulting microstructure can be described as a nano-composite material composed of a low resistivity crystalline phase embedded in a high resistivity amorphous matrix. Purely nano-crystalline films have metal-like TCR while purely amorphous films are much too resistive for current read-out circuitry. Our results suggest that both phases are required to achieve a high TCR, low resistivity material. Preliminary results using a generic mixing rule to simulate the composite resistivity validate the need for both phases and show promise for future predictive capabilities

8012-119, Session 23

Thin film silicon and germanium for uncooled IR microbolometer applications

N. J. Podraza, D. B. St. John, H. Shin, M. Lee, E. C. Dickey, T. N. Jackson, The Pennsylvania State Univ. (United States)

Hydrogenated amorphous and nanocrystalline silicon (a/nc-Si:H), germanium (a/nc-Ge:H), and their alloys (Si1-xGex:H) are currently used and continue to be assessed for use as the resistive sensing layer in uncooled infrared microbolometer applications. Optimization of the a/nc-Si1-xGex:H system for uncooled microbolometers requires both accurate measurement of the electrical properties of interest; namely resistivity (ρ), temperature coefficient of resistance (TCR), and the 1/f noise character, as well as a better understanding of how these electrical properties vary as a function deposition conditions changing the composition, microstructure, and relative order in the material. Si1-xGex:H thin films have been deposited using plasma enhanced chemical vapor deposition (PECVD) and monitored during growth using in situ, real time spectroscopic ellipsometry (RTSE). RTSE provides a means of detecting changes in the growth evolution, structure, and occurring within a single film as a function of thickness. Amorphous germanium films have also been prepared by magnetron sputtering. Variations in the electrical properties have been tracked as a function of the choice of dopant (n- or p-type), the relative amounts of silicon and germanium present, and the structure of the material (amorphous, nanocrystalline, mixed-phase amorphous+nanocrystalline). Coupling the electrical properties obtained ex situ after film deposition with RTSE feedback obtainable during film growth allows for the development of thin films with tailored structural, and thus electrical properties. By assessing the potential beneficial affects associated with composition and structure, pathways to designing high-TCR, low-noise materials compatible with existing device fabrication processes can be established.

8012-120, Session 23

A 256 pixel pyroelectric linear array with new black coating

V. Norkus, M. Schossig, G. U. Gerlach, Technische Univ. Dresden (Germany); R. Köhler, DIAS Infrared GmbH (Germany)

Numerous applications in the field of infrared measurement technology demand uncooled linear arrays which show such qualities as high signal-to-noise ratio, a flat spectral responsivity, reasonable costs as well as reproducible detector parameters that are stable in the long run. Some of the applications of LiTaO3-linear arrays are infrared line cameras for the non-contact temperature measurement as well as spectrometers in the wavelength range of 0.8...25 µm.

This paper gives a survey of both the design and essential properties of newest developed pyroelectric linear arrays made on the basis of lithium tantalate (LiTaO3). There are up to 256 pixels with a minimum pitch of 50 µm. The detector is a hybrid arrangement of pyroelectric detector chip and 0.8 µm CMOS read-out circuit in a metal hermetic housing. Thanks to the development of a new black coating technology there has been a permanent improvement of the thermal resolution and the homogeneity of the spectral responsivity. The absorption layer consists of a columnarly patterned NiCr thin-film. It is deposited by a special GLAD technique in high vacuum. The band absorption coefficient in the wave-length range of 1...15 µm is about 0.9 for a layer with a thickness of 1 µm. The NiCr absorption layer has a very low thermal mass and high temperature stability. It can be patterned by lift-off technology. The measurement results demonstrate the excellent homogeneity of the spectral responsivity and the improvement of the signal-to-noise ratio of the linear arrays.

8012-121, Session 23

Small-pitch high-performance thermopile focal plane arrays

D. Kryskowski, UD Holdings LLC (United States)

In this paper, we show that with our new readout approach, thermopile focal plane arrays can now reach the necessary LWIR performance levels that have been set by current microbolometer technology. Moreover, this paper shows that these new focal plane arrays can be made in commercial foundries using standard low cost CMOS. Besides improved performance, the additional benefit afforded by using these advanced thermopile focal plane arrays will be a simpler, more robust instrument. These attributes translate directly to lower cost and greater commercial potential.

Detailed modeling shows that 50um, 25um, 17um and 12um pitch thermopile focal plane arrays compare favorably in performance (NETD, tau) against microbolometer focal plane arrays with similar array size and detector geometry. The benefit of using thermopile focal plane arrays is the near elimination of 1/f noise and offset drift which has plagued microbolometers from their inception. Because of this noise reduction, shutterless operation could be possible. It is also shown that high performance thermoelectric materials are compatible with post-CMOS MEMS processes which, again, compares favorably to microbolometer focal plane arrays. Due to the potential lower system cost with thermoelectrics, these focal plane arrays could provide the path to deliver very low cost, high volume infrared imaging devices.

8012-122, Session 23

Application of Graphene for infrared detection

A. H. Jayatissa, M. Gautam, The Univ. of Toledo (United States)

Fundamental investigation was carried out to understand the IR detection capability of graphene. Graphene was synthesized by a CVD process followed by a transfer techniqie on SiO2 substrate. These device structure was tested for IR light sensitivity by measuring the change of resistance across planner gold electrodes. The sensitivity was measured for a long range of spectrum. In order to develop a bandgap in graphene films, few techniques were explored; (1) hydrogenation of graphene, (ii) surface modification by plasma, (ii) fabrication of bilayer structure. The results obtained were compared based on the processing conditions. In addition, the optical properties of our graphene, mainly the reflectance spectra were modeled and analyzed to determine the optical properties of graphene as a function of wavelength of the spectrum. In this paper, details of experimental theoretical investigations towards understanding of fundamental properties of graphene will be presented.

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8013-01, Session 1

A polynomial regression approach to subpixel temperature extraction from a single-band thermal infrared image

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Target temperature estimation from thermal infrared (TIR) imagery is a complex task that becomes increasingly more difficult as the target size approaches the size of a projected pixel. At that point the assumption of pixel homogeneity is invalid as the radiance value recorded at the sensor is the result of energy contributions from the target material and any other background material that falls within a pixel boundary. More often than not, thermal infrared pixels are heterogeneous and therefore subpixel temperature extraction becomes an important capability. Typical subpixel estimation approaches make use of multispectral or hyperspectral sensors. These technologies are expensive and multispectral or hyperspectral thermal imagery might not be readily available for a target of interest.

A methodology has been developed to retrieve the temperature of an object that is smaller than a projected pixel of a single-band TIR image using physics-based modeling. The process can be broken into two distinct pieces. In the first part, the Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool will be used to replicate a collected TIR image based on parameter estimates from the collected image. This is done thousands of times to build a multi-dimensional lookup table (LUT). For the second part, a regression model is built from the data in the LUT and is used to perform the temperature retrieval. The results presented are from both synthetic and collected imagery.

8013-02, Session 1

New developments in the NIST spectral radiance and radiance temperature metrology in the thermal and far infrared

S. N. Mekhontsev, L. M. Hanssen, V. B. Khromchenko, B. Wilthan, National Institute of Standards and Technology (United States)

The Optical Technology Division of NIST maintains and disseminates, among others, the scales of spectral radiance and radiance temperature in the thermal infrared (IR) wavelength range and at temperatures from -50°C to +1000°C. Since 2006, the Advanced Infrared Radiometry and Imaging (AIRI) facility serves as a national standard of radiance temperature in the aforementioned temperature range, as well as spectral radiance for sources at temperatures below 250 °C, including spectral and spatial characterization of cavity and flat plate blackbody sources. The facility and some measurement results were reported on at Thermosense in 2008.

This paper reports recent developments, which include updated uncertainty budgets, validation via comparisons with other National Metrology Institutes, expansion of the spectral and temperature ranges, and improvement of the turnaround time. Recently added services include IR spectral radiance measurements of blackbody sources at temperatures above 250 °C, which are now offered by the NIST emittance facility.

A new primary standard facility the Controlled Background Spectrophotometry and Spectroradiometry System (CBS3) is being established for realization of both spectral radiance and reflectance in the spectral range from 3 μm to 50 μm. Although it will initially only be operated under high vacuum, it is anticipated that with the addition of an Altitude Chamber eXtension (ACX), it will be able to operate under dry nitrogen purge at variable pressure up to atmospheric, and potentially handling all spectral calibrations of near- and sub-ambient sources.

8013-03, Session 1

Status of the NIST program for infrared emittance measurement

L. M. Hanssen, B. Wilthan, S. N. Mekhontsev, National Institute of Standards and Technology (United States)

Over the past two decades, the Optical Technology Division at NIST has developed extensive capabilities for the characterization of the infrared optical properties of materials and components. These include the more recent development of infrared spectral emittance (emissivity) measurements by the direct method of radiance comparison to blackbody reference sources over a temperature range of 200 °C to 900 °C over a wavelength range of 2 μm to 20 μm. The facility for emittance measurements and initial test results were reported on at Thermosense in 2004. This paper reports on the progress made since then. Initial validation of the measurement methodology was made through comparisons with the indirect method of reflectance measurement on the NIST infrared reference integrating sphere at the same temperature. Subsequently, NIST piloted and participated in an international intercomparison of infrared spectral emittance with the national measurement institutes of France, Germany, Italy and Japan. The overall agreement of the results provides a strong validation of NIST's methodologies and uncertainty budgets. Most recently, to address the current lack of standards for total emittance, measurements are being extended to wavelengths up to 100 μm, initially with ambient background, and later as low as -80 °C. Finally, angle-dependent emittance measurements are being implemented, which will also provide sufficient data for the calculation of hemispherical emittance.

8013-04, Session 1

Measurement of true temperature fields by bicolor thermoreflectometry

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The paper will present a new radiative method, called thermoreflectometry, which measures true temperature fields with an on-line determination of emissivity, in a context of a study of dynamic behaviour of materials. The method consists in measuring simultaneously the flow emitted by the object's surface and the flow reflected by the same surface subject to a laser spot lighting. Following the Kirchoff's law, the indirect emissivity measurement, by the reflectometric method, involves the measurement of the directional hemispheric reflectivity. But it requires an infinity of value on all the hemisphere which is not adapted to an embedded system. The originality of the method is to measure the bidirectional reflectivity, in a unique angle, and to link it to directional hemispheric reflectivity by the introduction of the parameter 'reflexion factor'. This parameter is considered like only geometrical and the strength of the method consists in its independence with the wavelength. The method is then based on the measurement, at two wavelengths, of the radiance temperature, thanks to a specific SWIR model, and the bidirectional reflectivity. Finally, those four measures are fused in a system of two equations which can be solved to provide the true temperature and the 'reflexion factor'. A precise description of the theoretical basis and of the apparatus composed (camera and lasers) will be given. The results, on a plate uniformly heated from 300 to 500 °C and exhibiting 4 areas of different emissivities, confirms the accuracy of the method with a precision lower then 5%.

8013-05, Session 2

Use of infrared imaging for investigation of chicken embryo development

R. A. Frye, Vanderbilt Univ. (United States); S. Hsieh, J. B. D. Girón Palomares, Texas A&M Univ. (United States)

The focus of this study is two-fold: first, to investigate the feasibility of thermal imaging for characterizing the development of chicken embryos; and second, to compare the effects of photo periods of 11 hours of light followed by 11 hours of darkness versus 24 hours of darkness during the incubation cycle on embryo development. Previous reported work has used invasive MRI and ultrasound tomography to study chicken embryos with some success. However, very little work has been reported on use of non-invasive thermography. Results suggest that use of a cooling-heating-cooling cycle can reveal the anatomy of chicken embryos. A statistical comparison of image data from the two photo cycles found no difference in the average cooling rates. However, the 11 hours of light group of eggs did hatch earlier than the 24 hours of darkness group. Of the hatched eggs, the chicks in the 24 hours of darkness cycle were observed to be in normal physical condition. However, two of the chicks in the 11 hours of light cycle were observed to have weak legs after hatching. One fully recovered the next day and the second was in the same condition after two days of observation. The second chick took about 48 hours to hatch.

8013-06, Session 2

Dynamic infrared imaging for biological and medical applications in Boron neutron capture therapy

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Boron Neutron Capture Therapy is a treatment modality, currently focused on the treatment of cancer, that involves a selective 10B compound and a specially tuned neutron beam to produce a lethal nuclear reaction. BNCT kills target cells with microscopic selectivity while sparing normal tissues from potentially lethal doses of radiation. In the context of the Argentine clinical and research BNCT projects at the Comisión Nacional de Energía Atómica and in a strong collaboration with INVAP SE, we successfully implemented Dynamic Infrared Imaging (DIRI) in the clinical setting for the observation of cutaneous melanoma patients and included DIRI as a non invasive methodology in several research protocols involving small animals.

We were able to characterize melanoma lesions in terms of temperature and temperature rate-of-recovery after applying a mild cold thermal stress, distinguishing melanoma from other skin pigmented lesions. We observed a spatial and temporal correlation between skin acute reactions after irradiation and the treatment field.

We studied temperature distribution as a function of tumor growth in mouse xenografts, observing a significant correlation between tumor temperature and drug uptake; we investigated temperature evolution in the limbs of Wistar rats for a protocol of induced rheumatoid arthritis (RA), DIRI being especially sensitive to RA induction even before the development of clinical signs and studied surface characteristics of tumors and normal tissues in a model of oral cancer treatment developed in the hamster cheek pouch, where low temperatures were observed, possibly related with water exudation.

8013-07, Session 3

Using a combination of aerial infrared and handheld infrared cameras for measuring, analyzing, and prioritizing the thermal performance of “big box” buildings

G. R. Stockton, Stockton Infrared Thermographic Services, Inc. (United States)

While enormous amount of infrared techniques have been developed in the past, recent new testing protocols combining aerial infrared surveys, with handheld infrared measurements along with blower door testing, and computational analyses of the optimal solutions to increase building efficiency have provided some surprising results. These new product testing protocols and the results now point the way to suggested changes in the construction of big-box buildings, the weatherization of operating big-box buildings, and a methodology for prioritizing optimal solutions based upon the net present value of any efforts for improvement relative to projected energy costs.

8013-08, Session 3

Improvement of energy efficiency: the use of thermography and air-tightness test in verification of thermal performance of school buildings

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

The improvement of energy efficiency is the key issue after the energy performance of buildings directive came into the force in European Union countries. The city of Kuopio participate a project, in which different tools will be used and tested to improve the energy efficiency of public buildings. In this project there are 2 schools, the other consuming much more heating energy than the other same type of school. In this paper the results of the thermography in normal conditions and under 50 Pa pressure drop will be presented; as well as the results of remote controlled air tightness test of the buildings. Thermography combined with air tightness test showed clearly the reasons of specific consumption differences of heating energy - also in the other hand, the measurements showed the problems in the performance of ventilation system. Thermography, air tightness test and other supporting measurements can be used together to solve energy loss problems - if these measurements will be carried out by proper way.

8013-09, Session 3

A hybrid, infrared thermography: heat diffusion equation, method for the 3D air-temperature measurement

F. B. D. Djupkep, X. P. V. Maldague, A. H. Bendada, Univ. Laval (Canada)

The question of how to map the 3D indoor temperature by infrared thermography is solved by a hybrid method which is a combination of infrared thermography and the well known heat diffusion equation. The idea is to use infrared thermography to get the surface temperature of each frontier of the 3D domain of interest. A suitable procedure is devoted to this, allowing an automatic scanning of the whole frontier, the registration of data and computation. These surface temperatures constitute the boundary conditions of the heat equation solved in the domain of interest. The solution of the heat equation allows analysing and controlling the temperature of every point belonging to the considered domain. This temperature distribution is controlled over the time with a period of the same order than the necessary time to obtain the frontier temperatures and at end contributes to the analysis of the thermal comfort.

The study is done first for the steady-state's conditions under various weather situations. In this case the temperature depends only on space coordinates. Secondly we consider the transient conditions by turning on the Heating, Ventilation and Air Conditioning (HVAC) system. With such procedures, we can have an idea about the time necessary to reach thermal equilibrium; time which has a great impact on the thermal comfort sensation. The results yielded by this method are compared with those given by others techniques used for temperature measurement. Finally, the method is used to access 3D temperature distribution for various geometric shapes.

8013-10, Session 4

IR gas cloud imaging in oil and gas applications: immunity to false stimuli

E. Naranjo, S. B. Baliga, J. H. Park, General Monitors Inc. (United States); P. Bernascolle, Bertin Technologies (France)

Fixed gas detection equipment for the petroleum industries is no ordinary equipment. It is designed for continued unattended surveillance in harsh environments. The equipment must be reliable and require limited field maintenance. An additional requirement is a high resistance to false alarms and interferences, which can potentially reduce the detector's efficacy and the level of protection provided.

In recent years, several manufactures of IR imaging devices have launched commercial models that are applicable to a wide range of chemical species and suitable for industrial use. These cameras are rugged and sufficiently sensitive to detect low concentrations of combustible and toxic gases. Nonetheless, as users become acquainted with these imaging systems, questions of resilience to solar and flame radiation and other IR sources, interferences by fog or steam, have begun to emerge. These questions, in fact, reflect similar concerns as those raised with open path IR gas detectors when they first appeared in the market over 20 years ago.

This paper examines an IR gas imager's performance when exposed to several false alarm sources. Gas detection sensitivity in the presence of false stimuli and response and recovery times under an uncontrolled outdoor environment were measured. The results show the specific model tested is reasonably immune to false alarms, while response times were unaffected by the presence of these sources.

8013-11, Session 4

Development of a gas leak detection method based on infrared spectrum imaging utilizing microbolometer camera

T. Sakagami, Kobe Univ. (Japan); H. Anzai, S. Kubo, Osaka Univ. (Japan)

Development of an early gas leak detection system is essential for safety of energy storage tank fields or chemical plants. Contact-type conventional gas sensors are not suitable for remote surveillance of gas leakage in wide area. Infrared camera has been utilized for gas leak detection, however it is limited only for detecting particular gas. In this study a new gas leak identification system, which enables us to detect gas leakage and to identify gas type and density, is developed based on infrared spectrum imaging system utilizing low cost and compact microbolometer infrared camera. Feasibility of the proposed system was demonstrated by experimental results on identification of hydrofluorocarbon gas.

8013-12, Session 4

Detectivity of gas leakage based on electromagnetic radiation transfer

Y. Long, J. Li, C. Zhang, B. Zhang, L. Wang, Beijing Institute of Technology (China)

Standoff detection of gas leakage is a fundamental need in petrochemical and power industries. The passive gas imaging system using thermal imager has been proven to be efficient to visualize leaking gas which is not visible to the naked eye. The detection probability of gas leakage is the basis for designing a gas imaging system. Supposing the performance parameters of the thermal imager are known, the detectivity based on electromagnetic radiation transfer model to image gas leakage is analyzed. This model takes into consideration a physical analysis of the gas plume spread in the atmosphere-the interaction processes between the gas and its surrounding environment, the temperature of the gas and the background, the radiant emissivity, and also its concentration, etc. Under a certain environmental conditions, through calculating the radiance reaching to the detector from the camera's optical field of view, we obtain an entity "Gas Equivalent Temperature Difference (GETD)" which is the radiation difference between the on-plume and off-plume regions. Comparing the GETD with the minimum detectable temperature difference (MDTD) of the thermal imager, we can know whether the system can image the gas leakage. At last, an example of detecting CO_2 gas by Jade mid-wave IR thermal imager with a bandpass filter is presented.

8013-13, Session 4

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

D. Burleigh, La Jolla Cove Consulting (United States)

IR is used to evaluate insulated pipelines for the presence of water trapped in the insulation. This trapped water may lead to corrosion of the steel pipe, which could cause a leak.

8013-14, Session 4

Corrosion detection on pipelines by IR thermography

P. Bison, S. Marinetti, G. P. Cuogo, Consiglio Nazionale delle Ricerche (Italy); P. Zonta, Venezia Tecnologie S.p.A (Italy); E. G. Grinzato, Consiglio Nazionale delle Ricerche (Italy)

IR thermography is applied to detect hidden corrosion on steel pipelines for oil transport. The research is aimed to set up a robust technique, oriented to in situ measurements, for early detection of corroded zones that may evolve either towards leakage or rupture. The use of a transient thermographic technique is investigated on 12.2 mm thick samples, made of a material typically used on pipelines. Some zones are machined to artificially create a material loss that simulates the effect of real corrosion in pipes. The extension and depth of the artificial defects measured by ultrasounds represent the reference for the results obtained by thermography.

Two approaches are proposed: the first is based on the processing of a single thermogram taken at the optimum time after a step heating of a large area of the exterior surface; the second technique is carried out by scanning the pipeline with a device composed of linear lamp and a thermographic camera flying jointly over the sample. The thermographic camera produces a sequence of IR images of the surface at a fixed time delay, that is at a fixed distance, with respect to the heating line. A suitable reconstruction algorithm furnishes an isochronal map of the tested surface with possible hot spots in correspondence with the

corroded areas. The analysis of the thermal problem by Finite Element Method is used to optimize the experimental parameters.

The experimental results demonstrate a detection capability starting from 15 % of the material loss referred to the original thickness.

8013-15, Session 5

Enhancing time resolution of infrared cameras using a heterodyne approach: application to the mapping of fast temperature transients upon electronic micro-chips

N. Boutellis, A. H. Bendada, Univ. Laval (Canada); J. Batsale, C. Pradere, Ecole Nationale Supérieure d'Arts et Métiers (France)

Thermal transport in electronic microchips is a prime example of a class of not understood problems. This difficulty can be attributed to many problems that cannot be addressed by classical means. It has also been well documented that over 50 % of electronic failures are thermally related. A major issue in the thermal design of electronic chips is linked to the high-speed thermal phenomena that may occur in some components with micron-scale sizes. Currently, commercial infrared cameras have a relatively limited full frame rate, i.e. a few hundreds of frames per second at best; this is very slow when compared to the high frequencies involved in fast heat transfer transients in microchips, i.e. more than a few kHz. In this article, we propose an experimental procedure that allows the enhancement of the time resolution capabilities of infrared imaging systems. The procedure is based on a heterodyne approach and is used for the monitoring of the temperature versus time curves upon tiny micro-resistors heated up by the Joule effect in a kHz range periodic mode. The heterodyne approach consists in using a full frame rate for the infrared imaging system that would be slightly different from the frequency of the heat transfer phenomenon under observation. The integration of the heterodyne approach to an infrared imaging system is not as simple as it seems to be, many technological challenges have to be solved. In the article, we thoroughly describe our heterodyne setup as integrated to a high-end mid-wave infrared camera (full-frame acquisition rate ~ 90 Hz); we also show some highly time-resolved temperature transients.

8013-16, Session 5

Comparative analysis of pulse and active thermography for investigating solder joint geometry prediction

B. M. Vela, S. Hsieh, J. B. D. Girón Palomares, Texas A&M Univ. (United States)

Solder joint defects are a major variable in the failure of many printed circuit boards in the electronics industry. In this study, we utilized a heat source and infrared camera to construct an experiment to test the visibility of solder joints of different geometries with and without a cover. The objectives of this work were to (1) understand the effects of different amounts of energy on solder and printed circuit boards; (2) use active thermography and pulse thermography to inspect solders with three different geometries: 60, 90, and 120 degrees; and (3) create plots depicting the relationship between the average cooling rate for each solder geometry and time per data set collected. Major tasks included: (1) construct a fully automated heating and imaging chamber and write a PLC program to control the heating process; (2) create hypotheses and conduct experiments; (3) capture and analyze infrared images of each printed circuit board; and (4) create models and evaluate data. Results suggest that (1) active and pulse thermography can be used to visibly see solders of different geometries without a cover; (2) average cooling rates plotted over time are a good indicator for predicting the type of solder geometry; (3) as differences in cooling rates increase, prediction rates improve; and (4) active thermography performed better than pulse with a prediction rate of 84.3% as compared to 61.9% without a cover.

8013-17, Session 5

Using 3D infrared imaging to calibrate and refine computational fluid dynamic modeling for large computer and data centers

G. R. Stockton, Stockton Infrared Thermographic Services, Inc. (United States)

Over the last 10 years, very large government, military, and commercial computer and data center operators have spent millions of dollars trying to optimally cool data centers as each rack in the data center has begun to consume more than 10 times as much power as just a few years ago. In fact the maximum amount of data computation in a computer center is becoming limited by the amount of available power, including the number of underground cables, to provide cooling for some data centers. Tens of millions of dollars and megawatts of power are being annually spent to keep data centers cool.

The air flows dynamically change away from any predicted 3-D computational fluid dynamic modeling, the efficiency and effectiveness of the actual cooling rapidly departs from the predictive models. By using 3-D infrared imaging and other techniques to calibrate and refine the computational fluid dynamic modeling for large computer and data centers, the required power or data centers can be dramatically reduced which reduces costs and improves reliability.

8013-18, Session 5

Infrared imaging of LED lighting tubes and fluorescent tubes

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

We have applied several high performance infrared cameras in different kinds of measurements and spectral imaging, e.g. measurement of LED lighting tube versus fluorescent tube surface temperature, which is an important issue in energy efficiency of buildings and especially in cooled buildings.

We made infrared imaging measurements of a batch of LED lighting tubes and fluorescent tubes in laboratory conditions. Fluorescent tubes were of type T8 and lamp fitting used was equipped with a magnetic ballast. Aim was to compare surface temperature profiles and surface temperatures as a function of time. Test was successful, and we were able to detect that fluorescent tubes had higher surface temperatures than LED lighting tubes. Surface temperatures were verified with a handheld thermometer with and industrial surface temperature detector. Additionally, electrical power consumed and illuminance created was measured applying measurement standards EN 13032-1:2004 AnnexA and IES LM-79-08. After this, luminous intensities of the luminaries were estimated by calculations. The fluorescent luminaries were pre-aged applying the standard EN 13032-1:2004. The LED luminaries were not pre-aged referring to the standard IES LM-79-08.

8013-19, Session 6

A thermographic survey for evaluating in situ the performance of photovoltaic panels

N. P. Avdelidis, National Technical Univ. of Athens (Greece); Y. Markopoulos, I. Katsis, Green Project S.A. (Greece); M. Koui, National Technical Univ. of Athens (Greece)

Infrared thermography could be an important diagnostic tool for assessing the performance of photovoltaic panels. Malfunctions, material and insulation defects can be detected easily and fast without complicated proceedings. It can be applied to large and small scale systems so as to secure the best possible function and thus performance of the panel(s). In this work, a thermographic survey was performed on a photovoltaic plant of 1 MW in Greece. Various deficiencies were detected

Return to Contents

by using in situ thermography. Although these panels were only a few months into use, there were defected areas spotted by thermography, indicating the poor performance of these panels and thus affecting the total power output of the photovoltaic plant.

8013-20, Session 6

Infrared lock-in techniques for solar cell inspection

R. A. Rotolante, MoviTherm (United States)

Infrared active-source lock-in techniques are used for a variety of solar cell inspections. The principles and power of the lock-in technique are reviewed for these inspection methods. Dark Lock-In Thermography (DLIT is the most widely used active-source technique to be used with solar cells. A reverse or forward electrical bias is applied, and the localized heating due to shunts is observed with an MW camera. Phase and amplitude images in the frequency domain images are important. Optical bias, rather than electrical bias, can also be used to stimulate shunts in a solar cell, referred to as Illuminated Lock-In Thermography (ILIT). Laser illumination (usually around 810 nm) or lamps are commonly used for ILIT. Also, a MW camera, together with laser stimulation, can be used to image carrier density, minority-carrier lifetime in semiconductor materials. Another valuable tool for semiconductor studies is a NIR camera. Lock-in with an electrical bias or an optical bias produces electroluminescence (EL) and photoluminescence (PL), respectively. Both techniques give lifetime and defect-level information. Measurements are presented of several manufacturing yield limiting parameters, and the advantages and limitations of the different techniques are discussed.

8013-21, Session 6

The use of infrared imaging with actual input and output power measurements to significantly change the weighted average power conversion efficiencies for photovoltaic solar plant inverters

G. R. Stockton, Stockton Infrared Thermographic Services, Inc. (United States)

As photovoltaic solar plant systems integrators work to achieve grid parity, each and every subsystem in a fully integrated solar powered must operate as close to 100% efficient as possible. Even if there is a few percent variance among the power inverters which convert DC power to AC power for connection to the utility power grids, the weighted average reduction in efficiency of a few fractions of 1% can be worth tens of thousands of dollars to hundreds of millions of dollars over a few years depending upon the projected size of the solar power system.

The reliability and operating efficiency of most electronic systems typically degrade as a function of increasing temperature, and the inefficiencies in the conversion in solid-state devices can easily be detected using infrared thermography. By combining the cost to reduce temperatures in the inverters with the value of the increased output from the photovoltaic solar system, a system designer or system operator can make pragmatic decisions about the best way to improve and operate multiple sets of inverters.

8013-22, Session 7

IR imaging for machine vision and process control

J. Styron, FLIR Systems, Inc. (United States)

No abstract available

8013-23, Session 7

Experimental study of the detection of buried landmines in soils with increasing water content by infrared imaging

D. J. Dadamia, Univ. de Buenos Aires (Argentina); E. H. Castro, Univ. de Buenos Aires (Argentina) and CITEDEF (Argentina)

It is well known that metallic or plastic landmines buried to a certain depth in soil can be detected by infrared imaging during warming or cooling of the soil. Detection and identification of the mines is dependent of the material of the mine, metallic or plastic, and of the composition and water content of the soil.

We have obtained infrared images of cylindrical metallic and plastic objects, buried at the same depth in soils of different composition, including sand, during the cooling process. We have filled containers with different types of soils, buried the objects, warmed the soil with the objects by exposition to solar radiation during half an hour and then screened the radiation to allow cooling and obtained images in the 8-12 micrometer spectral interval every 5 minutes. After this, we have repeated the process increasing the content of water of the soil until it was difficult to detect and identify the object.

The infrared images were processed, analysed to detect shape and dimensions for every soil and water content, and the results are discussed. Conclusions of the study are presented.

8013-24, Session 7

High-speed IR monitoring of a turbojet engine gas flow using an uncooled MWIR imaging sensor

R. Linares-Herrero, M. T. Montojo, R. Gutiérrez, A. Baldasano, New Infrared Technologies, Ltd. (Spain); V. Archilla-Prat, Ctr. de Turborreactores (Spain)

Several types of sensors are used during the performance test trials of a turbojet engine to monitor different parameters such as temperature, pressure, vibration, etc. However, most of these sensors have long time constants and are unable to measure fast transients and fluctuations.

In this paper we show an alternative measurement sensor to characterize some phenomena observing the flow resulting from the combustion at the outlet of a turbojet engine, using a high speed uncooled MWIR imaging sensor able to provide more than 1,600 frames per second.

The experiments made, include monitoring of flow stability during a long period of observation where accelerations and stationary regimes are performed, and monitoring of higher frequency phenomena such as surges. Compressor surges (or stalls) are identifiable because they produce one or more extremely loud bangs from the engine, and may be accompanied by a fast increment of the exhaust gas temperature and an increase in rotor speed due to the large reduction in work done by the stalled compressor, causing severe stresses within the engine from the intense aerodynamic buffeting within the compressor.

8013-26, Session 7

Implementation of thermographers certification in Brazil

L. Santos, Furnas Centrais Elétricas S.A. (Brazil); L. M. Alves, ABENDI (Brazil); E. da Costa Bortoni, Univ. Federal de Itajubá (Brazil)

In recent years Brazil has experienced an extraordinary growth despite the recent economic global crisis. The demand for infrared thermography products and services has accompanied this growth. Like other non-destructive and inspection methods, the results obtained

by thermography are highly dependent on the skills of thermographer. Therefore, it is very important to establish a serious and recognized process of Certification to assess thermographers' qualifications and help services suppliers to establish credibility with their customers and increase the confidence of these costumers on the quality of these services.

The Brazilian Society of Non-Destructive Testing and Inspection, ABENDI, a non-profitable, private technical-scientific entity, recognized nationally and internationally, has observed the necessity of start a process for certification of thermographers in Brazil. With support of a working group composed by experts from oil and energy industries, transportation, universities and manufactures, the tasks were started in 2005.

This paper describes the economic background required for installation of the certification process, its initial steps, the main characteristics of the Brazilian certification and the expectation for starting certifications.

8013-27, Session 8

Signal and image processing techniques for digitized frequency modulated thermal-wave imaging for characterization of fiber-reinforced plastics

R. Mulaveesala, S. V. Ghali, L. K. Balyan, S. S. Lamba, Indian Institute of Information Technology (India)

Active infrared nondestructive evaluation (AIRNDE) involves mapping of surface temperatures over the test object, for a known imposed incident heat flux, to detect surface and subsurface defects (voids, disbands, cracks etc.). It is a fast, remote and whole field method for defect detection. Since most of the solids conduct heat, AIRNDE has the potential for wide use in non destructive testing of variety of solid materials. It is achieved by observing, recording and analyzing the thermal response over the material surface to a heat stimulus and is broadly known as active thermography in contrast to passive thermography where no heat stimulus is applied. This paper highlights the defect detection capabilities of digitized frequency modulated thermal wave imaging for carbon and glass fiber reinforced plastic materials.

8013-28, Session 8

Automatic thermographic image defect detection in composites

B. Luo, B. Liebenberg, J. Raymont, S. P. Santospirito, Kingston Computer Consultancy Ltd. (United Kingdom)

An automatic NDT defect detection software system has been developed for the analysis of pulsed thermography and near IR images of composite materials to automatically detect, reliably measure and then sentence defects in composite panels completely independent of operator decisions. A general panel surface profile definition has been introduced so all panel surfaces can be modelled, and the inspection system has been developed to automatically generate an optimized inspection plan in which sampling images cover the whole panel surfaces, and automatically control and communicate with robot-arms and cameras to implement image acquisition. Algorithms were developed so that the defect sizes can be correctly evaluated. Individual inspection images can also be stitched together to be processed as a single object or for ROI to be selected and specifically analysed. A statistical model was built up to analyse and evaluate the image background ranges. By studying and extracting features of inspection sample data, extendable inspection standards for thermographic image system have been built up. The software system works with the inspection standards to robustly detect defects. Various image processing operators have been studied. Full width half maximum algorithm has been used to measure the flaw sizes. Defect analysis is then performed to determine if the defect can be further classified and the sentencing engine then compares the most significant defect or group of defects against the inspection standards.

Testing during the EC funded ComPair project into impact damage on composite panels has successful detected and correctly sentenced all defected samples.

8013-29, Session 8

Fixed eigenvector analysis of thermographic NDE data

K. E. Cramer, W. P. Winfree, NASA Langley Research Ctr. (United States)

Principal Component Analysis (PCA) has been shown effective for reducing thermographic NDE data. This paper will discuss an alternative method of analysis that has been developed where a predetermined set of eigenvectors is used to process the thermal data from both reinforced carbon-carbon (RCC) and graphite-epoxy honeycomb materials. These eigenvectors can be generated either from an analytic model of the thermal response of the material under examination, or from a large set of experimental data. This paper provides the details of the analytic model, an overview of the PCA process, as well as a quantitative signal-to-noise comparison of the results of performing both conventional PCA and fixed eigenvector analysis on thermographic data from two specimens, one Reinforced Carbon-Carbon with flat bottom holes and the second a sandwich construction with graphite-epoxy face sheets and aluminum honeycomb core.

8013-30, Session 9

Improved flaw detection and characterization with difference thermography

W. P. Winfree, J. N. Zalameda, P. A. Howell, NASA Langley Research Ctr. (United States)

Flaw detection and characterization with thermographic techniques in graphite polymer composites is often limited by localized variations in the thermographic response. Variations in properties such as acceptable porosity, variations in fiber volume content and surface polymer thickness result in variations in the thermal response that in general cause significant variations in the initial thermal response. These variations result in a "noise" floor that increases the difficulty of detecting and characterizing deeper flaws. The paper investigates comparing thermographic responses taken before and after a change in state in a composite to improve the detection of subsurface flaws. A method is presented for registration of the responses before finding the difference. A significant improvement in the detectability is achieved by comparing the differences in response. Examples of changes in state due to application of a load and impact are presented.

8013-31, Session 9

Defense and illustration of the pulse-stimulated IR thermography for NDE

D. L. Balageas, ONERA (France)

Since many years in the non-destructive literature, it has grown into a platitude that the pulse stimulated thermography, whose results are constituted by amplitude or amplitude contrast images, has an unacceptable weakness when compared to thermographic techniques such as lock-in thermography (LT) and Pulse-Phase thermography (PPT) leading to phase or phase-contrast images. This weakness lay in the strong dependence of the temperature increase of the tested structures or materials resulting from the thermal stimulation on the space variability of i) their optical properties (absorptivity and emissivity), ii) the fluence of the stimulating heat flux.

This petitio principii is sometimes validated by biased comparisons in which a phase-based technique is compared to a pulse stimulated

experiment with a crude amplitude-based data processing.

In this article it is demonstrated that already published simple and efficient normalisations of the thermograms are possible and constitute a drastic remedy to this weakness. This is illustrated by several applications to realistic defects and configurations. After normalisation, the amplitude based pulsed thermograms present strong advantages compared to phase-based thermograms, in particular their large pass-band which allow the precocious detection/characterization of defects, making the technique a multi-scale tool for really quantitative analysis.

The way to optimize the normalisation is also discussed and illustrated by the analysis of NDE experiments.

It is concluded that it is urgent that really objective inter laboratory comparisons be performed on well-documented representative coupons to highlight the real performances of the different thermographic approaches in NDE.

8013-32, Session 10

Automated transient thermography for the inspection of CFRP structures: experimental results and developed procedures

P. Theodorakeas, N. P. Avdelidis, K. Chryssagis, National Technical Univ. of Athens (Greece); C. Ibarra-Castanedo, Univ. Laval (Canada); M. Koui, National Technical Univ. of Athens (Greece); X. P. V. Maldague, Univ. Laval (Canada)

In thermography surveys, the inspector uses the camera to acquire images from the examined part. Common problems are the lack of repeatability when trying to repeat the scanning process, the need to carry the equipment during scanning, and long setting-up time. The aim of this paper is to present transient thermography results on CFRP plates, as well as to discuss and present a prototype robotic scanner to apply non destructive testing (thermographic scanning) on materials and structures. Currently, the scanning process is not automatic. The equipment to be developed will be able to perform thermal NDT scanning on structures, create the appropriate scanning conditions (material thermal excitation), and ensure precision and tracking of scanning process. A thermographic camera that will be used for the image acquisition of the non destructive inspection, will be installed on a x, y, z, linear manipulator's end effector and would be surrounded by excitation sources (optical lamps), required for the application of transient thermography. The procedures developed will be discussed as a new approach for transient thermography testing.

8013-33, Session 10

Issues in on-aircraft application of thermographic NDT

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

While the potential of thermography for NDT of in-service aircraft has been widely recognized, implementation has been limited to relatively simple applications such as detection of trapped water in honeycomb structures or impact damage in composites. Reluctance to pursue thermography as a solution more aggressively is often attributed to factors including cost, size and complexity of the equipment, and the difficulty of adapting equipment designed for the laboratory to the maintenance hangar or flight line environment. Using a pragmatic approach to excitation with simple, inexpensive heat sources, and adapting the Thermographic Signal Reconstruction (TSR) method to accommodate a broad class of temporally extended input signals, we have developed an alternative approach to the thermographic NDT paradigm that provides performance with the sensitivity normally associated with full scale thermography systems, yet in in a configuration that can be realistically deployed for use by a single operator in an on-aircraft scenario. Inspection case studies on actual aircraft will be discussed.

8013-34, Session 10

Thinning identification technique using stainless steel film heater and response surface method

N. Ogasawara, H. Yamada, National Defense Academy (Japan)

The infrared thermographic testing has not been widely applied to nondestructive inspection for metals. It is because the metal emissivity is too low to be measured the surface temperature. To make up for these disadvantages of the active thermograph, a new heating technique using a stainless steel film was proposed and a nondestructive inspection system with the response surface method was developed.

The stainless film has a high electric resistance and can generate large Joule heat. Its heating response is very quick and the quantity of heat is easily controlled. Thus this heating technique works well for an active thermography. In addition, the stainless film has a high enough thermal conductivity, therefore a black painted stainless film can be a blackbody surface of metal structures and parts. Consequently an infrared thermographic camera can easily measure the temperature of the metal surface accurately. This technique spreads applications of the infrared thermography widely.

The nondestructive inspection system which can quantitatively identify geometrical parameters of a local thinning was developed. The system consists of two parts; a forward analysis and an inverse analysis. In the forward analysis, the response surface which shows a relationship between geometrical parameters and characteristic values is built by experimental design method. In the inverse analysis, the characteristic values obtained by inspections are substituted for the response surface and the geometrical parameters of local thinning are finally identified. The inspection system can identify the shape of the local thinning robustly by selecting the attribute for the shape parameters.

8013-35, Session 10

Real-time principle component analysis for thermograms processing and fusion

M. A. Omar, Y. Zhou, Q. Shen, Clemson Univ. (United States)

This presented manuscript discusses the use of the Principle Component Analysis PCA in processing infrared thermo-gram sequences in real-time. Two case studies will be specifically discussed; the first is for thermograms resulted from selective (induction), transient (flash), and steady (halogen) stimulation sources, for the nondestructive evaluation of adhesive bonded joints. While the second case is concerned with enabling thermal imagery and visible acquisition to be fused in real-time to assess the thermal signature of sheet metal forming. The text will explain the different variations of implementing a PCA routine for infrared thermography; using the standard PCA calculations, the use of a Singular Value Decomposition SVD code, and the use of a modified SVD routine that allows for faster computations. The role of the PCA statistics on enhancing the contrast signal will be analyzed and quantified for each case study. Also, the text describes the advantage of complementing the PCA routine with a self-referencing routine to help expedite the PCA implementation and reduce its memory and time requirements.

8013-36, Session 10

Detection of subsurface defects in metallic materials with thermo-inductive inspection

B. Oswald-Tranta, M. Sorger, Montan Univ. Leoben (Austria)

Active thermography can be well used to detect subsurface defects like buried cavities in materials. For metallic materials induction heating is the most efficient technique, because the heat is generated directly in the material and therefore the usually low emissivity and absorption coefficient of the metallic surface does not affect the heating process.

Short inductive heating pulses (0.5 - 2 s) have been used to detect holes with a diameter of 2-4 mm in a depth of 2-4 mm below the surface in steel and in aluminum samples. Some of the defects were created artificially; other ones were generated during the production process. The size and the depth of these defects were determined with the help of computer tomography. Additionally to the experimental data, also finite element simulations and analytical calculations have been carried out in order to model the heat distribution for different defect sizes and defect depths. The calculations have been used to optimize the heating pulse duration. Based on the modeling results, an evaluation algorithm has been developed, which allows an automatically localization of the defects with help of image processing techniques. With this algorithm also the real size and depth of the defect can be estimated. In order to test the stability of the automated evaluation, noise has been added to the calculated temperature distribution. The same processing technique has been used for the evaluation of the experimental data and very good detection results could be achieved.

8013-37, Session 10

Thermography based inspection of turbine airfoils

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

Inspection of aircraft turbine airfoils is a critical and complex task that must be performed at the casting, coating and machining stages of the manufacturing process. A variety of technologies, including penetrant, ultrasound, eddy current, x-ray and neutron radiography, air and water flow and visual inspections are routinely involved in the evaluation of each airfoil. The process can be streamlined, and some inspections can be significantly improved using thermographic methods. A modular airfoil inspection station, combining several excitation and analysis methods, has been successfully developed and implemented. The net result is a significant reduction in the inspection time for a single blade over the course of the entire manufacturing process.

8013-38, Session 10

Pulse and lock-in IR NDT in complex structures

M. Tarin, moviMED (United States)

No abstract available

8013-39, Session 10

Infrared thermography as a nondestructive tool for materials characterisation and assessment

T. Gan, TWI Ltd. (United Kingdom); N. P. Avdelidis, National Technical Univ. of Athens (Greece)

In this work, thermography is presented as one of the main inspection NDT techniques for various applications, such as aerospace composites (sandwich, honeycomb, CFRP structures), automotive panel inspection, as well as in the power industry (i.e. wind turbine blades, thermal barrier coatings, etc) and computer manufacturing industry. Different examples are presented concerning detection of defects in large composite structures, detection of hot-spots in electronic circuitry, inspection of flaws and disbonds on plastic composite pipes, etc, with the aim of developing proper thermographic inspection procedures. The overall aim of this paper is to present the capabilities of a fast area inspection ndt technique, as thermography, for materials characterisation and/or assessment.

8013-40, Session 11

Fiber optic thermal detection of composite delaminations

M. Wu, W. P. Winfree, NASA Langley Research Ctr. (United States)

A recently developed technique is presented for thermographic detection of delaminations in composites by performing temperature measurements with fiber optic Bragg gratings. A single optical fiber with multiple Bragg gratings employed as surface temperature sensors was bonded to the surface of a composite with subsurface defects. The investigated structure was a 10-ply composite specimen with prefabricated delaminations of various sizes and depths. Both during and following the application of a thermal heat flux to the surface, the individual Bragg grating sensors measured the temporal and spatial temperature variations. The data obtained from grating sensors were analyzed with thermal modeling techniques of conventional thermography to reveal particular characteristics of the interested areas. Results were compared and found to be consistent with the calculations using numerical simulation techniques. Also discussed are methods including various heating sources and patterns, and their limitations for performing in-situ structural health monitoring

8013-41, Session 11

Thermoelastic stress analysis of overlap shear splices constructed from wet lay-up FRP composites

J. R. Brown, B. Fineout, Hope College (United States)

Overlap shear splices are common in civil FRP strengthening applications when the overall length of a saturated ply becomes prohibitive or access to the surface being strengthened is restricted. The objective of this research was to develop a standard test method for evaluating overlap splices in wet lay-up FRP composite samples. Single-shear specimens were constructed from carbon fiber FRP with variable overlap splice lengths ranging from 1 in to 4 in. Each specimen was subjected to cyclic loading at a rate of 1 Hz and an IR camera was used to monitor the temperature variations resulting from the cyclic stress. A sinusoidal curve fit was applied to the temperature response for each pixel and the resulting amplitude image was used to evaluate the severity of stress concentrations at the ends of the overlap splice region as well as where the top ply of saturated composite formed a kink during lay-up.

8013-42, Session 11

Preliminary investigation of polarization effects during metal cutting

E. Whitenton, National Institute of Standards and Technology (United States)

Under certain conditions, the polarization state of infrared light emitted by metal changes when the metal is strained. During machining, metal is severely strained. Assessing both strain and strain rate is of interest to the machining research community. Over large areas, Digital Image Correlation (DIC) performed on high-speed video can provide approximate values. However, small areas such as the shear zone are difficult to image with enough resolution to perform DIC. Thus, if the thermal radiation emitted by these small areas do emit polarized light, there is the potential to provide valuable information to the machining community. This study is an initial investigation into that possibility. It utilizes a rotating polarizer which triggers a thermal spectrum camera to acquire an image at specific angles. By comparing the intensities of the images at those angles, and assuming the light is linearly polarized, the polarization state may be estimated. Since the metal is constantly moving, the material imaged is different from one image to the next.

Return to Contents

Averaging multiple images at each angle of the polarizer is used to estimate typical intensity for that angle.

8013-43, Session 11

Infrared imaging during ballistic testing of self-healing materials

K. E. Cramer, S. G. Allison, E. R. Burke, P. A. Howell, W. T. Yost, NASA Langley Research Ctr. (United States)

Self-healing materials have the potential to mitigate significant damage caused by high velocity impacts. This class of materials also has the potential to improve damage tolerance in load bearing structures thus enhancing vehicle health and aircraft durability. In order to better characterize the physical mechanisms associated with the material's self-healing properties, high speed infrared thermography was performed as ballistic projectiles passed through samples of two different materials. This paper will discuss the materials being investigated, the data acquisition system used for high speed thermal imaging and the temperature response of the specimens after impact. The temperature images obtained from the high speed thermography system are then compared with residual stress images obtained by photoelastic techniques to more fully characterize the specimens.

8013-44, Session 11

Modeling of laser-analyte-substrate interaction in photo-thermal infrared imaging and laser trace vaporization

R. Furstenberg, J. Grosser, C. A. Kendziora, M. R. Papantonakis, R. A. McGill, U.S. Naval Research Lab. (United States)

We are developing two techniques for non-contact detection of trace explosives and other analytes with low vapor pressure. In one approach, quantum cascade lasers (QCL) at eye-safe power levels are used to heat the analyte on the surface at stand-off and image the photo-thermal signal with an infrared camera. By varying the excitation wavelength and/or collection bands, the absorption spectrum of the analyte is mapped out. In the second approach, a QCL or other IR laser is used at higher optical power to enhance the vapor signature of the analyte, suitable for vapor-based (e.g. ion mobility spectrometry) techniques. Detailed description and advances in these techniques will be reported elsewhere. In this paper, we study the interaction of the laser beam with the analyte particles and heating of the particle and substrate using the COMSOL simulation package. Validation of the model was done by comparison with experimental measurement of laser heating of well-characterized particles (both perfectly spherical and randomly shaped) and substrates. In particular, we investigate the nature of the heat transfer between a particle and substrate in terms of relevant parameters (particle size, material, roughness at contact etc.). Several important measurement scenarios are examined in order to maximize the sensitivity and selectivity of the techniques. The effects of substrate heating on signal contrast as well as exploiting the transient thermal response are discussed. For laser trace vaporization, we also study the enhancement of vapor generation and demonstrate that the substrate-mediated heating of neighboring interferent particles is negligible.

8013-45, Session 11

Application of micro-scale thermography to the thermal analysis of polymeric and organic materials

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

The applications of uncooled micro-bolometer VOx FPA to the micro-scale thermal analysis of polymeric & organic materials are presented. The latent heat during phase transition is analyzed with the emmisivity correction calculation for all pixels that includes the calibration algorithm using a black point reference pixel. It enables to visualize the exothermic latent heat of freezing biological cells at minus temperature. In comparison with the previously obtained data by using the InSb FPA sensor, the limitation and the possibility of the un-cooled micro-bolometer in view of application in thermal analysis of materials characterization are discussed.

The hardware of the measuring system consists of

A: Signal (NTSC & parallel signal) capturing part,

B: Superimposer of video signal,

C: Timing trigger generator,

D: Synchronous IR/ visible camera with a half-mirror control,

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

F: Acutuator and laser drive

G: Stage scanner,

and the calibration table for all pixels are experimentally prepared. The total system is designed in a handy size.

In order to improve the thermal time constant, the triggering system with a superimpose is examined. The laser beam modulated spot-heating visualizes the thermal diffusivity and its anisotropic properties depending on the materials molecular orientation. Combining all these technique the handy-type thermal analysis measuring system is designed and applied to polymeric and organic materials for the thermal properties characterization.

8013-46, Session 11

Infrared imaging for process control of laser glass tube

M. Lopez Saenz, O. Schreer, IRCAM GmbH (Germany)

In the research project LAFUESOL, a manufacturing process and a prototype industrial machine for laser-based glass tube fusing are developed. An infrared camera is used for process monitoring and the thermal information is used as an input for process control.

Long glass tubes are used in the production of solar thermal collectors. These are usually formed by fusing several short tubes using flame-based heating and melting technology. The low incoupling efficiency of the flame in conjunction with long process times, depending on the operator's skills, leads to an enormous consumption of burner gases. The main goal of the project is to develop a manufacturing process with better energy efficiency and higher final quality. A promising tool for energy-efficient glass fusing is a high-power carbon dioxide (CO_2) laser which deposits its radiative energy very effectively and with an exactly defined temporal and spatial distribution. To optimize the process a built-in measurement system for the temperature distribution on the glass tube has been implemented. The temperature distribution is measured using a high-speed thermal infrared camera and used to control the laser and the fusing process. Real-time image processing and evaluation of temperature profiles permits to control the laser process with very low latency. Moreover, an additional stress measurement system is used to measure internal residual stress in the glass tubes before and after the process."

8013-25, Poster Session

Measurement method based on directional contrast in infrared image for tracking filter

W. Lee, C. Park, Samsung Thales Co., Ltd. (Korea, Republic of)

Dynamics model and measurement of target is necessary to track target with tracking filter. Measurement of target position is computed with image signal. But it is difficult to detect target in small difference temperature between background and target object. Because infrared image is generated by infrared radiation from objects. In addition, there are many clutters that are similar to target in ground.

In this paper, we define directional contrast that has 8 component to left, right, up, down, left-up, left-down, right-up, and right-down. Each component means difference between average intensity of center area and adjoining area. We propose algorithm based on this concept, directional contrast, to detect small target in ground. The experimental result of proposed algorithm shows detected target even low contrast image in ground and improvement of tracking filter.

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8014-01, Session 1

Modeling of pixel edge effects in a novel micro-filter array for the visible spectrum

F. E. Strömqvist Vetelino, A. A. Abtahi, Aerospace Missions Corp. (United States); P. B. Griffin, Stanford Univ. (United States); R. J. Morgan, U. Raghuram, Aerospace Missions Corp. (United States)

The modeling of a novel hyperspectral filter array for the visible spectrum, constructed of an array of micron sized Fabry-Perot band-pass filters, is presented. Each filter forms a squared cavity pixel, less than 10 μm wide, resonating at a different wavelength than the neighboring pixels. For such small cavities, traditional 1D modeling of Fabry-Perot cavities of infinite extent is insufficient. To study pixel edge effects and pixel cross-talk, 2D FDTD simulations were carried out. Extensive modeling was done for a cavity array with several pixels, and sloped cavity edges were compared to vertical ones. Both the optical field inside each cavity, and the corresponding integrated power over the whole cavity were calculated. Comparisons of the peak power and spectral bandwidth were made between a finite pixel cavity and a cavity of infinite extent. Both normal and oblique incident light was included in the simulations.

8014-02, Session 1

Conspicuity of moving soldiers in the field

J. A. Beintema, A. Toet, S. C. de Vries, TNO Defence, Security and Safety (Netherlands)

Conspicuity is a fast and validated metric that can be used to estimate the mean search time for real targets in natural scenes. Conspicuity can be defined as the radius of the area that can be detected during a single eye fixation. For static vehicles, this metric has been shown to be linearly related to search time and independent of viewing distance. The construction and validation of soldier combat simulations requires conspicuity data on camouflaged soldiers in the field. Also, little is known on the contribution of motion relative to other parameters, such as luminance contrast. Here, we measured the conspicuity of static, walking and running soldiers in the field with different parameters (viewing distance, camouflage type, background scene and season) using either naked eye observations (NE) or thermal image recordings (IR).

The stimulus was a person in Dutch army camouflage (woodland or desert) against a pine-tree or deciduous forest edge. Possible confounding effects of motion and position were avoided by having the person make cyclic movements confined to a few meters. Although conspicuity was much larger for IR, in both cases the effects of movement were large and saturated as a function of retinal speed. For NE, we find large effects of shading that are not captured by local luminance contrast. Also for NE, conspicuity in winter was reduced, presumably by increased clutter. The data suggest that conspicuity can be modeled as function of retinal speed and a more global luminance contrast, but the influence of clutter remains an important factor as well.

8014-03, Session 1

Modeling human performance with low-light sparse color imagers

D. P. Haefner, J. H. Cha, J. P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Electro-optic imagers in the reflective bands are often noise limited in low-light conditions, and color imaging in low-light only becomes worse due to the narrower spectral bands. By using a sparse array of spectral filters, this loss of signal can be largely circumvented at the cost of greatly reduced resolution in the color planes. Utilizing human in the loop color target search experiments, we quantify this trade between color, noise, and resolution. We utilize a modified version of the Night Vision Image Generator that allows sensor effects to be added separately to the luminance and color planes. Using the simulated imagery allows an efficient sampling of the various design parameters, for example, scene luminance and color filter density, without the expense of building multiple prototype imagers. Search rates and probabilities are used to define the optimal design.

8014-04, Session 1

Visibility of F-16's with the naked eye, NVG's, and thermal sensor

F. L. Kooi, TNO Defence, Security and Safety (Netherlands)

In order to calibrate the visibility of jets in the simulator, we collected a database of representative measurements in the field. The database allows an objective comparison of day versus night, naked-eye versus image intensified (NVG), and image intensified vs. thermal. The database consists of military jets flying head-on towards the observer, the observer's task is to notify when the plane is first spotted. The distance is then recorded; later the measurement is repeated in one of our flight simulators. The results show that the day view is much better than the NVG night view, thermal is only marginally better than NVG {given the full moon}, and detection ranges in the simulator are much shorter than in reality. Implications are that a simple method like the one employed in our study suffices to calibrate simulators. Given the technological feasibility to perfectly simulate the NVG night (which cannot be done for day imagery) and the high risks of night training, makes it attractive to focus the simulation effort on the night environment.

8014-05, Session 1

Passive SWIR sky-glow illuminated imaging compared with NIR-visible for low-light nighttime observations

D. C. Dayton, J. G. Allen, J. D. Gonglewski, Applied Technology Associates (United States)

It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (~85 km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band with wavelength between 0.9 and 1.7 um. By directly and simultaneously examining images in an urban and a rural setting, we investigate the correlation between the appearances of passive dark of night images in the SWIR with NIR- visible. The experimental setup consists of two sensors, one a NIR-visible CCD and a InGaAs array sensitive in the SWIR, both co-located on an AZ-EL mount, and both co-boresighted so that different viewing angles of the sky and terrestrial scenes are possible. By making corrections for focal length and pixel size, the visible and SWIR data can be compared. After taking several nights of data in the urban environment of Albuquerque, NM, the entire system was then re-located to a rural location on the island of Kauai in a rural setting with very low ambient light. It is shown that under most conditions the SWIR sensor produces significantly better imagery using the sky-glow illumination source.

8014-06, Session 2

Modeling MRT for well characterized thermal imagers

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

Predicting an accurate Minimum Resolvable Temperature Difference (MRTD) for a thermal imaging system is often hindered by accurate measurements of system gain and display characteristics. Such variations are often blamed for poor agreement between model predictions and measured MRTD. By averaging over repeated human measurements and carefully recording all system parameters affecting image quality, it should be possible to make an accurate prediction of MRTD performance for any resolvable frequency. Utilizing the latest NVESD performance models with updated models for noise, target subtense, and human vision, predicted MRT are compared with measured curves. We present results for one well characterized midwave thermal staring system.

8014-07, Session 2

Performance evaluation of panoramic electro-optic imagers using the TOD method

P. Desaulniers, S. Thibault, Univ. Laval (Canada)

The triangle orientation discrimination (TOD) method is an emerging technique used for the evaluation of opto-electronic (EO) systems. In TOD, the test pattern is a non-periodic equilateral triangle in one of four different orientations (apex up, down, left, or right), and the measurement procedure is a robust four-alternative forced-choice psychophysical procedure. This leads to a heavy workload and time-consuming task. Consequently, software models have been developed to replace human observers. These models base their decision on correlation between observed data and the set of four targets.

This study investigates for the first time how this method can be applied to highly distorted OE systems like hemispheric imagers. These types of systems have inherent large distortion, but this distortion should not be considered as an aberration but rather the result of the projection of a hemispheric field (3D) on a 2D sensor. The distortion deforms the targets and image processing is habitually performed to remove distortion and straighten the field of view.

We present a comparison in accuracy and computational burden for the evaluation of EO performance between the cases where tested images are pre-processed and correlated to unchanged triangle targets or where untouched (distorted) images are correlated with position-wise distorted targets. This is a first evaluation of the application of the TOD with the goal of obtaining image quality criteria for panoramic imager.

8014-08, Session 2

Thermal imager non-uniformity sources modeling

E. Guadagnoli, C. Giunti, SELEX Galileo S.p.A. (Italy); P. Mariani, ALTRAN Italy S.p.A. (Italy); M. Olivieri, A. Porta, B. Sozzi, S. Zatti, SELEX Galileo S.p.A. (Italy)

The raw output of a generic infrared vision system, based on staring arrays, is spatially not uniform. This spatial noise can be much greater than the system NETD, and determines a strong drop in system performance.

Therefore we need to model all system non-uniformity (NU) sources to highlight the parameters that should be controlled by optical and mechanical design, the ones depending on the focal plane array and those that can be corrected in post-processing.

In this paper, we identify the main NU sources (optical relative irradiance, housing straylight, detector pixel-pixel differences and non linearity), we show how to model these sources and how they are related to the design and physical parameters of the system. We then describe the total signal due to these sources at the detector output. Applying different NUC algorithms to this signal, the final results on the image can be simulated finding a proper correction algorithm. At the end we show the agreement between the model with the experimental data taken on a real system.

Changing a limited set of parameters, this model can be applied to many third generation thermal imager configurations.

8014-09, Session 3

Matched filtering determines human visual search in natural images

A. Toet, TNO Defence, Security and Safety (Netherlands) and Univ. van Amsterdam (Netherlands)

Wang and Bovik (IEEE Signal Processing Letters 9-3, pp. 81-84, 2002) introduced the structural image similarity index (SSIM) which measures the similarity between images in terms of luminance, contrast en structure. The SSIM has successfully been deployed to model human visual perception of image distortions and modifications in a wide range of different imaging applications. Chang and Zhang (Infrared Physics & Technology 51-2, pp. 83-90, 2007) recently introduced the TSSIM clutter metric, which deploys the SSIM to quantify the similarity of a target to its background in terms luminance, contrast en structure. They found that the TSSIM correlates significantly with mean search time and detection probability. However, it is not immediately obvious to what extent each of the three TSSIM components contributes to this correlation. Here we evaluate the TSSIM by the TSSIM was evaluated by deploying it to a set of natural images for which human visual search data are available. By analyzing the predictive performance of each of the three TSSIM components, we find that it is predominantly the structural similarity component which determines human visual search performance, whereas the luminance and contrast components of the TSSIM show no relation with human performance.

8014-10, Session 3

Analytical calculation for probability of detection given time-dependent search parametes

M. H. Friedman, J. P. Reynolds, D. L. Wilson, U.S. Army Night Vision & Electronic Sensors Directorate (United States); R. G. Driggers, U.S. Naval Research Lab. (United States)

The problem solved in this paper is easily stated: given search parameters (P_{∞}, τ) that are known functions of time, calculate how the probability a single observer will acquire a target grows with time. This problem has been solved analytically. Here we describe the analytical solution, a derivation of the result and a Mathematica computer program that implements several approaches to the solution of the problem. The model is validated by the logic of the derivation, internal consistency checks, and comparison with perception experiments. The method is applicable to any scenario where the search parameters are changing with time and are specified. In particular it can be used to estimate the probability of target acquisition as a function of time: 1) when the sensor-target range is changing 2) for a slewed sensor where the target is alternately in and out of the field of view and 3) for a sensor that switches between wide and narrow fields of view.

8014-11, Session 3

Drift-insensitive dim-target detection using differential correlation

A. Y. Hsu, Sandia National Labs. (United States)

Extending the capability of current remote imaging systems to detect dimmer and dimmer targets is of very high interest to the community in order to expand the possible mission space.

Conventional methods for target detection using pixellated focal-plane arrays (FPA's) require the target signal to be some multiple larger than the noise signal, typically 5-10 times, which can be problematic for very dim targets and/or high-noise sensor conditions. Therefore, the detection of dim targets with low signal-to-noise (SNR) of less than 5 is challenging and often not possible with current approaches.

We investigate a fundamentally different detection algorithm approach based on differential correlation detection. The change in the temporal correlation of the output signals between an illuminated pixel and a dark reference pixel is measured in real time over some number of samples and may enable more sensitive detection of dim targets whose signal amplitudes are on the order of the noise levels of the sensor. If successful, target detection may be possible with target SNR's of less than 1 under practical conditions where dark drift may occur.

8014-12, Session 3

Software toolkit for evaluating infrared imaging seeker

M. A. Degache, TNO Defence, Security and Safety (Netherlands)

Modern infrared imaging seeker can nowadays deal with higher resolution and less noisy sensor images. The testing of new image processing or tracking algorithms requires a fitted set of relevant sensor images. When no actual recordings are available, when experimental benches are not adapted or at an early of development, one can require a simulation tool to generate such infrared sensor images.

This paper presents the first version of ISISserver (Infrared Sensor Image Simulation Server) a software library developed at TNO and typically used for imaging seeker applications. Based on the model suite EOSTAR (Electro-Optical Signal Transmission And Ranging), the set of functions offered by this toolkit allows analysis of synthetic sensor images generated for various synthetic environments and targets. Typical targets from a database can be used as well as externally user designed 3D targets. Simulation results using ISISserver toolkit will be shown.

8014-13, Session 4

Collaborative search with independent sensors

M. H. Friedman, J. P. Reynolds, T. W. Du Bosq, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

We consider the following problem. Three stationary observers with three sensors independently search for a stationary target. Each sensor is characterized by individual search parameters (P_{∞}, τ) which are different either because the sensors are at different ranges or are different because the sensors are at the same range but have different properties. The target is said to be detected when the first observer detects the target. Using this definition for time to detect, in this paper we derive an analytical expression for the mean detection time. The analytical expression is validated by internal consistency checks, simulation and comparison with perception experiment results. A comparison is made with the well-established war game model OneSAF. The computational effort of the Monte Carlo calculation used by OneSAF increases rapidly with the required accuracy and is generally much greater than the computational effort of the analytical model presented here. The analytical model is used to analyze the benefit of putting multiple sensors on a single platform.

8014-14, Session 4

LWIR thermal imaging through dust obscuration

F. A. Smith, E. L. Jacobs, S. K. Chari, J. M. Brooks, The Univ. of Memphis (United States)

The physical model for long wave infrared (LWIR) thermal imaging through a dust obscurant incorporates transmission loss as well as an additive path radiance term, both of which are dependent on an obscurant density along the imaging path. When the obscurant density varies in time and space, the desired signal is degraded by two anti-correlated atmospheric noise components--the transmission (multiplicative) and the path radiance (additive)--which are not accounted for by a single transmission parameter. This research introduces two approaches to modeling the performance impact of dust obscurant variations. The first approach derives effective noise terms for obscurant variations detected by a sensor via a forward radiometric analysis of the imaging context. The noise parameters derived here provide a straightforward approach to predicting imager performance with existing NVESD models such as NVThermIP. The second approach reformulates the problem in an information theoretic context by modeling the obscurant volume as a noisy channel. A comparative analysis of the information rates is reported for various cases related to imaging through dynamic obscurant volumes such as dust storms or rotor wash induced brownout.

8014-50, Session 5

Wide-area infrared surveillance: performance requirements and technology needs

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

The emergence of asymmetric and terrorist threats as a prime focus of military operations is placing high demands on airborne reconnaissance, surveillance, and targeting systems. When placed within the context of a complex, urban landscape, a need arises for advanced electro-optical and infrared (EO/IR) sensing techniques to deal with the combination of small, diverse, and elusive targets and broad area, complex, and highly structured regions of interest. One particular research emphasis within the Air Force Research Laboratory (AFRL) has been toward the development of wide area IR surveillance capabilities that can continuously image city-sized areas with sufficient fidelity to detect and track individual personnel, or dismounts, in order to monitor their activity and ultimately assess their intent. This research has involved infrared signature phenomenology investigations of dismount activity to understand performance requirements, prototype infrared sensor system development to assess current technology capabilities, and enabling sensor component research to provide the necessary future advancements. This presentation will provide a summary of this on-going research, with a specific focus on establishing the technical requirements for dismount detection and tracking and the future infrared technology advances that will likely be required in order to address this challenging need.

8014-15, Session 6

Performance assessment of treating aliased signal as target-dependent noise

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

This paper assesses the performance of several theories to account for aliasing artifacts of a sampled imager on target acquisition. Currently the Army's imager performance model, NVThermIP, uses the MTF squeeze model. MTF squeeze applies an additional degradation to the targeting task performance metric based upon a parametrized fit to measured

performance of aliased systems. While this model achieved good results, new sensor designs and complex image processing techniques often step outside the validity of this approach. It has been suggested that the artifacts arising from aliasing may be treated as a target-dependent noise. Modeling aliasing as noise allows proper treatment of sampling artifacts across all types of linear processing, improving the applicability of the Army's imager performance model. Unlike the MTF squeeze model, this method accounts for the performance detriment due to both in-band and out-of-band aliasing in the same manner. Several historical, and newly conducted, perception experiments are used to assess the performance of this method with promising results.

8014-16, Session 6

Identification of human activities in a thermal system with noise varied in temporal frequency

J. M. Brooks, E. L. Jacobs, F. A. Smith, The Univ. of Memphis (United States)

A forced choice perception experiment is designed to measure the probability of identification of human activities captured in a mid-wave thermal system at 3 ranges and intentionally degraded with Gaussian white noise. The zero-mean noise is varied in standard deviation and temporal frequency. With respect to the frame rate of the target videos, noise is added at full-frame rate, half-frame rate, and also held static. Activities involve small to moderate amounts of motion in a localized area but do not result in large target shifts with respect to the entire scene. The 24 unique human activities are presented in randomized cells of 5-second video clips that repeat once. Results are compared to NVThermIP model predictions that utilize the Targeting Task Performance (TTP) metric and assume a static target. A primary interest is the model's performance in sub-frame rate noise. In low temporal frequency noise, it is expected that unmasking provided by the motion of the targets will lead to an increased performance over model predictions. Conversely, reduced integration time on any specific point of a moving target is expected to lead to over-predicted performance in high frequency noise. In this research, we examine these expected behaviors in light of perception experiment data and model predictions. We further comment on the way forward to a non-static model that accounts for target motion.

8014-17, Session 6

System considerations of aerial infrared imaging for wide-area persistent surveillance

M. R. Kruer, J. N. Lee, D. C. Linne von Berg, G. Howard, U.S. Naval Research Lab. (United States); J. A. Edelberg, V-Systems, Inc. (United States)

No abstract available

8014-18, Session 6

Developing adequate definitions for detection, recognition, and identification of human targets

P. D. O'Shea, J. T. Meier, U.S. Army Redstone Technical Test Ctr. (United States)

Traditional target acquisition models, such as NVThermIP developed by Night Vision Electronic Sensors Directorate (NVESD), are well defined and well calibrated for vehicular targets. There is a common language for detection, recognition, and identification (DRI), and several well-defined target groups with measured task difficulties. Even so, there is a common misconception that only a couple of words (e.g. "vehicle recognition") fully define a task difficulty. The fallback is to use a standard target set definition, such as the NATO standard, but few threats of interest match this target set exactly, or even approximately. For sensor performance to be measured and/or modeled, the target set must be more precisely defined, to match the mission. This lack of definition is even more problematic for human targets. While modelers may use a "standard human target" for predicting performance, the difficulty of recognition and identification varies widely depending upon mission, threat, and confusers. In the past, NVESD has measured task difficulties for various human activities, and for identification of hand-held objects (which is often the task required to make a determination for human targets), which is an excellent start. Detection is less well defined, especially the marked difference between stationary and moving targets, or self-illuminating targets (e.g., smoking). Another ill-defined task in need of bounding is "suspicious or hostile activity," which again varies widely depending upon definition, threat, and confusers. This paper presents more recent results to help define the variety of tasks that fall under human DRI.

8014-19, Session 6

TOD to TTP calibration

P. Bijl, TNO Defence, Security and Safety (Netherlands); J. P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate (United States); W. K. Vos, M. A. Hogervorst, J. D. Fanning, TNO Defence, Security and Safety (Netherlands)

Current US DoD camera system performance requirements are based on the TTP (Targeting Task Performance) metric, the standard US Army EO/IR sensor performance metric developed at NVESD. This model however does not have a corresponding lab or field test to empirically assess the performance of a camera system. The TOD (Triangle Orientation Discrimination) method, developed at TNO in The Netherlands, provides such a measurement. The test is fast, accurate, un-biased, requires no training and can be automated. In this study, we make a direct comparison between the TOD for a range of sensors with the extensive historical US observer performance database built to develop and calibrate the TTP metric. While the US perception data were collected using a standard tacticle vehicle image set and simulated sensors for which the most fundamental sensor parameters such as noise, blur, and sampling were varied, we measured TOD sensor performance using exactly the same sensors processing a set of TOD test patterns. Calibration of the TOD to the TTP can be hightly beneficial to the sensor modeling and testing community for a variety of reasons. These include: i) a connection between requirement specification and acceptance testing, and ii) a very efficient method to quickly extend the TTP range prediction model to new systems and tasks.

8014-20, Session 7

Dependence on target spatial frequency signatures in infrared performance modeling

T. W. Du Bosq, J. T. Olson, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The standard model used to describe the performance of infrared imagers is the U.S. Army thermal target acquisition model, NVThermIP. The model is characterized by the resolution and sensitivity of the sensor and the contrast of the target. The contrast of the target is defined as a spatial average contrast consisting of the root sum squared (RSS) difference between the target and background means and the standard deviation of the target internal contrast. The model treats the average contrast of the target set as white, i.e. constant over a band-limited set of spatial frequencies. Previous experiments have shown that this assumption is adequate for many target sets under normal conditions. Recent experiments suggest the need to provide fidelity beyond the limitations of RSS contrast and a white target spectrum. To investigate improved target models, this paper describes the spatial frequency dependence of the standard U.S. Army Night Vision tracked vehicle target set with various image processing techniques applied. The results

of human perception experiments are modeled and evaluated using both frequency dependent and independent target signature definitions.

8014-21, Session 7

Estimating the blur kernel for blurry IR imagery from edge profiles

L. N. Smith, U. S. Naval Research Lab. (United States); J. R. Waterman, U.S. Naval Research Lab. (United States)

This paper presents a simple, fast and robust method to estimate the blur kernel from edge profiles in a blurry image that incorporates blur from all sources, including factors inherent in the imaging system. Knowledge of the blur kernel defines the underlying sharp image, which is computed via non-blind deconvolution methods. A robust method to obtain clear, sharp imagery would be a valuable asset across the spectrum of applications, including long range surveillance through turbulent atmosphere. Visual and timing comparisons are presented of the deblurring results from this method to current common practices for real-world visible, NIR, SWIR, MWIR and active IR imagery. This method is based on concepts drawn from statistics; that is, using the tools for fitting data distributions allows optimization of the blur kernel functional form by matching the edge profile to ones theoretically generated by general families of distribution functions. In addition, this method provides a simple measure of asymmetry and spatial variation, which allows one to make an informed decision on whether to use a symmetric or asymmetric, spatially varying or non-varying blur kernel over an image. Also, an algorithm is described to automatically obtain the blur kernel from strong edges everywhere in an image. Deblurring results are given for IR images with asymmetric spatial variation using this technique and contrasted to results from using a constant, symmetric blur kernel. Furthermore, this method is shown to be robust to image noise. The effect of image noise on this method is compared to the effect of noise on blind deconvolution methods.

8014-22, Session 7

Development of a moving platform model from the ACQUIRE model using first principles

S. K. Moyer, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

In 1958 John Johnson introduced his target acquisition imager model that predicted the probability a human could perform a visual task given the resolution and sensitivity of the sensor and the target size, the range to the target, and the illumination level. In 1975 James Ratches extended Johnson's model to scanned infrared sensors, and in 1989 the ACQUIRE model was unveiled, which became the standard target acquisition model. The ACQUIRE model worked well with infrared sensors which were relatively insensitive when compared to the sensitivity of the human eye. As technology evolved and sensors became more sensitive and shifted away from scanning systems to staring focal plane arrays, the ACQUIRE model was adapted to account for these sensor changes. In 2003 the ACQUIRE model was adapted to model the probability of identifying small hand-held objects. This was the first major change of targets since the original Johnson model. It also brought forth some of the limiting assumptions the ACQUIRE model has concerning the target and sensor. Predominately, both the sensor and target are stationary.

In irregular warfare the stationary observer assumption is no longer valid; engagements are frequently made from moving vehicles at very short ranges, <500m. It is predominately this short range that renders the static observer assumption invalid. An observer moving at only 30 mph will cover a 500m range in less than 1 minute. Since 2009, the US Army Night Vision and Electronic Sensors Directorate (NVESD) has been developing a temporal extension of the ACQUIRE model to more accurately model this dynamic sensor and dynamic target scenario. This paper explores the development of this new moving platform model from first principles, and shows that how in the limiting case of no motion the moving platform model goes back to the ACQUIRE model. The new model is then applied to human perception experiments previously conducted by NVESD and compares the model predictions to actual human data.

8014-23, Session 7

Comparison of the performance of LWIR and MWIR thermal imagers for varying ambient temperature and humidity conditions

V. Dhar, Z. Khan, R. K. Sharma, R. Muralidharan, Solid State Physics Lab. (India)

Hodgkin et al (SPIE 6207(2006)) have extended NVThermIP so that it is applicable in cold weather conditions (not just 300K). We have also (IRPhys&Technol.51 (2008)520) published an analysis of the effect of varying ambient temperature (Tamb)by modifying the inputs to NVTherm2002, and by using spectrally-weighted atmospheric transmission calculated from MODTRAN at different ambient temperatures and relative humidities (RH). While we took into account the effects on the integration time and NETD, we did not account for the variation of T with varying Tamb, as Hodgkin has done. We have now revised our calculations to do so. The overall trends are similar, although results are not directly comparable because we have NVTherm, not NVThermIP and we have used spectrally-weighted atmospheric transmission (not the band average). We emphasize that diurnal, seasonal, climatic and microclimatic variations of relative humidity (RH) significantly impact the performance of thermal imagers. RH adversely affects the performance of LWIR thermal imagers. We have applied these facts to compare the performance of thermal imagers in clear weather conditions for terrestrial imagers and ground targets/scenes in both LWIR and MWIR bands. This comparison is carried out as a function of the ambient temperature from -40 °C to +50 °C and also as a function of relative humidity (10%,30%,50%,70% and 90%). We have also done some analysis of how motion blur affects the two bands.

8014-24, Session 8

Improved signature prediction through coupling of ShipIR and CFD

D. A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada)

Most existing platform signature models use semi-empirical correlations to predict flow convection on internal and external surfaces, a key element in the prediction of accurate skin signature. Although these convection algorithms are capable of predicting bulk heat transfer coefficients between each surface and the designated flow region, they are not capable of capturing local effects such as flow stagnation, flow separation, and flow history. Most computational fluid dynamics (CFD) codes lack the ability to predict changes in background solar and thermal irradiation with the environment and sun location, nor do they include multi-bounce radiative surface exchanges by default in their solvers. Previous attempts to interface signature codes with CFD have resulted in uni-directional mapping of CFD predicted temperatures to the signature model. This paper will describe a new functional interface between the NATO-standard ship signature model (ShipIR) and the ANSYS Fluent model, where a bi-directional mapping is used to transfer the thermal radiation predictions from ShipIR to Fluent, and after re-iteration of the CFD solution, transfer the wall and fluid temperatures from Fluent to ShipIR to further refine the local-area heat transfer coefficient and re-iterate the ShipIR solution. Within a few successive iterations (3-5) of the two interfaced models, both solutions converge to within an RMS variation in surface temperatures of less than 0.3°C. This new functional interface will be described through a detailed thermal/IR simulation of an unclassified platform, showing the differences between the coupled and uncoupled solutions. Future efforts to validate the new interface using shipboard measurements will also be discussed.

8014-25, Session 8

Simulation of laser beam reflection at the sea surface

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A 3D simulation of the reflection of a Gaussian shaped laser beam on the dynamic sea surface is presented. The simulation is suitable for both the calculation of images for a SWIR (short wave infrared) imaging sensor and for determination of detected total power of reflected laser light for a bistatic configuration of laser source and receiver at different atmospheric conditions.

Our computer simulation comprises the 3D simulation of a maritime scene (open sea/clear sky) and the simulation of laser light reflected at the sea surface. The basic sea surface geometry is modeled by a composition of smooth wind driven gravity waves. The propagation model for water waves is applied for sea surface animation. To predict the view of a camera in SWIR the sea surface radiance must be calculated. This is done by considering the emitted sea surface radiance and the reflected sky radiance, calculated by MODTRAN. Additionally, the radiances of laser light specularly reflected at the wind-roughened sea surface are modeled in SWIR considering an analytical statistical sea surface BRDF (bidirectional reflectance distribution function). This BRDF model considers the statistical slope statistics of waves and accounts for slope-shadowing of waves that especially occurs at flat incident angles of the laser beam and near horizontal detection angles of reflected irradiance at rough seas.

Simulation results are presented showing the variation of the detected laser power dependent on the geometric configuration of laser, sensor and wind characteristics.

8014-26, Session 8

SMART and SMARTI: visible and IR atmospheric radiative transfer libraries optimized for wide-band applications

V. Ross, AEREX avionique inc. (Canada); D. Dion, Jr., Defence Research and Development Canada (Canada)

A new C++ library for radiative transfer calculations in the visible and infrared bands which uses MODTRAN as a primary source for atmospheric optical parameters has been developed at Defense R&D Canada, Valcartier (DRDC Valcartier). The main benefit of the library is its capability to perform fast wide spectral band calculations with an appreciably high accuracy. Coherent calculations on wide bands are made possible by using a modified version of the correlated-k theory. The main features of the library are discussed, and comparisons with conventional spectral MODTRAN 4 calculations are presented. It is shown that the library is capable of producing band results that are usually within 5% of MODTRAN 4 with computation times that are thousands of times faster.

8014-27, Session 8

Simulation of a laser range-gated SWIR imaging system in weak turbulence conditions

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Active imaging systems, including laser range-gated short wave infrared (LRG SWIR) systems, are currently being developed to increase the identification range performance of ground-to-ground electro-optical targeting systems. These systems have several distinct technological and practical advantages over passive systems, but they also suffer from peculiar phenomena. This paper reports on the development of a simulation of a LRG SWIR imaging system that includes the principal phenomena of scintillation, distortion, blurring and speckle. Although the simulation is restricted to weak turbulence conditions, it is much less computationally expensive than typical phase-screen simulation techniques. The results of the simulation are compared with those from field collections using simple targets from both down- and up-range locations using appropriate statistical metrics. Finally, the simulation is applied to a standard target set and the results of a human perception experiment are compared with those from a parametric performance model.

8014-28, Session 8

Computer simulation of image degradations by atmospheric turbulence for horizontal views

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The development and implementation of a computer model to simulate the impact of atmospheric turbulence on image quality for a passive imaging system is presented. The presented model is an empirical one based upon the analysis of imaging distortions in real image sequences recorded under different atmospheric conditions. Only horizontal views are considered, which are typical for a ground to ground application.

The computer simulation uses pristine, single images (showing no turbulence effects) as input and produces image sequences that are degraded by the specified turbulence. The implemented method can be applied for instance to the images calculated by any existing imaging simulation tool of a passive camera in a post processing step. Imagers with high frame rates can be simulated. The simulation results for a medium and a strong turbulent condition are compared to field data collected by Germany during the NATO-RTG40 White Sands Missile Range field trials of November 2005.

An important feature of the presented simulation method is the consideration of the range information, which is the viewing distance to an object, or in other words, the length of the optical propagation path. In contrast to the usual way how turbulence is included into imaging simulations by assuming only a single viewing distance for all parts of a scene, different range information for different image areas can be used in our simulation. Such spatially high resolved range information can be for instance easily calculated for synthetic scenarios by computer graphics tools. Examples are presented showing the advantages of the range dependent turbulence simulation.

The presented simulation method is fast in terms of computing time and well suited for real-time simulations using the computing power of nowadays graphics processors.

8014-29, Session 8

Spatial and temporal variability of SWIR air glow measurements

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It is well known that luminance from photo-chemical reactions of hydroxyl ions in the upper atmosphere (~85 km altitude) produces a significant amount of night time radiation in the short wave infra-red (SWIR) band between 0.9 and 1.7 m wave length. The phenomenon, often referred to as air glow or sky glow, has been demonstrated as an effective illumination source for passive low light level night time imaging applications. It addition it has been shown that observation of the spatial and temporal variations of the illumination can be used to characterize atmospheric tidal wave actions in the sky glow region. These spatio-temporal variations manifest themselves as traveling wave patterns whose period and velocity are related to the wind velocity at 85 km as well as the turbulence induced by atmospheric vertical instabilities. In this paper we present nearly a year of sky glow observations over the whole sky, showing long term and short term fluctuations to characterize SWIR night time image system performance.

8014-30, Session 9

Statistics of the point spread function for imaging through turbulence

M. I. Charnotskii, Zel Technologies, LLC (United States)

We use a rigorous Markov approximation-based propagation model to calculate statistical properties of the instantaneous turbulent point spread function (PSF) for the weak and strong turbulence condition. Long-Term PSF is well known and is currently widely used for the estimates of the optical system performance and simulation of the image distortions caused by turbulence. We discuss some peculiarities of the Long-Term PSF that are related to the specifics of the propagation in turbulence, and are overlooked in the recent literature. We calculate the variances of the total power in the instantaneous PSF and the Strehl ratio at the average PSF center, and correlation between the total power and the Strehl ratio. This information allows modeling the instantaneous PSF with random width and height.

The next level model accounts for the random displacements of the instantaneous PSF (image warping). We use the results of (Charnotskii, JOSA A, 1993) where the average Short-Term PSF was calculated based on the rigorous Markov approximation technique with better accuracy than conventionally used (Fried, JOSA 1966) theory, and extend the Charnotskii 1993 technique to calculate the variance of the Strehl ratio at the PSF random centroid, and correlations between the instantaneous values of the PSF wander, total power and Strehl ratio. This analysis provides information for modeling the instantaneous PSF as bell-shaped curve with random position, width and height. Our models are valid for weak and strong scintillation conditions in the aperture plane, and for the large and small ratios of the wave coherence radius to the aperture size.

8014-31, Session 9

CART V: recent advancements in computer-aided camouflage assessment

T. Müller, M. Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

In order to facilitate systematic, computer aided improvements of camouflage and concealment assessment methods, the software system CART (Camouflage Assessment in Real-Time) was built up for the camouflage assessment of objects in multispectral image sequences (see contributions to SPIE 2007-2010). It comprises a semi-automatic marking of target objects (ground truth generation) including their propagation over the image sequence and the evaluation via user-defined feature extractors as well as methods to assess the object's movement conspicuity.

In this 5th part in an annual series at the SPIE in Orlando, this paper presents the enhancements over the recent year and addresses the camouflage assessment of static and moving objects for image data that can show noise or image artefacts. The presented methods fathom the correlations between camouflage assessment, MTI (moving target indication) and image processing. As the results show, the improvements extend the evaluation methods significantly to a broader application range.

8014-32, Session 9

A simple physical model for simulating turbulent imaging

G. Potvin, J. L. Forand, D. Dion, Jr., Defence Research and Development Canada (Canada)

We show how to simulate realistic looking turbulent imagery using only two scalar fields, from which we derive a Gaussian and non-isoplanatic Point-Spread Function (PSF). The first field controls mainly scintillation effects, while the second principally controls image displacements. The model is designed for weak turbulence and is based on the first-order Rytov theory for propagation through turbulence. We explain the physical principles behind the model and justify them using empirical evidence.

8014-33, Session 9

MATISSE-v2.0: new functionalities and comparison with MODIS satellite images

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MATISSE (Advanced Modeling of the Earth for Environment and Scenes Simulation) is an infrared background scene generator developed for computing natural background spectral radiance images. The code also provides atmospheric radiative quantities along lines of sight. Spectral bandwith ranges from 0.4 to 14 m. Natural backgrounds include atmosphere, sea, land and high and low altitude clouds. The new version MATISSE-v2.0, released this year, has been designed to treat spatial multi resolution in the generated images in order to be able to reach metric spatial variability in pixels fooprints. Moreover, MATISSE-v2.0 includes a new sea surface radiance model (water waves and surface optical properties) which depends on wind speed, wind direction and fetch value. Preliminary validations using radiometric mesurements have been conducted concerning sea radiances and give promising results. In order to go further in the validation process of MATISSE-v2.0, comparisons with MODIS satellite images have been carried out. The investigations comprised selected surface structures like sea, desert, mountains and cropland (mixed vegetation). Furthermore, different standard cloud types have been tested. The results on radiance images show a good correlation between original MODIS image and the MATISSE simulation and therefore proof, that the code is performing well.

This paper gives a description of MATISSE-v2.0 new functionnalities and focuses on comparison results between simulated MATISSE radiance images and the MODIS observations.

8014-34, Session 10

3D detector noise revisited

A. Lundmark, Autoliv Electronics AB (Sweden)

The 3D description of noise has since its introduction been extensively utilized for specifying, testing, evaluating and analyzing IR imaging systems. A frequency domain representation approach adds new possibilities by enabling signal-to-noise based analysis in selected frequency regions, e.g. in a system designed to detect pedestrians at a 160 meter distance, the frequency content of the interesting objects can be analyzed and relevant requirements set up on the noise levels in these frequency regions.

We also show how to compute the well-known spatial and temporal noise components, avoiding "spill-over" between the different noise types.

Another aspect of 3D noise estimation is how to avoid low-frequency shading caused by e.g. optics to interfere with the analysis of detector noise. This has traditionally been handled by preprocessing consisting

of fitting a polynomial to the observed data and removing that slowly changing part, or by spatial filtering, but spatial filtering may also reduce the noise, leading to an overoptimistic noise estimate.

In the proposed scheme, the problem is easily handled by avoiding the low frequency components corresponding to shading when computing the 3D noise terms.

The paper gives a detailed description of how to perform calculations, and shows results of frequency analysis on synthetic and real image material.

The main contribution of this work is to enable new ways of specifying requirements on noise and provide a description of how to do the corresponding measurements for the purpose of ensuring system performance.

8014-35, Session 10

MRi dual-band MWIR imaging FTS

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MRi is an imaging version of the ABB Bomem MR Fourier-Transform spectroradiometer. This field instrument generates spectral datacubes in the MWIR and LWIR. It is designed to be sufficiently fast to acquire the spectral signatures of rapid 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.

Overview of the instrument capabilities will be presented. Test results and results from field trials for a configuration with two MWIR cameras will be presented. That specific system is dedicated to the characterization of airborne targets. The two MWIR cameras are used to expand the dynamic range of the instrument and simultaneously measure the spectral signature of the cold background and of the warmest elements of the scene (flares, jet engines exhausts, etc.).

8014-36, Session 10

Design and characterization of an integral uniform radiance source for integral veiling glare testing of optical systems

J. Jablonski, G. A. McKee, C. Durell, Labsphere, Inc. (United States)

An application-specific contracted integrating sphere source of uniform spectral radiance and contrast is described. The source uses the integral method for testing veiling glare index using of telescope optics and imaging systems used is surveillance. The calibration source simulates a situation where the black area and bright surround are at sufficiently great object distance to give measurements of veiling glare index which are the same as that which would result if the distance were infinite.

Design criteria for the integral veiling glare test source are presented. Included is a summary of the end-user specifications in regards to spectral radiance, irradiance levels of attenuation, irradiance stability, and aperture uniformity and contrast. Radiometric theory used to predict the source radiance for a specific spectral flux input is reviewed. Reasoning for the use of an integrating sphere platform for this application and characteristic features of the source are discussed.

Calibration methods and instrumentation are described. The resultant data presented include the modeled data compared with the measured performance. Methods of data reduction and uncertainty are addressed where applicable.

8014-37, Session 10

Confirming the performance of LWIR optical systems: an affordable high-accuracy lens measurement system

S. D. Fantone, D. Orband, J. Zhang, R. Kirschner, Optikos Corp. (United States)

A compact low-cost LWIR test station has been developed that provides real time MTF testing of IR optical systems and EO imaging systems. The test station is intended to be operated by a technician and can also measure the focal length, blur spot size, distortion, and other metrics of system performance. The challenges and tradeoffs incorporated into this instrumentation will be presented.

The test station performs the measurement of an IR lens or optical system's first order quantities (focal length, back focal length) including on and off-axis imaging performance (e.g., MTF, resolution, spot size) under actual test conditions to enable the simulation of their actual use. Also described is the method of attaining the needed accuracies so that derived calculations like focal length (EFL = image shift/tan(theta)) can be performed to the requisite accuracy. The station incorporates a patented video capture technology and measures MTF and blur characteristics using newly available low cost LWIR cameras. This allows real time determination of the optical system performance enabling faster measurements, higher throughput and lower cost results than scanning systems. Multiple spectral filters are also accommodated within the test stations which facilitate performance evaluation under various spectral conditions.

8014-38, Session 10

Blackbody source technology trends

J. A. Mazzetta, S. D. Scoptaz, J. E. Sgheiza, M. A. Medina, Electro Optical Industries, Inc. (United States)

The infrared test equipment industry has matured over the past half century and has historically offered test equipment that met and often exceeded the capabilities of the units under test. The majority of improvements in sources have been iterative instead of revolutionary innovations. However, in recent trends infrared imagers have begun to press the limits of infrared test equipment. Today, infrared imagers incorporate focal plane arrays that offer a significantly higher resolution and sensitivity than their predecessors. Additionally, current infrared imagers are expanding their role in the field and are being developed for a wide variety of applications. These applications demand that optical infrared test equipment begin to fill a larger role. Roles such as: larger, more uniform, higher emissivity emitting surface areas, temperature ranges from cryogenic to sunlight, wide ambient temperature ranges, vacuum ambient conditions, vehicle installation, field portability, computer interface compatibility, applications level software integration, and high off-axis uniformity and emissivity. How does infrared test equipment improve to meet these demands while maintaining excellent uniformity and stability, two of the traditionally most scrutinized specifications? This paper will present specific methods for achieving the rigorous demands for test equipment outlined above, it will present a brief outline of the development and technology trends of blackbody/infrared test equipment over the past 50 years, and finally this paper will discuss the expected development challenges of blackbody/infrared test equipment for near team.

8014-39, Session 10

Calibration and control of a large dynamic range visible source

J. D. LaVeigne, N. Radtke, Santa Barbara Infrared, Inc. (United States)

The use of image intensified (I2) and other low light level devices has grown considerably over the past decade. As the systems have become more common place, a need to provide production line testing has also grown. Accurate measurements of device response are a key part of determining acceptable system operation. However, differences in the spectral response of the UUT devices and the control detector, and the spectral distribution of the source can lead to errors in test accuracy. These errors can be compounded by spectral variation in the source (or color temperature shifts) as a function of attenuation. These issues are often further confused by test system requirements that are not consistent with the desired parameter to be measured. For example, source requirements are often specified in illuminance while the UUT actually measures radiance. We report on the calibration of a large dynamic range system (> 7 orders), and discuss methods to compensate for systems which control in a band different than that which is being tested.

8014-40, Session 11

Removing ths statistical bias from three-dimensional noise measurements

Z. Bomzon, CI Systems (Israel) Ltd. (Israel)

The three dimensional noise model (3D noise) is a widely used model for characterizing noise in thermal imaging system. In this model, a sequence of images of a uniform background are acquired, and organized in a three dimensional matrix. This matrix is then decomposed into eight orthogonal noise components. Each component provides a unique that can be assessed individually to yield an understanding about the magnitude and source of noise in a given system. In particular, two of the noise components calculated using the 3D model can be identified with the Noise Equivalent Temperature Difference (NETD) and Fixed Pattern Noise (FPN), which are classical measures for noise in thermal imagers.

In a previous publication we showed that the estimators used to assess 3D noise are biased statistical estimators, which lead to systematic errors when measuring system noise. The systematic error is especially profound when the dimensions of the 3D matrix acuqired for the noise estimation are small. For instance, if the noise measurements are performed on a region of interest of 50X50 pixels, and 50 images are acquired for the estimation, then the 3D noise model will underestimate the system NETD by about 6%.

In this paper we provide a rigourous mathematical formulation for the 3D noise model. This formulation enables us to redefine the noise estimators in a manner that removes their statistical bias. We demonstrate the unbiased nature of these estimators using Monte Carlo simulatuions and noise measurements performed on thermal imagers.

8014-41, Session 11

A common architecture for TPS development

B. Nehring, A. Irwin, J. D. LaVeigne, Santa Barbara Infrared, Inc. (United States)

Test Program Set (TPS) software development for Electro-Optical (EO) testing has traditionally been an expensive and lengthy process. A major cause of this has been the development of new test executive software on an ad-hoc basis for each program. Furthermore, there have typically been different needs for production versus lab environments with production needing a set of standard tests, while users in a lab environment requiring the capability to modify certain aspects of their tests as needed. At Santa Barbara Infrared, a new architecture for TPS development has been engineered that addresses these concerns. The new architecture can host a complete TPS development environment that eliminates the need for a separate test executive. It supports EO testing in both engineering development and production testing through the use of user editable test scripts along with distinct user accounts and privileges. The new architecture is unit under test (UUT) centric, allowing a user to define UUT parameters once and easily share the results between tests. In this article we will review the new architecture and give examples of TPS development under that architecture.

8014-42, Session 11

SR-5000N: spectroradiometer's new performance improvements in FOV flatness, scan speed, and other important features

D. Cabib, M. Lavi, A. Gil, S. Shapira, CI Systems (Israel) Ltd. (Israel)

CI has been the only manufacturer in the world of commercial visible/infrared spectroradiometers for remote sensing applications for many years. In this paper we describe the new design and many performance improvements that we just developed to renew and modernize the system. Calibration accuracy, field of view flatness of response, scan speed are only a few of the areas which we have significantly improved in the system. An important factor in the success of this endeavor is the development of the Circular Variable Filter (CVF) production capability developed recently by the company and presented in a parallel paper, since this is a critical component of the system.

8014-43, Session 11

Increased responsivity pyroelectric radiometer with dome input and temperature control

G. P. Eppeldauer, J. Zeng, L. M. Hanssen, National Institute of Standards and Technology (United States)

The $LiNbO_3$ pyroelectric radiometer standard developed at NIST earlier has a dome-input for increased absorption and a noise equivalent power (NEP) of 50 nW/rootHz [1]. Due to the large NEP, this radiometer can be used only with laser sources. Since monochromator-based sources are the best choice for routine spectral responsivity calibrations in the broad infrared wavelength range, a new pyroelectric radiometer standard with low-NEP had to be developed. The low-NEP was needed to get large signal-to-noise ratios at the monochromator output where the maximum power is only a couple of microwatts.

A thin $LiTaO_3$ pyroelectric crystal with an organic black coating and a current-to-voltage converter were put together in a compact detector arrangement. The thickness of the crystal was decreased to 25 micrometer to obtain increased detector responsivity. This compact detector arrangement is located in the center of a reflecting dome and its temperature is stabilized using a thermistor and a thermoelectric (TE) cooler/heater. The operating temperature is tuned slightly above the room temperature to avoid condensation. The 7 mm diameter crystal collects most of the reflected radiation from the internal wall of the dome. The dome is made from Pyrex-glass and it is coated inside with a gold layer which has high reflectance in a broad spectral range. The reflecting dome is designed to produce multiple input reflections to increase the detector-absorption and to minimize the structures of the spectral responsivity function. The spectral structures depend on the optical properties of the crystal coating. The geometrical design to increase absorption is especially important at long wavelengths where the coating-reflectance is significantly higher than at short wavelengths. The manually processed coating (paint) introduces a frequency-compensation that results in a constant signal-gain to about 100 Hz. This compensation and the lowered stray capacitance (parallel to the feedback resistor) in the compact detector arrangement made it possible to increase the feedback resistor from 1 Gohm to 10 Gohm. The responsivity increase of the detector was influenced by the increased capacitance of the thin crystal. The higher capacitance caused some noise-boosting to the output of the current-to-voltage converter. A responsivity of 1.6 microamp/watt was measured for the prototype detector at 633 nm using a chopping frequency of 10 Hz. This value is significantly higher than the 0.33 microamp/watt responsivity of our earlier developed LiNbO3 dome-input pyroelectric radiometer standard [1]. The improvement is even better compared to the 0.105 microamp/watt responsivity of our earlier developed single-element LiNbO3 pyroelectric detector-standard [2].

The newly developed dome-input pyroelectric radiometer has been characterized in detail. The noise performance was tested and the absolute responsivity was measured at a few wavelengths. The noise-equivalent-power was determined. The spectral reflectance from the near-IR to 14 micrometers was measured to determine the relative spectral responsivity. The spatial uniformity of responsivity was measured as well.

References

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8014-44, Session 11

Fast MTF and aberrations analysis of MWIR and LWIR imaging systems using quadri wave interferometry

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

In the last years, infrared imaging has known a rapid expansion due to its increasing applications (intelligence gathering, security issue, thermography). High-performance systems require high precision control systems, particularly in optical metrology. Though MTF remains a standard for objective qualification, it does not quantitatively diagnose possible defects of the analyzed objective (misalignment, inadequate aspherization, ...). 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 is only composed of a specific diffractive grating placed in front of a focal plane array. On the bench, the objective is illuminated by a source point (black body or laser radiation) at a finite or infinite position. The sensor is then placed in the divergent beam, a few millimeters after the focal spot, and analyzes the wave front transmitted by the objective. The aberration function is then deduced from this wave front. The MTF is recovered from the aberration function by numerical analysis. It is given with a high precision for all directions with a single wave front acquisition. 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. Experimental analysis and comparison to theoretical values of optical components will be discussed.

8014-45, Poster Session

Dual-wavelength transfer standard for laser peak-power measurement

R. Leonhardt, National Institute of Standards and Technology (United States); D. King, Naval Surface Warfare Ctr. Corona Div. (United States)

The National Institute of Standards and Technology (NIST) and the Naval Surface Warfare Center - Corona Division (NSWC) have jointly developed a low-level peak-power radiometer that functions as a transfer standard for measuring laser pulses at wavelengths of 1.06 and 1.55 µm. The peak-power irradiance range is from 500 pW/cm2 to 50 µW/cm2 within the wavelength range of 1.54 to 1.58 µm. A similar peak-power range is covered at a wavelength of 1.06 µm. The measurement range is covered by using smaller apertures or a neutral density filter to reach the highest peak-powers. The radiometer is based on a custom fabricated InGaAs avalanche photodiode (APD) detector/preamplifier module. The light collecting optical system has a maximum aperture of approximately 125 cm2. The radiometer is able to measure Gaussian pulse durations from 4 to 400 ns. The output is a negative going pulse waveform and the peak voltage is measured with an oscilloscope. The total uncertainty of the calibrated radiometer is approximately 9% (coverage factor k=2).

8014-46, Poster Session

Field performance evaluation for Heliborne FLIR systems by the devised conversion methodology

K. T. Han, Agency for Defense Development (Korea, Republic of)

The conversion methodology for the field performance of an HFLIR(heliborne FLIR) has been established to reasonably evaluate the detection and identification ranges, where the conversion from the performance at test condition to that at evaluation criteria is made. By analyzing the FLIR performance model based on Johnson criterion, the model factors to system performance are derived as follows: the bar target size, the temperature difference between black and white bar, the atmospheric transmittance, the background temperature, the instability involved system MRT requirement, and so on. Then, their sensitivities to total field performance are investigated to set up the test and evaluation procedures.

With this conversion methodology, the detection and recognition ranges of HFLIRs on UH-60 and HH-47 helicopters are measured and evaluated to check the performances to the requirement of capability(ROC). To do these, firstly the test procedures and relevant necessities are in detail determined by considering the evaluation criteria and the helicopter flight paths with respect to test targets. Secondly the two measured ranges are converted into the ones at ROC conditions with the help of the conversion methodology, and then they are compared to those in ROC for evaluation. As for HFLIR on UH-60, the detection and recognition ranges turn out to be respectively longer with big margins than those in ROC criteria, and so do those for HFLIR on HH-47. From these research results, one can apparently see that all the field performances for the two HFLIRs meet the top level requirements in ROC. Meanwhile, the proposed evaluation method is convinced to be applicable to any types of IR camera systems.

8014-47, Poster Session

SIFT-based localization and tracking in IR imaging system

C. Park, Samsung Thales Co., Ltd. (Korea, Republic of)

In this paper, we deal with real-time intelligence tracking of moving dim point object in open and unknown environments for an infrared (IR) and visible (VIS) vision system. Moving dim point object in cluttered real-world scenes requires localization that are unaffected by nearby clutter or partial occlusion. The problems of localization can be classified as either global or local localization. We propose an approach that can reduce the feature extraction time in scale invariant feature extraction (SIFT). The main idea is to search for the key-points around a set of randomly generated particles rather than to perform exhaustive search in the whole difference of Gaussian pyramid. The proposed method makes it possible to define the required number of key-points in advance. Proposed method consists of two stages. First, we must localize the interest point in position and scale of moving dim point objects based on facet-based filter. Second, we must build a description of the interest point and tracking moving dim point objects. Experimental result, the proposed method can acquired real-time intelligence tracking and high recognition rate. We also present results showing that using these descriptors in an image retrieval application results in increased accuracy and faster matching.

8014-48, Poster Session

Laboratory for testing electro-optical surveillance systems

K. Chrzanowski, Military Univ. of Technology (Poland)

Equipment for testing electro-optical surveillance systems (thermal imagers, CCD/CMOS/ICCD/EBAPS cameras, night vision goggles, night vision sights, laser range finders/designators/illuminators, multi-sensor imaging systems) and basic modules of such systems (optical modules, image intensifier tubes, IR FPA sensors, CCD/CMOS/ICCD/EBAP sensors, SWIR sensors) has been developed during last several decades in about a dozen of scientific/industrial centers and such test equipment is commercially available. However, the test equipment for testing all the mentioned above surveillance systems/components can be get only from several commercial sources (at least 3-4 sources). This situation creates technical problems to develop a fully integrated laboratory for testing electro-optical systems/components as commercial test systems were not developed to cooperate.

A modern laboratory capable to carry out expanded tests of all types of electro-optical surveillance systems and basic modules of such systems was developed and is presented in this paper. The laboratory can be treated as a both scientific and technical achievement due to its several features. First, all important parameters of modern electro-optical surveillance systems or parameters of basic modules of such surveillance systems can be measured. Second, the laboratory is built using a wide set of modules. This modular concept enables easy creations of many versions optimized for different applications from simple versions optimized for beginner users of electro-optical systems to sophisticated versions optimized for highly experienced manufacturers of these surveillance systems. Third, interpretation of the measurement data is supported by a set of specialized computer programs, including computer simulators of thermal imagers, TV cameras, and night vision devices.

8014-49, Poster Session

Precision centering error measurement of assembled IR optics in the wavelength range from 3-5 and 8-12µm

J. Heinisch, H. Pannhoff, Trioptics GmbH (Germany)

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. Once the optics is assembled it is difficult to find the cause of a bad imaging quality. TRIOPTICS developed a special centring error measurement system to measure the centring error of each surface with respect to a given mechanical reference axis. The main component of this equipment is an electronic autocollimator designed for the IR range. Additionally the setup is equipped with a focusing mechanism and a high precision rotation axis. This rotation axis serves as a reference axis for measurement. This device enables the operator to measure the tilt of all optical surfaces without touching and destroying the sample. Even in case the surface under test is inside of the optical assembly. The optical setup will be described and measurement results of an IR sample will be displayed.

8014-50, Poster Session

Feasibility analysis and demonstration of high-speed digital imaging using micro-arrays of vertical cavity surface-emitting lasers

M. A. Mentzer, U.S. Army Aberdeen Test Ctr. (United States)

Previous laser illumination systems at Aberdeen Proving Ground (APG) and elsewhere required complex pulse timing, extensive cooling, large-scale laser systems (frequency-doubled flash-pumped Nd:YAG, Cu-vapor, Q-switched ruby), making them difficult to implement for range test illumination in high speed videography. Requirements to illuminate through the self-luminosity of explosive events motivate the development of a high brightness imaging technique obviating the limitations of previous attempts. Vertical Cavity Surface-Emitting Laser (VCSEL) arrays and a lens system are proposed with temporal and spectral filtering to effectively remove self-luminosity and fireball from the image, providing excellent background discrimination in a range of range test scenarios.

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8015-01, Session 1

IR emitter non-uniformity correction (NUC): making sense of the data

J. Oleson, Oleson Convergent Solutions LLC. (United States); B. A. Sieglinger, R. J. Rapp, Air Force Research Lab. (United States); D. Greer, Naval Air Warfare Ctr. Aircraft Div. (United States)

Several organizations in the government and industry are actively developing IR emitter array nonuniformity correction (NUC) algorithms. While significant effort has been expended and respectable progress has been made, there are no comprehensive metrics for describing post NUC emitter nonuniformity. Subsequently, the nonuniformity data reported by one organization is not comparable with data from another. Further, the sigma/mean uniformity values typically reported do not shed light on fixed pattern noise such as row and column offsets. This current state of NUC reporting does not give a customer adequate insight into the value of emitter nonuniformity correction.

This paper establishes metrics for measuring and reporting IR emitter array nonuniformity. The metrics established here allow data from one measuring organization to be directly comparable with that of another. Further, more practical aspects of nonuniformity correction are addressed which shed light on issues such as fixed pattern noise, emission gradients and other undesirable artifacts. Data analysis techniques described in this paper demonstrate the new metrics and their descriptive role in the NUC process. The NUC parameters established here characterize the ability of IR emitter arrays to accurately represent terrestrial scenes as well as hot objects and plumes. This paper also explores areas in the emitter dynamic range that provide special challenges for generating a NUC table and their influence in selecting nonuniformity correction radiance levels.

8015-02, Session 1

IR imaging bundles for HWIL testing

B. Shaw, D. J. Gibson, U.S. Naval Research Lab. (United States); G. Farrar, Univ. Research Foundation (United States); R. Gattass, V. Q. Nguyen, J. S. Sanghera, I. D. Aggarwal, U.S. Naval Research Lab. (United States)

We report on the development of infrared imaging bundles in the MWIR for HWIL testing. The IR imaging bundles are fabricated from IR transmitting chalcogenide fiber. Fiber geometry is square cladding with round center core for form square registered arrays to match the square registered pattern of scene projector arrays and sensors. Currently, 64 x 64 element arrays are being fabricated with the goal of 512 x 512 elements. The bundles have a pixel pitch (distance between cores) of 48 µm. Cross-talk measurements show <1% cross-talk between pixels.

8015-03, Session 1

MWIR LED performance enhancement by nano-plasmon layer

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

Recently, there has been great interest in using infrared light emitting diode (LEDs) devices as light sources for IR scene projection experiments. There exist various techniques to improve the out-coupling of IR light from GaSb substrate including grating [1], antireflection coating [2] and sloped mesa structure [3]. However, recently there are increased interests to use nano meter (nm) scale surface plasmon layer to increase the light emission efficiency of LED devices [4]. In this paper we report the enhancement of LED emission power by 100% due to the presence of nano-plasmonic Au layer deposited by e-beam evaporation technique.

The IC LED structure was grown by molecular-beam epitaxy on an n-type GaSb substrate. After growing a 1.0 m p+ GaSb bottom contact layer, the MWIR IC LED structure was grown containing 9 period active/injection regions. Finally a 1.4 m p+ GaSb top contact and grating formation layer was grown. Each active/injection period includes an asymmetric InAs/Ga1-xInxSb/InAs "W" quantum well preceded by an n-type digitally graded InAs/AlSb super lattice injector.

The LED fabrication process starts with reactive ion etching of a top mesa area with different sizes. After silicon nitride deposition for mesa isolation, Ti/Au metal layer was deposited. Finally a 20 nm Au nano-plasmon layer was layer deposited by e-beam technique. The black body emission temperatures of both plasmon and standard devices are shown in figure 1. Plasmon device has about 30% higher emission power compared to standard device. In figure 2, we have shown the spectra of light emission for device with different injection currents. We observed higher light intensity for plasmon devices compared to standard devices.

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8015-04, Session 1

Contrast analysis for DMD-based IR scene projector

J. Rentz Dupuis, D. J. Mansur, 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. In this paper we present a detailed analysis of the contrast of our MWIR DMD-based scene projector. A series of factors which affect the overall contrast are modeled and design approaches to address the worst offenders are presented. In addition, we present methods for meeting the grayscale digitization requirements through the drive electronics.

8015-05, Session 1

Multispectral polarized scene projector (MPSP)

L. Li, Kent Optronics, Inc. (United States)

This newly developed prototype Multispectral Polarized Scene Projector (MPSP), configured for the short wave infrared (SWIR) regime, can be used for the test & evaluation (T&E) of spectro-polarimetric imaging sensors. The MPSP generates both static and video images (up to 200

Hz) with 512x512 spatial resolution with active spatial, spectral, and polarization modulation with controlled bandwidth. It projects input SWIR radiant intensity scenes from stored memory with user selectable wavelength (850-1650 nm) and bandwidth (12-100 nm), as well as polarization states (six different states) controllable on a pixel by pixel basis. The system consists of one tunable liquid crystal spectral filter with variable bandpass, and multiple liquid crystal on silicon (LCoS) spatial modulators for intensity control and polarization modulation. In addition to the spectro-polarimetric sensor test, the instrument also simulates polarized multispectral images of military scenes/targets for hardware-in-the loop (HIL) testing.

8015-06, Session 1

System for driving 2D infrared emitter arrays at cryogenic temperatures

C. Lange, R. McGee, F. E. Kiamilev, Univ. of Delaware (United States)

Large IR detector arrays, particularly ones intended for military and aerospace applications, are often difficult and expensive to directly test. These detectors require an IR projector for scene simulation. Recently there has been increased interest and development of semiconductor-based infrared (IR) LED-based emitter array devices (e.g. SLEDS), due to their ability to produce higher apparent temperatures, lower background temperatures, and much faster rise and fall times than thermal emission techniques. These devices flip-chip a large CMOS driver chip onto a two-dimensional array of IR emitter devices typically fabricated on a GaSb substrate. Several testing sessions showed the unique functionality and capabilities in several important areas such as: apparent temperature exceeding 1000 Kelvin, rise and fall time of 3-4 microseconds, and low apparent background temperatures.

Our involvement in SLEDs development has demonstrated need for aggressive thermal management. We found that most commercially available systems can remove a few watts at cryogenic temperatures and cooling technology based on water systems would not function at 77K. Additionally, even systems that can remove a large amount of heat still allow a high amount of temperature rise. This is because of the thickness of the metal that couples the device to the heat sink.

In the talk, we will describe our efforts to develop a RIIC capable of driving a large SLEDs array (e.g. 4cm x 4cm CMOS die size with 512x512 pixels), a custom cryogenic package for the array, and a top-level cryogenic testing and IR detection system.

8015-07, Session 2

Integrated optical payload simulator

J. Lee, S. Ryoo, Kongju National Univ. (Korea, Republic of); D. Seo, J. Yang, Korea Aerospace Research Institute (Korea, Republic of)

The importance on the simulation of earth observation optical payloads has been recently emphasized in order to estimate on-orbit imaging performance of the payloads. The estimation should consider all aspects of payload development; design, manufacture, test, assembly, launch and space environment. Until recently several studies have been focused the evaluation of the individual factors rather than the integrated. This paper presents the development of an integrated payload simulator, which generates realistic artificial remote sensing images as taken by defined earth observation payloads. The simulator considers the imaging performance of the payload, geodynamical behavior of the satellite and some aspects of the altitude variation of the earth surface. The simulator is developed for the use of evaluating pre- and post-launch imaging performance and assisting on-board calibration of the KOMPSAT3 optical payload.

8015-08, Session 2

Allegany Ballistics Lab.: Sensor Test Target System

D. Eaton, Naval Surface Warfare Ctr. Indian Head Div. (United States)

Leveraging the Naval Surface Warfare Center, Indian Head Division's past experience in weapon simulation, Naval Sea Systems Command commissioned development of a remote-controlled, digitally programmable Sensor Test Target as part of a modern hardware-in-the-loop test system for ordnance-related guidance, navigation and control systems. The overall Target system design invokes a sciences-based, "design of automated experiments" system approach. This enables operating modes that employ broad spectrum electromagnetic energy in many a desired combination, variably generated using a Jet Engine Simulator, a multispectral infrared emitter array, optically enhanced incandescent Flare Simulators, Emitter/Detector Pods, and an RF corner reflector kit. As assembled, the recently tested Sensor Test Target prototype being presented can capably provide a full array of useful RF and infrared target source simulations for RDT&E use with developmental and existing sensors. Certain Target technologies are patent pending, with potential spinoffs in aviation, metallurgy and biofuels processing, while others are variations on well-established technology.

Planned for extended installation at Allegany Ballistics Laboratory (Rocket Center, WV), of particular interest is Sensor Test Target system's capacity to provide a comprehensive target simulation test bed in a countermeasures environment, and do so with rapidly reconfigurable equipment to reduce the logistics costs of using live action test ranges.

8015-09, Session 2

Missile airframe simulation testbed: MANPADS (MAST-M) for test and evaluation of aircraft survivability equipment

J. L. Clements III, U.S. Army Aviation and Missile Command (United States); R. M. Robinson, J. Robinson, The AEgis Technologies Group, Inc. (United States)

A number of techniques have been utilized to evaluate the performance of Aircraft Survivability Equipment (ASE) against threat Man-Portable Air Defense Systems (MANPADS). These techniques include flying actual threat MANPADS against stationary ASE with simulated aircraft signatures, installed systems testing of ASE against simulated threat signatures, and laboratory hardware-in-the-loop testing with simulated aircraft and simulated missile signatures. All these tests lack the realism of evaluating installed ASE against in-flight MANPADS on a terminal homing intercept path toward the actual ASE equipped aircraft. This limitation, driven primarily by the availability and expense of the ASE, is due primarily to the current inability to perform non-destructive MANPADS/Aircraft flight testing. The U.S. Army Aviation and Missile Research and Development and Engineering Center (AMRDEC) is working to overcome this limitation with the development of a recoverable surrogate MANPADS missile system capable of engaging aircraft equipped with ASE while guaranteeing collision avoidance with the test aircraft. Under its Missile Airframe Simulation Testbed - MANPADS (MAST-M) program, the AMRDEC is developing a surrogate missile system which will utilize actual threat MANPADS seeker/guidance sections to control the flight of a surrogate missile which will perform a collision avoidance and recovery maneuver prior to intercept to insure non-destructive test and evaluation of the ASE and reuse of the MANPADS seeker/guidance section. The remainder of this paper provides an overview of this development program and intended use.

8015-10, Session 2

Rapid common hardware-in-the-loop development

H. J. Kim, U.S. Army Research, Development and Engineering Command (United States); S. Moss, The AEgis Technologies Group, Inc. (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. With increased microprocessor speed, FPGA capacity and increased bus bandwidth, a common interface design can support a large number of HWIL interfaces that required custom designs in the past.

The U.S. Army Research, Development and Engineering Command (RDECOM) Aviation and Missile Research, Development and Engineering Center (AMRDEC) is 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 employ 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.

Keywords: hardware-in-the-loop, real-time, synthetic environment, simulation, FPGA, network, architecture, cost-reduction

8015-11, Session 3

Calibration and deployment of a new NIST transfer radiometer for broadband and spectral calibration of space chambers (MDXR)

T. M. Jung, Jung Research and Development Corp. (United States); A. C. Carter, Booz Allen Hamilton Inc. (United States); S. I. Woods, S. G. Kaplan, National Institute of Standards and Technology (United States)

The Low-Background Infrared (LBIR) facility at NIST has performed on-site calibration and initial off-site deployments of a new infrared transfer radiometer with an integrated cryogenic Fourier transform spectrometer (Cryo-FTS). This mobile radiometer can be deployed to customer sites for broadband and spectral calibrations of space chambers and low-background hardware-in-the-loop testbeds. The Missile Defense Transfer Radiometer (MDXR) has many of the capabilities of a complete IR calibration facility and replaces our existing filter-based transfer radiometer (BXR) as the NIST standard detector deployed to customer facilities. The MDXR features numerous improvements over the BXR, including: a cryogenic Fourier transform spectrometer, an on-board absolute cryogenic radiometer (ACR), an internal blackbody reference, and an integrated collimator. The Cryo-FTS can be used to measure high resolution spectra from 4 to 20 micrometers, using a Si:As blocked-impurity-band (BIB) detector. The on-board ACR can be used for self-calibration of the MDXR BIB as well as for absolute measurements of infrared sources. A set of filter wheels and a rotating polarizer within the MDXR allow for filter-based and polarization-sensitive measurements. The optical design of the MDXR makes both radiance and irradiance measurements possible and enables calibration of both divergent and collimated sources. Results of on-site calibration of the MDXR using its internal blackbody source and an external reference source will be discussed, as well as the performance of the new radiometer in its initial deployments to customer sites.

8015-12, Session 3

Development of technologies for imaging sensor testing at AEDC

H. Lowry, Aerospace Testing Alliance (United States)

Arnold Engineering Development Center (AEDC) is involved in the development of technologies that enable Hardware in the Loop (HWIL) testing with high-fidelity complex scene projection to validate sensor mission performance. Radiometric calibration with the NIST BXR and MDXR has improved radiometric and temporal fidelity testing in this cold background environment. The development of hardware and test methodologies will 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.

8015-13, Session 3

Fine range-motion simulation for hardware-in-the-loop testing of monostatic-pulsed LFM radars

R. F. Olson, Jr., U.S. Army Aviation and Missile Command (United States)

Frequency stepping is an established technique for increasing the range resolution of pulsed Linear Frequency Modulation (LFM, or chirp) radar waveforms. When a monostatic radar system employs this waveform for increased range resolution measurements on an object with motion relative to the radar platform, simple changes in the received waveform arise, requiring fine motion compensation on a per-pulse basis. These motion effects include phase, frequency and frequency slope offsets which vary according to the transmitted pulse frequency and frequency rate, and the object range and range rate. All three offsets are easily compensated by complementary offsets in Direct Digital Synthesizer outputs used to form frequency conversion LO signals in the radar receiver. Radars employing stepped frequency LFM waveforms may be tested in a Hardware-in-the-Loop (HWIL) facility in simulations involving scenes or objects with radar-relative motion. Under these conditions, the motion effects on the radar receiver input signals must be accurately computed, synthesized and must modify the transmit signal prior to its return to the receiver. Engineers at the U.S. Army AMRDEC Advanced Simulation Center have developed signal processing techniques for accurate simulation of fine range motion effects to support HWIL testing of pulsed LFM radar systems. This paper provides an analysis of the signal processing involved for a simple model of an HWIL RF signal generation chain. Requirements for HWIL RF signal delay control and fast time phase modulation timing accuracy are developed. Finally, some results are presented from successful application of the motion simulation methods in an HWIL test setting.

8015-14, Session 4

DRDC's approach to IR scene generation for IRCM simulation

J. Lepage, Defence Research and Development Canada

Return to Contents

(Canada); M. Labrie, É. Rouleau, J. Richard, LTI Informatique et Génie (Canada); V. Ross, AEREX avionique inc. (Canada); D. Dion, Jr., N. Harrison, Defence Research and Development Canada (Canada)

An object oriented simulation framework called KARMA has been developed over the last years at Defence Research and Development Canada - Valcartier to study IR countermeasures (IRCM) methods and tactics. It provides a range of IR guided weapon engagement services from constructive to HWIL simulations. To support the increasing level of fidelity of its seeker models, DRDC Valcartier has recently developed an IR scene generation (IRSG) capacity for the KARMA framework. The approach relies on Open-Source based rendering of scenes composed of 3D models, using commercial off-the-shelf (COTS) graphics processing units (GPU) of standard PCs. The objective is to produce a high frame rate and medium fidelity representation of the IR scene, allowing to properly reproduce the spectral, spatial, and temporal characteristics of the aircraft's and flare's signature. In particular, the OpenSceneGraph library is used to manage the 3D models, and to send high level rendering commands. The atmospheric module allows for accurate, run-time computation of the radiative components using a spectrally correlated wide-band mode. Advanced effects, such as surface reflections and zoom anti-aliasing, are computed by the GPU through the use of shaders. Also, in addition to the IR scene generation module, a signature modeling and analysis software tool (SMAT) has been developed to help the modeler in building and validating signature models that are independent of the particular sensor type. Details of the IR scene generation module and associated modeling tool will be presented.

8015-15, Session 4

Real-time maritime scene simulation for LADAR sensors

C. L. Christie, E. T. Gouthas, L. Swierkowski, Defence Science and Technology Organisation (Australia)

The continuing advancement in laser and sensor technology stimulates the growing interest in LADAR sensors for both military and commercial applications. The complex signal processing in dynamic environment required for many of the applications motivates continuing efforts to develop cost-effective synthetic environments for testing LADAR sensors. An important part of such environments is a scene generation system capable of generating frames of LADAR scenes in real time.

In this paper we describe a PC-based system for real-time LADAR scene simulation of ships and small boats in dynamic maritime environment. In particular, we describe the techniques employed to generate the range images that are properly affected by transmission, reflection and emission effects, and which are accompanied by radiometrically valid radiance images. The current LADAR scene generation system is a further extension of our maritime simulation program for generating IR seeker scenery and includes all previous features like the simulation of ocean surfaces in different sea states, the physically-realistic representation of boat and ship dynamics, wake generation and generation of surface effects including whitecaps, spray, wake trails and foam. This paper outlines the development, capabilities and limitations of the new scene generation system.

8015-16, Session 4

High-fidelity real-time maritime scene rendering

T. M. Taczak, Applied Technology Inc. (United States); H. S. Shyu, U.S. Naval Research Lab. (United States); K. Cox, Space/Ground System Solutions, Inc. (United States); C. P. Cahill, Envisioneering, Inc. (United States); C. G. Maraviglia, R. E. Gover, U.S. Naval Research Lab. (United States)

High-fidelity rendering of ships and small vessels in maritime and littoral environments is challenging due to the complexity and random (chaotic) dynamics of the scene, the strong influence of the background on the signature of the targets of interest, and the long distances over which engagements occur that result in sub-filled pixels. Some real-time IR scene rendering techniques (REF) have attempted to approximate sea surface clutter using OpenGL and GPUs to render sea surface scenes using texture maps applied to sea surface facets. This technique will inherently render the sea surface clutter with incorrect temporal and spatial statistical characteristics. Additionally, issues with rendering subpixel bright sources will frequently bias the range at which targets can be detected and tracked.

The Naval Research Laboratory (NRL) reports on a new real-time analytical technique for rendering radiometrically accurate ships in maritime and littoral scenes. The technique uses existing algorithms from the NRL CRUISE_Missiles model that have undergone optimization and parallelization using OpenMP techniques. The code runs on a single dual-quad core Linux box with real-time interfaces to external inputs and output for post processing the imagery.

This paper presents a review of the scene-rendering algorithms, the modifications required to run this code in real time, preliminary performance assessments of the runtimes of the component models, and preliminary analysis of the accuracy of the rendered imagery.

8015-17, Session 4

EO/IR scene generation open source initiative for real-time hardware-in-the-loop and all-digital simulation

D. E. Trimble, The AEgis Technologies Group, Inc. (United States); W. M. Lowry, U.S. Army Redstone Technical Test Ctr. (United States); J. W. Morris, U.S. Army Research, Development and Engineering Command (United States); B. A. Boren, U.S. Army Redstone Technical Test Ctr. (United States); D. H. Bunfield, J. B. Towers, The AEgis Technologies Group, Inc. (United States)

The US Army Aviation and Missile Research and Development Engineering Center (AMRDEC) and the Redstone Test Center (RTC) has formed the Scene Generation Development Center (SGDC) to support the Department of Defense (DoD) open source EO/IR Scene Generation initiative for real-time hardware-in-the-loop and all-digital simulation. Various branches of the DoD have invested significant resources in the development of advanced scene and target signature generation codes. The SGDC goal is to maintain unlimited government rights and controlled access to government open source scene generation and signature codes. In addition, the SGDC provides development support to a multi-service community of test and evaluation (T&E) users, developers, and integrators in a collaborative environment. The SGDC has leveraged the DoD Defense Information Systems Agency (DISA) ProjectForge (https://Project.Forge.mil) which provides a collaborative development and distribution environment for the DoD community. The SGDC will develop and maintain several codes for tactical and strategic simulation, such as the Joint Signature Image Generator (JSIG), the Multi-spectral Advanced Volumetric Real-time Imaging Compositor (MAVRIC), and Office of the Secretary of Defense (OSD) Test and Evaluation Science and Technology (T&E/S&T) thermal modeling and atmospherics packages, such as EOView, CHARM, and STAR. Other utility packages included are the ContinuumCore for real-time messaging and data management and IGStudio for run-time visualization and scenario generation.

8015-18, Session 4

The multispectral advanced volumetric real-time imaging compositor for real-time distributed scene generation

D. H. Bunfield, T. E. Peddycoart, D. E. Trimble, The AEgis

Technologies Group, Inc. (United States); J. W. Morris, G. H. Ballard, U.S. Army Aviation and Missile Research Development and Engineering Ctr. (United States)

AMRDEC has developed the Multi-spectral Advanced Volumetric Real-time Imaging Compositor (MAVRIC) for distributed real-time hardware-in-the-loop (HWIL) scene generation. MAVRIC is a dynamic object-based energy conserved scene compositor that can seamlessly combine distributed scene elements into temporally aligned physics-based scenes for enhancing existing AMRDEC scene generation codes. The volumetric compositing process accepts input independent of depth order. This real-time compositor framework is built around AMRDEC's ContinuumCore API which provides the common messaging interface leveraging the Neutral Messaging Language (NML) for local, shared memory, reflective memory, network, and remote direct memory access (RDMA) communications and the Joint Signature Image Generator (JSIG) that provides energy conserved scene component interface at each render node. This structure allows for a highly scalable real-time environment capable of rendering individual objects at high fidelity while being considerate of real-time hardware-in-the-loop concerns, such as latency. As such, this system can be scaled to handle highly complex detailed scenes such as urban environments. This architecture provides the basis for common scene generation as it provides disparate scene elements to be calculated by various phenomenology codes and integrated seamlessly into a unified composited environment. This advanced capability is the gateway to higher fidelity scene generation such as ray-tracing. The high speed interconnects using PCI Express and InfiniBand were examined to support distributed scene generation whereby the scene graph, associated phenomenology, and the scene elements can be dynamically distributed across multiple high performance computing assets to maximize system performance.

8015-19, Session 5

Analysis of a flight motion controller

T. L. Vu, R. M. Thamm, Defence Science and Technology Organisation (Australia)

Flight Motion Simulators (FMS) play an important role for Hardware-In-The-Loop (HWIL) Simulation of air vehicles and missiles since they are used to simulate the rotational motion of the Unit Under Test (UUT). Hydraulic based FMS have reasonably fast response, however, nonlinearities, such as stiction and nonlinear orifice flow rate, are often inherent in the hydraulic servo valves. The nonlinear effect should be considered when designing a control system for an FMS in order to minimise the impact of the nonlinearity on the dynamic performance of the FMS. Otherwise, the FMS can, in worst cases, start to oscillate if the nonlinearity becomes dominant.

The aims of this paper are firstly to describe the characterisation of an FMS in order to identify the nonlinearities existing in the FMS. As part of the characterisation of an FMS, a nonlinear model of one axis of an FMS was developed in order to analyse and specify a new control system for a FMS.

Secondly, the paper details the requirement specification of a new FMS motion controller in order to achieve the FMS's optimum dynamic performance despite the nonlinearities existing in the system.

Finally, the paper presents a proposed control structure of an FMS motion controller, the role of different control loops and how to tune the compensator in each control loop of an FMS motion controller.

8015-20, Session 5

Novel distributed real-time control system for a target motion simulator

R. Hauser, M. Kägi, D. Gunsch, W. Rindlisbacher, P. Wälti, ACUTRONIC Switzerland Ltd. (Switzerland)

After a short introduction to Flight Motion Simulators (FMS) and Target Motion Simulators (TMS) with the focus on flat frame TMS, the paper presents the difference of this novel approach of a distributed system design compared to the more traditional design for a DTMS control architecture.

In the traditional approach, the control architecture components such as the servo drives, position sensors or digital signals are discretely connected to the control computer. This approach has several disadvantages such as the large wiring effort, limited troubleshooting information or possible noise problems due to long cables.

In the novel approach all the control components are interconnected by an EtherCAT bus. This is an industrial Real Time bus based on Ethernet. By using such a bus, in conjunction with state of the art components, the system design can be simplified and modularized. Demand and feedback data remain in the digital domain and do not have to be converted to analog signals when passing between the components. The sensor data are converted to the digital domain closer to its source. In addition detailed status information of all the components are directly available and can be presented to the user. Using an industrial bus instead of discrete signals the system is still deterministic and behaves Real Time.

This novel design approach is explained using the example of a large scale 10m by 15m DTMS System. It is a 10 degree of freedom Simulator which was successfully built. A few performance data and results will also be shown.

8015-21, Session 5

GPS synchronization of a motion simulator for hardware-in-the-loop applications

J. D. Marchetti, Ideal Aerosmith, Inc. (United States)

A typical hardware-in-the-loop (HWIL) laboratory integrates a wide array of digital equipment, each running from its own internal time-based oscillator. While the various laboratory systems have high-precision oscillators, if no synchronization scheme is employed, then time-based drift between the HWIL components is inevitable. When real-time communication between the motion simulator and the simulation (host) computer is required, this time-based drift can seriously degrade the simulation fidelity. This drift is exacerbated by timing jitter in the communication channel and each component's internal processing loop. A motion simulation controller synchronized to an external standards-based timing reference, such as GPS, can eliminate this time-based drift. This paper discusses the advantages of synchronization for improving simulation fidelity.

High fidelity HWIL simulation requires the host computer and the motion simulator controller utilize a low-latency communication channel for near real-time data transactions of motion demands and readout data. Generally this communication requirement is handled by a reflective memory interface (RMI) between the simulator controller and host computer nodes, where the data is replicated over a fiber optics cable to memory contained within each node. During the simulation, data is written and read in cycles by the host at a specific rate. If the frequency reference within the simulation controller and the host are synchronized to a common timing reference, then the host data "writes" and "reads" will always occur at the same phase within the simulation control cycle. This ensures that the data utilized by the simulation controller is precisely synchronized with the host computer.

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8016-01, Session 1

Effects and elimination of nanoporosity in transparent sintered spinel ($MgAl_2O_4$)

A. Krell, K. Waetzig, T. Hutzler, J. Klimke, Fraunhofer-Institut für Keramische Technologien und Systeme (Germany)

MgAl2O4 is a candidate for sintered windows, domes and lenses for ultraviolet, visible, and median infrared applications. However, exact Mie calculation shows that the transmission can be heavily deteriorated by as few as 0.01% of residual porosity. Optical evidence for such low levels of porosity is provided more readily by UV spectroscopy than at longer wave lengths, but even IR transmission cannot tolerate such porosity when used for imaging applications.

Commonly, an appropriate low level of residual porosity is achieved in polycrystalline sintered ceramics by approaches of pressure-assisted sintering. Without doping additives, the principles of solid state sintering suggest that smallest pores should be eliminated more easily than larger ones. It was, however, observed that a significant population of small nanopores (50-100 nm) exists in undoped transparent spinel ceramics after pressureless pre-sintering and subsequent hot-isostatic pressing (HIP), and surprising spectral features indicated a higher concentration of nanopores the finer the particle size of the raw spinel powder was. In fact, the correlation of coarser particle sizes of the raw powder and a decreasing frequency of such pores in the HIP-ed ceramics was confirmed by quantitative high-resolution SEM analyses of larger areas and initiated investigations of manufacturing approaches using coarser raw powders (with specific surfaces < 10 m2/g) than commercially available with a sufficiently high sintering activity.

As a result, sintered spinel ceramics were derived which fit the transmittance of comparable spinel single crystals from about 200 nm wave length up to the IR range.

8016-02, Session 1

Manufacturing solutions for polycrystalline transparent spinel domes

E. A. LaRoche, J. J. Kutsch, L. Fehrenbacher, Technology Assessment and Transfer (United States)

Magnesium aluminate spinel is a durable, broadband, electro-optical material that can be readily manufactured into transparent domes for multimode seeker applications. Technology Assessment & Transfer, Inc. will report on the results of its SBIR-funded research and development efforts to resolve manufacturing issues with regard to transparent spinel domes. The specific areas of study have been cost, quality, and ability to scale up to full production. Alternative manufacturing approaches were evaluated and compared. A clear path to full scale production has been identified.

8016-03, Session 1

High-performance spinel ceramics for IR windows and domes

J. L. Sepulveda, R. O. Loutfy, S. Chang, S. Ibrahim, Materials and Electrochemical Research Corp. (United States)

High performance spinel ceramic is required for near-term future applications based on the excellent spinel transmission properties in the UV-VIS-Mid IR wavelength range. Windows as large as 30”x60” and hemispherical domes 4”-7” in diameter have been distinguished as applications where the novel spinel technology could be successfully applied. Future applications involve the use of even more complex 3-D shapes like spinel superdomes and tubes. The thickness of some of these components has reached 1” and above. MER has been actively pursuing these design objectives and has shown the feasibility of producing some of these complex shaped parts. Optimization of transmittance and strength are always the main objective. MER has also been pursuing edge bonding technology, where large thick panes will be edge bonded into a final large window, and manufacturing of monolithic windows as large as 18”x22” which can be used as individual windows or as panes prior to edge bonding. Using the complex 3-D spinel process, MER has also demonstrated the feasibility of producing 4”-7” diameter hemispherical domes blanks of very high quality. After rendering and polishing, defect free domes have been produced. The process has been characterized and qualified using an optical grade spinel specification. Details of MER’s technology to produce low cost, high strength, transparent magnesium aluminum spinel windows and domes are described. High optical and IR transparency in the 0.3 - 5.5 µm wavelength range are obtained. Equibiaxial strength reaches 300 MPa. Spinel optical and mechanical properties are provided.

8016-04, Session 1

Joining of transparent ceramics

A. Shechter, E. Galun, Elbit Systems Electro-Optics El-Op Ltd. (Israel)

There is increasing interest in the world for large transparent structural ceramic windows for protected vision in sensing systems.

A selection of materials is available for visible and mid-wave infrared windows, but when looking for larger windows that can withstand harsh environments and demonstrate superior optical characteristics the selection of these materials is limited by technology, cost and availability.

One of the solutions for attaining large windows is joining several sections (windows) into the desired size.

Due to the matching in index refraction and close similarity in the coefficient of thermal expansion, Optical Glass Bonding (OGB) was chosen as leading candidate at ELOP for joining of transparent sapphire, both for large windows and formation of complex structures.

In addition the paste utilized for the bonding procedure showed feasibility and capability for receiving semi finished polished sapphire, reducing the huge cost of polishing.

8016-05, Session 1

Large-area electro-optic spinel windows: advances in manufacturing

J. J. Kutsch, E. A. LaRoche, L. Renomeron, L. Fehrenbacher, Technology Assessment and Transfer (United States); L. Shaffer, ArmorLine Corp. (United States); J. A. Randi, The Pennsylvania State Univ. Electro-Optics Ctr. (United States)

The use of magnesium aluminate spinel for electro-optic sensor window applications is increasing in part due to the material’s broadband transmission capability (0.2-5.5um), high hardness and erosion resistance and its scalable manufacturability. Advances in spinel processing methods and manufacturing equipment design are being driven by the demand for larger area E-O sensor windows in various programs throughout the DoD. Addressed here in three separate but related spinel programs are strength enhancement, optical homogeneity and the overall manufacturing process of spinel. The end goal of this research is to produce a 30” x 30” x 0.5” E-O sensor quality spinel window.

Progress on a design of experiments approach exploring the cause and effect relationship of hot press and hot isostatic press processing protocols is presented. Specific responses observed and discussed include optical and mechanical characteristics of spinel samples with the goal of defining a process specific to large area windows. In addition to the DoE, advanced approaches and results-to-date for enhancing spinel strength are also presented. The methods for increasing strength while maintaining optical properties are presented. Finally, results and recommendations from an all encompassing evaluation of the manufacturing process from powder to polishing are presented.

8016-06, Session 1

Large optical grade sapphire windows produced from a horizontal growth process

J. B. Levine, M. Montgomery, A. Novoselov, S. Podlozhenov, Rubicon Technology Inc. (United States)

As sapphire technology has advanced over the years, the size of the grown crystals has increased to the point where individual pieces are large enough for use as seamless integrated optical windows. Primary candidates for such sapphire are aerospace systems that require durable IR windows capable of withstanding supersonic flight while maintaining excellent transmission characteristics in the UV to IR range to protect onboard imaging systems. The current technology is unable to provide sapphire windows of sufficient size and quantity to meet the growing demand for these high quality crystals. Thus, a new growth technique is needed to enable high volume production of near net-shape large area sapphire windows. Rubicon Technology, with our strong history in both sapphire crystal growth and large scale production processes, has successfully produced large sapphire blanks using a horizontal directional solidification process. Advancements in the growth of crystals oriented with respect to r-, a- and c-plane will be discussed. Several prototypes, 1.75 inches thick, 14 inches wide and over 30 inches long have been synthesized. Crystal properties and optical characteristics such as refractive index homogeneity will be presented on several slabs that were machined to specific sizes and polished with excellent results.

8016-07, Session 2

ALON optical ceramic transparencies for window, dome, and transparent armor applications

L. M. Goldman, R. Twedt, S. Balasubramanian, S. Sastri, Surmet Corp. (United States)

Surmet continues to invest in and expand its manufacturing capability for ALON® Optical Ceramic, as the market demand for this material increases. The biggest demand and opportunity continues to be in the area of transparent armor, however, the market for sensor domes and windows, made from ALON, continues to grow at an impressive rate as well.

ALON® Transparent Armor's unsurpassed ballistic performance, combined with the robustness of ALON's manufacturing process and reproducibly high material quality make ALON the leading candidate for many future armor systems. Recent results for ALON armor windows will be presented.

Advances being made in Surmet's production capability to support the very large quantities of material required by the transparent armor market also benefit the sensor market. Improvements in quality, quantity and manufacturability of ALON material, combined with improvements being made in optical quality, ensure a robust supply of high quality material for high volume window and dome applications. Recent advancement in ALON® window and dome blanks, as well as in optical fabrication will be presented.

8016-08, Session 2

High-impact resistance optical sensor windows

J. Askinazi, Goodrich Corp. (United States); L. M. Goldman, Surmet Corp. (United States)

Recent field experience with optical sensor windows on both ground and airborne platforms has shown a significant increase in window fracturing from foreign object debris (FOD) impacts and as a by-product of asymmetrical warfare. Common optical sensor window materials such as borosilicate glass do not typically have high impact resistance. Emerging advanced optical window materials such as aluminum oxynitride offer the potential for a significant improvement in FOD impact resistance due to their superior surface hardness, fracture toughness and strength properties. To confirm the potential impact resistance improvement achievable with these emerging materials, Goodrich ISR Systems in collaboration with Surmet Corporation undertook a set of comparative FOD impact tests of optical sensor windows made from borosilicate glass and from aluminum oxynitride. It was demonstrated that the aluminum oxynitride windows could withstand up to three times the FOD impact velocity (as compared with borosilicate glass) before fracture would occur. These highly encouraging test results confirm the utility of this new highly viable window solution for use on new ground and airborne window multispectral applications as well as a retrofit to current production windows. We believe that this solution can go a long way to significantly reducing the frequency and life cycle cost of window replacement.

8016-09, Session 2

Dual IR/RF windows for laser communications

L. M. Goldman, R. Twedt, J. Zigman, Surmet Corp. (United States); R. J. Ondercin, Air Force Research Lab. (United States)

Future advanced communications systems will utilize lasers which operate at 1.55um backed up by an RF links. To the extent that such systems utilize a common aperture, dual IR/RF windows and domes will be required. The durability of such windows, with respect to rain and sand erosion damage, is also an important consideration as damaged surfaces will lead to significant degradation of system performance. This requirement drives the materials choices toward more durable materials such as ALON® Optical ceramic, spinel and sapphire. Single layer windows, with appropriately selected thicknesses of these materials can be used for narrow RF wavebands, but are not adequate for applications requiring broadband RF transparency. To this end, multilayer windows, with durable outer layers of ALON have been developed, built and tested. Recent IR and RF measurements of multilayered windows will be presented.

8016-10, Session 2

Transparent ceramics for demanding optical applications

M. V. Parish, M. R. Pascucci, B. Boucher-Puputti, N. Corbin, G. Chery, J. Small, CeraNova Corp. (United States)

Transparent ceramics are finding applications is demanding optical applications were traditional amorphous materials are limited. Polycrystalline ceramics offer a unique combination of mechanical, electrical and optical properties that allow window and dome applications and possibilities that were previously not possible. Many challenges in processing and fabrication of transparent ceramic optics have been met, though additional development is still necessary. Transparent ceramics are being developed for use in a number of applications, including visible and infrared transmitting windows and domes, lasers and scintillators,

with each material possessing a distinctive set of properties that address a particular application. The current status of CeraNova's fine grain transparent ceramic programs for aerodynamic dome and window applications will be presented with emphasis on their exceptional properties for specific applications.

8016-11, Session 2

Colloidal processing and optical transmittance of submicron polycrystalline alumina

T. Wen, D. K. Shetty, The Univ. of Utah (United States)

Grain-boundary scattering due to intrinsic birefringence limits the optical transmittance of polycrystalline alumina (PCA). Smallest grain size and highest density are desired for maximum real in-line transmittance (RIT). Grain size versus density or sintering path plots were employed to compare different colloidal routes for fabricating green bodies followed by pressureless sintering and hot-isostatic pressing. Compacts fabricated by pressure filtration showed superior density at smaller grain size as compared to slip-cast compacts. The real in-line transmittance of the PCA was measured over a range of wavelengths (0.19-10 micrometer). The compacts fabricated by pressure filtration showed higher transmittance as compared to slip-cast specimens. The measured transmittance was still, however, slightly lower than the throeretical values predicted by the grain-boundary scattering model of Apetz and van Bruggen. The grain-size dependence of RIT was analyzed using a model that combined grain-boundary scattering and scattering by isolated grain-boundary pores.

8016-12, Session 2

Synthesis, characterization, and densification of Al_2-xScx$(WO_4)_3$ ceramics for low-expansion infrared-transparent windows

N. Dasgupta, B. Butler, E. Sorge, Materials and Systems Research, Inc. (United States); T. Wen, D. K. Shetty, The Univ. of Utah (United States)

Materials and Systems Research, Inc. is developing a material with a low coefficient of thermal expansion (CTE) that could serve as an infrared-transparent window. The material is derived from a solid solution of Al2(WO4)3, which has positive thermal expansion, and Sc2(WO4)3 with a negative thermal expansion. An optimum composition of Al0.5Sc1.5(WO4)3 was identified by synthesizing solid solutions, Al2-xScx(WO4)3, by a solid-state route with compositions ranging from x = 0 to 2.0. A single orthorhombic phase was obtained at all compositions. A composition corresponding to x = 1.5 had the lowest CTE value of -0.15 x 10-6/oC in the temperature range, 25-700ºC. A low temperature solution combustion process was developed for this optimum composition resulting in a single phase powder with a surface area of ~ 14 m2/g and average particle size (as determined from surface area) of 91 nm. Preliminary densification experiments via dry uniaxial pressing and pressureless sintering at 1100°C for 2 hours resulted in a sintered compact 97.5% in density and submicron grain size. A combustion reactor is being set up to spray pyrolyze the solution and control the particle size and size distribution for colloidal processing.

8016-13, Session 3

Measurement of chalcogenide glass optical dispersion using a mid-infrared prism coupler

A. H. Qiao, N. C. Anheier, Jr., Pacific Northwest National Lab. (United States); J. D. Musgrave, K. Richardson, Clemson Univ. (United States); D. W. Hewak, Univ. of Southampton (United Kingdom)

Chalcogenide glass development continues to be the source of intense study by research groups around the world. Their physical properties, including broadband infrared transparency, high refractive index, low glass transition temperature, and nonlinear properties, make chalcogenide materials attractive candidates for advanced mid-infrared (3 to 12 μm) optical designs. Efforts focused at developing new chalcogenide glass formulations and processing methods require rapid quantitative evaluation of their optical constants to guide the materials research. However, characterization of important optical parameters such as optical dispersion and thermal index variations (dn/dT) remains a slow and costly process, generally with limited accuracy. The recent development of a prism coupler at the Pacific Northwest National Laboratory (PNNL) now enables rapid, high precision measurement of refractive indices at discrete wavelengths from the visible to the mid-infrared. Optical dispersion data of several chalcogenide glass families were collected using this method. Variations in the optical dispersion were correlated to glass composition and then compared against minimum deviation measurements. While this work has been focused on chalcogenide glass synthesis, mid-infrared prism coupler analysis has broader applications to other mid-infrared optical material development efforts, including oxide glasses and crystalline materials.

8016-14, Session 3

A mid-infrared prism coupler for bulk and thin film analysis

N. C. Anheier, Jr., A. H. Qiao, Pacific Northwest National Lab. (United States)

In this paper we present a prism coupler that is capable of characterizing optical dispersion and thermal index variations (dn/dT) in bulk and thin film materials at measurement wavelengths extending through the mid-infrared (3 to 12 μm). Our research was motivated by the need for precise, rapid, and low cost optical refractive index analysis to facilitate development of new mid-infrared optical materials, assessment of variability in mid-infrared optical materials acquired from commercial sources, and design of optical elements used in advanced, high performance mid-infrared sensing platforms. Such efforts commonly require ±1x10-3 or better absolute index measurement accuracy at measurement wavelengths spanning from the visible to the mid-infrared. Unfortunately most dispersion and dn/dT characterization methods require compromises in accuracy, cost, and timeliness, or cannot access the mid-infrared spectral region where many of the most important sensing and defense applications exist. A prism coupler, implemented at the mid-infrared, was found to provide rapid and cost-effective optical materials metrology with sufficient accuracy to meet most design requirements. We discuss the challenges of integrating the required mid-infrared optical components, including a sensitive mid-infrared detector and the quantum cascade and other infrared laser sources, with a commercial Metricon prism coupler and the calibration steps necessary to achieve the desired measurement accuracy. Dispersion data of mid-infrared optical materials is presented to demonstrate the mid-infrared prism coupler performance.

8016-15, Session 3

Methods for prediction of refractive index in glasses for the infrared

J. S. McCloy, Pacific Northwest National Lab. (United States)

It is often useful to obtain custom glasses that meet particular requirements of refractive index and dispersion for high-end optical design and applications. In the case of infrared glasses, limited experimental data are available due to difficulties in processing of these glasses and also measuring refractive indices accurately. This paper proposes methods to estimate refractive index and dispersion as a function of composition for selected infrared-transmitting glasses.

Methods for refractive index determination are reviewed and evaluated, including Gladstone-Dale, Wemple-DiDomenico single oscillator, Optical basicity, and Lorentz-Lorenz total polarizability. Various estimates for a set of PbO-Bi2O3-Ga2O3 (heavy metal oxide) and As-S (chalcogenide) glasses will be compared with measured values of index and dispersion.

8016-16, Session 3

Multiphonon difference band absorption in diamond

M. E. Thomas, The Johns Hopkins Univ. (United States)

The longwave absorption coefficient of diamond is composed of the two-phonon red wing and multi-phonon difference bands. As temperature increases the difference bands rapidly grow and dominate the absorption. A variation on a multiphonon sum band model is developed for difference bands and applied to a temperature dependent data set on polycrystalline diamond. The model can also be used to estimate multiphonon difference band contribution to the refractive index. The results of this study will be presented.

8016-17, Session 4

Anisotropy in structural and optical properties of chemical vapor deposited ZnS

J. S. McCloy, Pacific Northwest National Lab. (United States)

Significant anisotropy in as-deposited CVD ZnS has been demonstrated through investigation of the structural and optical properties. Compressive strength of cylinders of CVD ZnS oriented in the growth direction is ~50% higher than cylinders taken perpendicular to the growth direction. Additionally, lattice parameter measurements of mandrel side (first-to-grow) material is ~0.4% smaller than growth side (last-to-grow) material in a cored sample representing ~500 hours of CVD growth, indicating significant strain along the growth direction. X-ray diffraction also shows evidence of preferred orientations for hexagonality which differs depending on position in the growth. In cross-section, the core shows several large bands which are correlated with different degrees of infrared absorption. However, no clear trend is found from the mandrel to the growth side regarding optical properties. The extinction in the visible and infrared is lower for measurements perpendicular to the growth axis than parallel to it, possibly due to scattering from the growth bands.

8016-18, Session 4

Describing the flexural strength of IR-transmitting materials: case of CVD zinc selenide and CVD zinc sulfide

C. A. Klein, C.A.K. Analytics, Int'l. (United States)

The results of flexural strength testing performed on brittle materials are usually interpreted in the light of a “Weibull plot,” i.e., by fitting the estimated cumulative failure probability (CFP) to a linearized semi-empirical Weibull distribution. This procedure ignores the impact of the testing method on the measured stresses at fracture---specifically, the stressed area and the stress profile---thus resulting in inadequate characterization of the material under consideration. In a previous publication[1],the author reformulated Weibull's statistical theory of fracture in a manner that emphasizes how the stressed area and the stress profile control the CFP, which led to the concept of a characteristic strength, that is, the effective strength of a 1-sq.cm uniformly stressed area. Fitting the CFP of IR-transmitting materials was performed by means of non-linear regressions but produced evidence of slight, systematic deviations. In this paper we demonstrate that upon extending the previously elaborated model to distributions involving two distinct types of defects---bimodal distributions---fitting the estimated CFP of CVD-ZnS or CVD-ZnSe leads to a much improved description of the fracture process. In particular, the availability of two sets of statistical parameters (characteristic strength and shape parameter) can be taken advantage of for evaluating the failure-probability density, thus providing means of assessing the nature, the critical size, and the size distribution of surface/subsurface flaws.

[1] C. Klein, R, Miller, and R. Gentilman, “Characteristic strength and Weibull modulus of selected infrared-transmitting materials,” Opt. Eng. 41, 3151 (2002).

8016-19, Session 4

Microwave mediated synthesis of spherical ZnS nanoparticles

D. Ravichandran, Texas Biochemicals, Inc. (United States); B. K. Jones, U.S. Army Research, Development and Engineering Command (United States); D. C. Harris, Naval Air Warfare Ctr. Weapons Div. (United States); T. Wharton, D. Balachari, Texas Biochemicals, Inc. (United States); R. Korenstein, R. W. Tustison, Raytheon Co. (United States); S. Komarneni, The Pennsylvania State Univ. (United States)

The existing material choice for long wave-infrared (LWIR) and semi-active laser domes is multispectral Zinc Sulfide (ZnS), made by chemical vapor deposition. An alternative route to make more erosion-resistant ZnS could be through hot pressing ZnS nanoparticles into small-grain material. We have attempted to produce ZnS nanoparticles both by Microwave and Microwave-Hydrothermal methods. Microwave route produced homogeneous, well dispersed uniform spherical ZnS nanoparticles. Microwave-Hydrothermal route produced faceted cubic shaped nanoparticles. The choice of materials selection, correlation of processing parameters, and morphology for a facile and controllable synthetic route to generate monodispersed nanosphere and cubic ZnS will be presented.

8016-20, Session 4

Single crystal and polycrystalline CVD diamond for demanding optical applications

J. M. Dodson, J. R. Brandon, I. Friel, S. L. Geoghegan, T. P. Mollart, Element Six (UK) Ltd. (United Kingdom); P. J. Santini, Element Six (United States); G. A. Scarsbrook, A. J. Whitehead, J. J. Wilman, Element Six (UK) Ltd. (United Kingdom); H. G. M. de Wit, Element Six N.V. (Netherlands)

The combination of diamond's strength, thermal conductivity and wide spectral transmission make it an ideal material for windows and other optical components for use in extreme environments. Since its development in the 1990s, polycrystalline diamond grown by chemical vapour deposition (CVD) has become firmly established as the preferred window for high power CO2 laser systems, and the prime contender for ITER's megawatt gyrotrons. Over the past decade, single crystal CVD diamond with new levels of crystalline and chemical purity have been developed, with obvious potential for use in optical products. This paper will compare the optical performance of single crystal and polycrystalline CVD diamond, including absorption and scatter at 1.064 and 10.6 microns, and assess the relative merits of using these materials in a number of applications.

8016-21, Session 4

Depositing high-quality single-crystal-like diamond for optical window applications

C. Liu, W. Qiu, Valdosta Optics Lab., Inc. (United States)

Return to Contents

Optical quality diamond with a microscopic structure very close to that of single crystal diamond has been synthesized using microwave plasma enhanced chemical vapor deposition (MPECVD) technology. The bias-enhanced nucleation (BEN) of diamond on silicon substrate has been developed, and the processing parameters were systematically studied for a better understanding of the mechanism of the diamond nucleation with a preferred orientation. As a result, the density, spatial uniformity, and orientation regularity of the diamond nuclei were significantly improved. A subsequent diamond deposition was carried out for a short period of time with nitrogen-containing plasma chemistry promoting (100) direction growth, leading to a highly oriented diamond (HOD) thin film with adjacent diamond grains coalescing together forming a single-crystal-like structure. During the following long-term deposition for thick diamond synthesis, oxygen was introduced in the reaction chamber to grow high quality diamond on top of the coalesced HOD layer. Meanwhile the single-crystal-like structure was maintained and twinning and re-nucleation was effectively suppressed. The as-grown surface of the diamond is smooth, and the majority of grain boundaries are eliminated with the remaining boundaries isolated. The smooth surface and the single-crystal-like structure with low density grain boundary are of benefit to optical window applications due to less polishing effort, higher mechanical strength, and lower optical absorption and scattering compared with randomly oriented polycrystalline diamond.

8016-22, Session 5

History of magnetorheological finishing

D. C. Harris, Naval Air Systems Command (United States); W. I. Kordonski, D. Golini, QED Technologies, Inc. (United States)

Magnetorheological finishing (MRF) is a deterministic method for final finishing of optics with peak-to-valley figure accuracy of better than one tenth of an optical wavelength and root-mean-square surface roughness of 1 nm. The method was invented at the Luikov Institute of Heat and Mass Transfer in Minsk, Belarus in the late 1980s by a team led by William Kordonski. In 1993, Kordonski moved to the Center for Optics Manufacturing where he worked with Harvey Pollicove, Donald Golini and Prof. Stephen Jacobs of the University of Rochester to refine the technique. Prof. Gregory Forbes and doctoral student Paul Dumas developed algorithms for deterministic control of the finishing process. A prototype machine was operating by 1994. In 1996, Golini recognized the commercial potential of the process, wrote a business plan, and secured investment capital to found QED Technologies. The first commercial MRF finishing instrument was unveiled in 1998. In 2003, QED introduced their Subaperture Stitching Interferometer which was necessary to measure the precision optics that could be produced by MRF. QED has since introduced a whole product line for MRF, which has been widely adopted by the optics and semiconductor industries. In 2006, QED was acquired by and became a division of Cabot Microelectronics Corporation (CMC). This paper recounts the history of the development of MRF and the founding and evolution of QED Technologies.

8016-23, Session 5

Rapid optical manufacturing of hard ceramic conformal windows and domes

J. D. Nelson, A. Gould, D. Dworzanski, C. Klinger, M. Mandina, Optimax Systems, Inc. (United States)

Hard ceramic conformal windows and domes provide two challenges to the optical fabricator. The material hardness, polycrystalline nature and non-traditional shape demand creative optical fabrication techniques to produce these types of optics cost-effectively. VIBE is a high-speed, high-pressure, conformal optical fabrication process that is capable of rapidly polishing hard ceramic materials and non-traditional shapes such as toroids and tangent ogives. This paper will overview the recent progress made to rapidly manufacture hard ceramic conformal windows and domes as well as the challenges associated with it. Results will show 10-50x increase in removal rates using the VIBE platform to polish hard ceramic materials compared to conventional methods.

8016-24, Session 5

Ogive and free-form polishing with ultraform finishing

S. Bambrick, M. J. Bechtold, S. DeFisher, D. E. Mohring, OptiPro Systems (United States)

UltraForm Finishing (UFF), OptiPro Systems' five axis sub-aperture polishing machine has evolved from an initial prototype into a robust aspheric manufacturing system that can rapidly produce finished aspheres directly from a ground surface. UFF utilizes a belt of polishing material 50" long and backed by a polyurethane wheel to polish a wide variety of materials ranging from traditional glasses to IR materials. This backed belt polishing system provides a tuned stiffness that is capable of conforming to the polishing surface without replicating the surface roughness. When combined with state of the art figure correction algorithms, the UFF is capable of robust and deterministic figure correction for aspheric surfaces.

Recently, OptiPro Systems has expanded the capability of the UFF to include deep concave ogive and free form surfaces. Although these types of surfaces can be beneficial from an optical or aerodynamic standpoint they pose additional challenges both from their steep geometry as well as from a polishing tool path perspective. A brief description of these challenges as well as possible solutions to these problems will be presented. In addition, the current figure correction capability of the system utilizing feedback from OptiPro's five axis non-contact free from metrology system will be presented.

8016-25, Session 6

Moldable AR microstructures for improved laser transmission and damage resistance in IRCM fiber optic beam delivery systems

D. S. Hobbs, B. D. MacLeod, TelAztec LLC (United States)

Infrared Counter Measure (IRCM) systems utilize high power lasers to actively blind or confuse the targeting and tracking sensors on board a missile threat. IRCM system designs have recently been advanced using a new class of infrared transmitting chalcogenide fiber materials for distributing the high-energy light to multiple jamming turrets around a military platform. Such chalcogenide fiber glasses are moldable at low temperatures and pressures enabling the inexpensive fabrication of refractive and diffractive lenses, windows, filters, and in particular optical fiber. Chalcogenide materials produce high surface reflections that must be suppressed using some form of antireflection (AR) treatment. The conventional AR coating technology involving the deposition of multiple thin-film material layers is costly and impractical for fiber delivery systems, and severely limits the laser power transmission capacity to the point where IRCM mission objects cannot be met. An AR treatment based on surface relief microstructures has been shown to resist laser damage at power levels 2 to 5 times higher than thin-film coatings. The results of the direct molding of high performance AR microstructures (ARMs) into the end facets of chalcogenide fiber optic cables will be presented. The benefits of the novel embossing technique include low cost fabrication, significantly expanded bandwidth, lower reflection loss, and higher laser power capacity. Optical performance modeling and the fabrication of ARMs textured master stamping tools in several materials will be discussed. Standardized pulsed and continuous wave laser damage testing of ARMs treated chalcogenide fibers will be conducted and compared to the damage threshold attainable with no AR treatment.

8016-26, Session 6

Hyperspectral antireflective coatings for infrared windows

D. E. Patterson, B. G. Zollars, S. M. Savoy, Nanohmics (United

States)

Using conical “moth-eye” structures, a hyperspectral antireflective coating is being developed for use with ZnS (Cleartran) infrared windows. Moth-eye structures approximate a graded refractive index for wavelengths longer than the mean transverse spacing of the moth-eye features. These structures can reduce the reflection of electromagnetic radiation relative to an untreated surface over a wavelength range that is wider than a traditional multi-layer optical coating. For anti-reflection coatings in the near-infrared and visible spectral bands, the transverse size and spacing of moth-eye structures become challenging as conventional lithography and optical techniques become limited in the feature dimensions that can be routinely fabricated. In this work, we are using the emerging technique of imprint lithography to create moth-eye structures on the surface of Cleartran windows with transverse scales from 200-300 nm and with aspect ratios >10. The surface features, in conjunction with a conformal protective coating of amorphous AlN, can serve as anti-reflection surface treatments spanning the wavelength range from the visible through the long-wave infrared. The amorphous AlN coatings have proven to be extremely adherent and robust. Cleartran windows with imprinted moth-eye structures have application as aerospace transparencies for the protection of multi-band or hyperspectral sensors in aircraft, rotorcraft, and UAV platforms.

8016-27, Session 6

Development of nanostructured protective “sight glasses” for IR gas sensors

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Real-time monitoring and control of climate parameters like temperature, CO_2 and NH_3 during in-door animal production is essential to secure the well-being of the livestock, increasing the productivity, and increasing energy efficiency. Danfoss IXA’s sensors are based on infrared absorption spectroscopy to measure relevant gases and temperature in direct contact to the environment, essentially in free air. DTU Nanotech, in a collaboration with Danfoss IXA A/S and Skov A/S, are developing these extremely rugged sensors that can reliably perform in the dirty and harsh indoor environment of e.g. a chicken or pig production unit.

For this, “sight glass” shielding windows are needed to protect the emitting and detecting element of the sensor. The windows have to possess special properties such as high optical transmissivity in relevant infrared wavelength ranges, a superhydrophobic and “self-cleaning” surface to avoid water film formation and particle contamination, and chemical robustness towards harsh chemicals commonly used for cleaning and disinfection of stables.

For such windows we utilized silicon as a relative cheap and sufficient infrared transparent “sight glass” material. A sub-wavelength nanostructure with random pattern was created on the surface by reactive ion etching (RIE) in an easy and comparable cheap single step mask-less process. FT-IR spectroscopy concerning the optical properties of these nanostructured silicon windows revealed an anti-reflective (moth-eye) effect owing to the nanostructures. By applying an additional organic coating, the intrinsic water repellent property of the nanostructured surface could be enhanced, shown by contact angle and roll-off angle measurements. The “self-cleaning” effect and chemical robustness towards aggressive environments and chemicals are demonstrated.

8016-28, Session 6

High laser damage threshold optical microstructures in Raytheon ceramic YAG

D. S. Hobbs, B. D. MacLeod, TelAztec LLC (United States); T. M. Hartnett, R. Gentilman, Raytheon Co. (United States)

Metal ion doped yttrium aluminum garnet (YAG) material is widely used as a gain medium in high power solid-state lasers. Increasingly, the wide transmission bandwidth and mechanical durability of polycrystalline YAG has made its use as an infrared transparency attractive for laser targeting and sensor applications. Currently, the deposition of multiple layers of thin-film materials onto the YAG optic or window is necessary for producing wavelength filtering, polarizing, or anti-reflection (AR) functions. However, these thin-film material stacks are easily damaged at laser power levels that severely limit the lifetime and amount of power that can be transmitted by a laser system. Surface relief microstructures offer an alternative to thin-film coatings for high power laser systems. In standardized pulsed laser damage testing at multiple wavelengths ranging from the near UV through the long wave infrared, AR microstructures built in the surface of many types of materials have consistently exhibited damage thresholds 2 to 5 times higher than thin-film AR coatings. For this work, a laser damage resistance study will be presented for AR, polarizing, and wavelength selective microstructures built in Raytheon ceramic YAG windows. Multiple trials will be conducted at wavelengths ranging from 800 to 2100nm. Particular emphasis will be given to the 1053 to 1064nm wavelength range where AR microstructures have the potential to significantly increase the damage threshold of pump beam integrators, gain media facets, and laser cavity components. A practical, low cost embossing method for the fabrication of high performance microstructures in YAG will also be discussed.

8016-29, Session 6

Numerical comparison of grid pattern diffraction effects through modeling with OptiScan software

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Coatings of various metalized patterns are used for heating and electromagnetic interference (EMI) shielding applications. Previous work has focused on macro differences between different types of grids, and has shown good correlation between measurements and analyses of grid diffraction. To advance this work, we have utilized the University of Arizona’s OptiScan software, which has been optimized for this application by using the Babinet Principle. When operating on an appropriate computer system, this algorithm produces results hundreds of times faster than standard Fourier-based methods, and allows realistic cases to be modeled for the first time. By using previously published derivations by Exotic Electro-Optics, we compare diffraction performance of repeating and randomized grid patterns with equivalent sheet resistance using numerical performance metrics.

8016-30, Session 7

Advances in freeform optical metrology using a multibeam low-coherence optical probe (Quad-Probe)

D. W. Diehl, C. J. Ditchman, C. T. Cotton, N. E. Burdick, ASE Optics, Inc. (United States)

Windows and domes that conform to aerodynamic shapes can reduce drag, but they also introduce optical aberrations that degrade image quality. Freeform aspheric corrector optics can be added to the optical

Return to Contents

path to minimize or even eliminate these optical aberrations. Presently, however, there are no commercial methods for measuring strongly aspheric optical elements that deviate from a best-fit sphere by more than 1 mm. To address this problem, ASE Optics has developed a four-beam "Quad-Probe" as an accessory for the OptiGauge low-coherence fiber-based interferometer from Lumetrics. The Quad-Probe is capable of measuring both the position and orientation of surfaces with respect to the probe. By scanning the probe over the surface of the optic using a five-axis scanner (such as the UltraSurf from OptiPro), a 3D model of the interior and exterior surfaces can be built. This paper presents quantitative results for the latest Quad-Probe measurements of aspheric windows and corrector optics. We also explore the feasibility of using the Quad-Probe to measure optical components in situ, while the part is still mounted inside a polishing machine. Furthermore, we present preliminary work in self-guided "blind contouring" experiments, in which the Quad-Probe measurements are used as feedback to guide the scanner when measuring an unknown part.

8016-31, Session 7

A non-contact surface measurement system for freeform and conformal optics

S. DeFisher, M. J. Bechtold, D. E. Mohring, OptiPro Systems (United States)

OptiPro Systems has been developing the UltraSurf, a non-contact measuring system using state of the art, precision motion control. The goal is to precisely scan standard optical shapes such as concave and convex spherical surfaces, as well as the complex geometries of aspheric, ogive, and freeform shapes without the limitations associated with other measurement methods. Common optical measurement methods have limitations with surface roughness, slope error, and deviation from best-fit sphere. Optipro designed the UltraSurf to further the manufacturing capabilities of companies generating complex precision optics.

The UltraSurf measures with sub-micrometer non-contact point sensors to collect surface information. Various sensors are commercially available from multiple companies, each with their own distinct optical measuring technology. One optical sensor uses white light confocal chromatic imaging to measure individual optical surfaces. Another optical sensor uses low-coherence interferometry with a near infrared laser, and is able to measure the inside, outside, and thickness of optical materials at a single point.

The UltraSurf scans the optical sensors over the surface of the part under test, keeping it normal to the surface. The single point measuring method coupled with computer-controlled motion gives the UltraSurf flexibility to measure greatly varied geometries. Ultimately, a point cloud of the measured surface is generated. The cloud can be used to calculate deviation from the desired shape, as well as various surface parameters. Applications, definitions, and measurement results of freeform and conformal shapes using UltraSurf will be presented.

8016-32, Session 7

Interferometric tomography: a new tool for metrology on conformal optics

M. A. Gutin, O. N. Gutin, X. Wang, D. Ehlinger, Applied Science Innovations, Inc. (United States)

Fabrication and measurement of conformal aerodynamic windows and domes to precise optical tolerances from ceramic materials remains a problem. This paper describes the development of the Interferometric Tomography inspection system, based on a new method for wavefront and surface metrology on optics with very high aberrations. The metrology system is a modular attachment for integrating a standard commercial interferometer with an existing optical fabrication tool. The system will enable high precision measurement of infrared windows and domes in the process of their fabrication, until finished to specification. The capability for fabrication and metrology of aggressively aspheric optics ,"aberrated by design", will enable new optical designs of higher performance and lower cost, compared to existing optics.

8016-33, Session 8

Low-loss dual-wavelength laser optics coatings at 1060nm and 530nm

J. Wang, H. Schreiber, Corning Tropel Corp. (United States)

Remarkable advantages in laser sources and their wide range of applications require high performance laser optics in a wide spectral range from deep-ultraviolet (DUV) to long wavelength infrared (LWIR). Advanced optical coating plays a dominated role to meet the demand. Dual-wavelength laser optics coatings at 1060nm and 530nm were developed for frequency doubling applications. Loss analysis of the dual-wavelength coatings were presented at the two wavelengths for various types of coating designs, including antireflection at both 1060nm & 530nm (AR_1060 & AR_530), partial reflection at 1060nm and antireflection at 530nm (PR_1060 & AR 530), and high reflection at 1060nm and antireflection at 530nm (HR_1060 & AR_530). The results suggest that, for a given surface and interfacial roughness, scatter loss ratio at 530nm and 1060nm is 0.93, 4.4 and 12 for the AR_1060 & AR_530, the PR_1060 & AR 530, and the HR_1060 & AR_530, respectively. Smoothness of surface and interface was identified as critical deposition process control parameter that enables low loss dual-wavelength optical coatings. Accordingly, modified plasma ion assisted deposition process with in-situ plasma smoothing was developed to deposit dense and smooth HfO_2/SiO_2 multilayers for the dual-wavelength laser optics. Improved film microstructure was revealed on single layer and multilayer coated samples by means of atomic force microscopy and scanning electron microscopy. Improved film microstructure led to low loss & laser durable coating performance.

8016-34, Session 8

Optical properties of zinc nitride thin films

A. H. Jayatissa, The Univ. of Toledo (United States)

Optical and electronic properties of zinc nitride thin films were investigated. Zinc nitride is a low band gap (~1.25 eV) semiconductor material. Because of these interesting properties, this material can have potenhtial applications in IR detectors, smart window and energy conversion device applications. This materials can be fabricated by reactive sputtering method in and nitrogen ambient. In this paper, the structure, optical properties as well as electronic properties of zinc nitride were investigated. In particular, much attention was paid to understand the optical properties such as band gap, and optical constant of this material. The photoconductivity of zinc nitride films were investigated as film thickness, thermal annealing and film thickness. These results will be presented in this conference.

8016-35, Session 8

Highly abrasion resistant ultra-nanocrystalline diamond (UNCD) coatings for ZnS

R. Korenstein, Raytheon Co. (United States)

Zinc sulfide (ZnS) is a wide bandgap semiconductor with a long history of use in infrared windows and domes. Its wide bandgap, allows transmission from the visible all the way into the long-wave infrared. Although it has reasonable flexural strength, the ZnS transparency must be protected when it exposed to harsh conditions during flight. Although many types of durable, protective coatings have been developed for ZnS over the years most do not protect ZnS well against sand abrasion. Diamond, due its extreme hardness, is the ideal coating for protecting ZnS against sand abrasion. However, the harsh conditions under which

CVD diamond is typically deposited make this a very difficult task. UNCD on the other hand can be grown under conditions much more benign to ZnS. We will demonstrate for the first time UNCD coatings deposited on ZnS. We will also report the results of sand abrasion testing of UNCD coatings on ZnS.

8016-36, Session 8

Flexible transparent electrode

H. Demiryont, K. C. Shannon III, Eclipse Energy Systems, Inc. (United States); M. S. Bratcher, U.S. Army Research Lab. (United States)

This paper presents a flexible transparent conductor (EclipseTEC(tm)) for display applications. EclipseTEC(tm) is a room temperature deposited nanostructured thin film coating system comprised of metal-oxide semiconductor elements. The system possesses metal-like conductivity and glass-like transparency in the visible region. These highly conductive TEC films exhibit high shielding efficiency (35dB at 1 to 100GHz). EclipseTEC(tm) can be deposited on rigid or flexible substrates.

For example, EclipseTEC(tm) deposited on polyethylene terephthalate (PET) is extremely flexible that can be rolled around a 9mm diameter cylinder with little or no reduction in electrical conductivity and that can assume pre-extension states after an applied stress is relieved. The TEC is colorless and has been tailored to have high visible transmittance which matches the eye sensitivity curve and allows the viewing of true background colors through the coating. EclipseTEC(tm) is flexible, durable and can be tailored at the interface for applications such as electron- or hole-injecting OLED electrodes as well as electrodes in flexible displays.

8016-37, Session 8

Light weight, highly flexible, micro-patternable, electrically conducting polymeric nanocomposites

A. Khosla, Simon Fraser Univ. (Canada)

A new light weight, electrically conducting, thermosetting polymeric nanocomposite is formulated by physically dispersing electrically conducting high aspect ratio nanoparticle's (eg Ag, Au, CNT, Cu, Al) in polymer matrix. It is observed that percolation threshold is achieved at weight percentages below 20 depending on the type of nanoparticles being used. Electrical resistivity of the developed Ag doped nanocomposite polymer is found to be 4.73 x 10-7 Ω-m. The added advantage of the developed nanocomposite polymer is that it can be micropatterened down to a feature size of 5 micron easily. The developed nanocomposite polymer has the potential to be used as an alternative to Copper cables which currently contribute to approximately 7% of an aircraft's weight and as much as one-third of the weight of a 15-ton satellite. Similarly, copper wiring may make up a significant percentage of vehicular weight for other transportation applications (e.g. spacecraft, automobiles, watercraft). Light weight cables fabricated out of the electrically conductive, thermosetting elastomeric materials described herein weigh substantially less than copper cable (e.g. on the order of 1/4 of the weight of copper) and their AC and DC electrical characteristics are similar to those of bulk copper. Accordingly, cables fabricated (e.g. by molding or otherwise) from the electrically conductive, thermosetting elastomeric materials described herein may substantially reduce the weight currently contributed by copper cables.

Some other applications include developing tunable antennas, ultra-light wires for antennas in wireless devices, conductors for electronic interconnects, motors, transformers, miniaturized health care instrumentation - e.g. shape conforming (moldable) or deformable electrodes for impedance-based cancer/tumor detection; actuators based on extrinsic conducting polymers; flexible tactile and pressure sensors; bistable memory devices, in particular polymer based, bistable memory devices/switches; RF and microwave applications such as tunable antennas, passive microwave, components and conductive gaskets; automotive industry applications, wearable electronics; flexible resistors; flexible micro-electrodes for flexible electronics, lab-on-chip systems or the like; and microheaters.

Conference 8017: Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XVI

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8017-01, Session 1

Open area concealed weapon detection system

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Concealed Weapon Detection (CWD) has become a significant challenge to present day security needs; people carrying weapons into airplanes, schools, and secured establishments are a threat to public security. Although controlled screening, of people for illegal items, has been employed in many establishments, procedures and equipment are not adequately designed to work in large area environments likes airports lounges, military check points, hospitals, schools and universities. Furthermore, screening systems are generally unable to decipher between threat and non-threat metal objects, thus leading to high rate of false alarms which can become a liability to day-to-day operational needs of secured establishments. Therefore, the design and development of a new CWD system to operate in an open area environment with reduced incidences of false alarms is essential.

To solve the Open Area (OACWD) problem, a new model is being developed to operate in an open-air environment. The initial OACWD model has been designed and tested in the time-domain transient electromagnetic field environment using the Opera 3D modelling and analysis software. From the analysis it was found that each metal object has a unique secondary current decay time in a transient electromagnetic environment, which is known as time constant of metal. Hence, using key points from the time constant analysis, to develop unique object signatures, for different size, shape and metallic property could be identified by the OACWD system.

8017-02, Session 1

Magnetic sensing techniques for humanitarian ordnance detection and discrimination

J. G. Keranen, Sky Research, Inc. (United States); S. Billings, Sky Research, Inc. (Australia); J. Miller, G. Schultz, Sky Research, Inc. (United States)

Detection and discrimination of unexploded ordnance (UXO) in areas of prior conflict is of high importance to the international community and the United States government. For humanitarian applications, sensors and processing methods need to be robust, reliable, and easy to train and implement using indigenous UXO removal personnel. This paper focuses on magnetometer sensing techniques, processing, and operation for UXO detection and discrimination applications. Specifically, we discuss data collection, processing, and discrimination results from data collected using man-portable systems consisting of arrays of sensitive total-field magnetometers, global positioning systems (GPS) combined with digital odometers, and data acquisition systems. We outline preliminary standard operating procedures for optimal collection of magnetometer position data using either a GPS, or odometer when surveying in GPS-denied areas. We also discuss the use of a novel active source magnetic method for detection of deeply-buried UXO. The described technology uses large loops driven by a high-current transmitter to produce information about a targets DC magnetic character as well as its transient electromagnetic induction behavior. Results from the analysis of data collected at test sites with mineralized soils indicates the wide applicability of these methods. Processing techniques such as gridding and filtering, target picking algorithms, and discrimination routines lead to estimates of target size and location. Emphasis is placed on simplifying the production of magnetometer hardware and software for use by minimally-trained personnel with no advanced knowledge of magnetic sensing and geophysics.

8017-03, Session 1

Incorporating advanced EMI technologies in operational munitions characterization surveys

J. Miller, F. Shubiditze, L. R. Pasion, J. G. Keranen, G. Schultz, Sky Research, Inc. (United States)

The prevalence of unexploded ordnance (UXO), discarded military munitions (DMM), and munitions constituents (MC) at both active and formerly used defense sites (FUDS) has created a necessity for production-level efforts to eradicate these munitions and explosives of concern (MEC). UXO remediation operations typically employ electromagnetic induction (EMI) or magnetometer surveys to identify potential MEC hazards in previously determined areas of interest. A major cost factor in these operations is the significant allocation of resources for the excavation of harmless objects associated with fragmentation, scrap, or geological clutter. Recent advances in classification and discrimination methodologies, as well as the development of sensor technologies that fully exploit physics-based analysis, have demonstrated promise for significantly reducing the false alarm rate due to MEC related clutter. This paper identifies some of the considerations for and the challenges associated with implementing these discrimination methodologies and advanced sensor technologies in production-level surveys. Specifically, we evaluate the implications of deploying an advanced multi-axis EMI sensor at a variety of MEC sites, the discrimination methodologies that leverage the data produced by this sensor, and the potential for productivity increase that could be realized by incorporating this advanced technology as part of production protocol.

8017-04, Session 1

Fast inversion of single target dynamic MetalMapper data

T. M. Grzegorczyk, Delpsi, LLC (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); D. George, G&G Sciences Inc. (United States); F. Shubitidze, J. P. Fernandez, Dartmouth College (United States); K. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States)

The MetalMapper is part of a new generation of electromagnetic induction (EMI) sensors used for the detection and discrimination of UXO. Compared to older generations of sensors, the MetalMapper present three large (1m x 1m) perpendicular transmitting coils which alternatively excite targets with primary fields in different directions. All three components of the secondary magnetic field are collected by seven receiver cubes collocated with the instrument. In its full operating mode, 63 data channels are therefore available (3 transmitting coils times 7 receivers times 3 field components), measuring the secondary magnetic field over typically a few milliseconds during which the primary field is switched off.

For a faster data acquisition, the MetalMapper can also operate in dynamic mode, whereby only the z oriented transmitting coil is active and data are acquired over a shorter time period of about a millisecond. In this work, we focus on this operation mode and evaluate the stability and efficiency of our inversion algorithms on single target real time inversion. As expected, the probably becomes mathematically ill-posed and additional regularization is added for more stable inversion. Results will be presented using real data and processed with both our Gauss-Newton and Kalman filter approach.

8017-05, Session 1

Comparison of support vector machines and neural networks for UXO classification using EMI data

A. Bijamov, Dartmouth College (United States); F. Shubitidze, Dartmouth College (United States) and Sky Research, Inc. (United States); J. P. Fernandez, Dartmouth College (United States); I. Shamatava, Sky Research, Inc. (United States) and Thayer School of Engineering (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States) and ERDC-CRREL (United States); K. O'Neill, Dartmouth College (United States) and ERDC-CRREL (United States)

The classification tools based on SVM and Neural Networks (NN) will be employed, and their performances compared, to perform the UXO classification using the live UXO site EMI data. Both SVM and NN are examples of supervised machine-learning techniques, whose purpose is to label the features (extracted from the incoming data of the unknown anomalies) based on previously trained examples. In this paper a set of three Pasion-Oldenburg parameters will be extracted from the EMI decay curves of the physics based intrinsic, effective dipole moment, called the total Normalized Surface Magnetic Source (NSMS). This data will first be used to train both SVM and NN models and, further, serve as a basis for UXO classification. Crucial to successful implementation of both SVM and NN are the issues of over- or under-training - the delicate balance between these two extremities is essential for successful implementation of classification algorithms and depends on the UXO caliber, material composition and actual live UXO sites conditions. Therefore, to fully demonstrate the SVM and NN capabilities here we will report the classification results for actual live UXO data sets, collected at former Camp San Luis Obispo. This study includes four targets-of-interest: 60-mm, 81-mm, and 4.2-in mortars and 2.36-in rockets. The classification performance between clutters and UXOs, and between different caliber UXOs will be studied and the corresponding ROC curves will be analyzed.

8017-06, Session 1

MPVII: an enhanced vector man-portable EMI sensor for UXO identification

J. P. Fernandez, Dartmouth College (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); N. Lhomme, Sky Research, Inc. (Canada); A. Bijamov, Dartmouth College (United States); T. M. Grzegorczyk, Delpsi, LLC (United States); K. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States); I. Shamatava, F. Shubitidze, Dartmouth College (United States)

The Man-Portable Vector (MPV) electromagnetic induction sensor has proved its worth and flexibility as a tool for identification and discrimination of unexploded ordnance (UXO). The MPV allows remediation work in treed and rough terrains where other instruments cannot be deployed; it can work in survey mode and in a static mode for close interrogation of anomalies. By measuring the three components of the secondary field at five different locations, the MPV provides diverse time-domain data of high quality. The MPV is currently being upgraded, streamlined, and enhanced to make it more practical and serviceable. The new sensor, dubbed MPVII, has a smaller head and lighter components for better portability. The original laser positioning system has been replaced with one that uses the transmitter coil as a beacon. The receivers have been placed in a configuration that permits experimental computation of field gradients. In this work, after introducing the new sensor, we present the results of several identification/discrimination experiments using data provided by the MPVII and digested using a fast and accurate new implementation of the dipole model. The model performs a nonlinear search for the location of a responding target, at each step carrying out a simultaneous linear least-squares inversion for the principal polarizabilities at all time gates and for the orientation of the target. We find that the MPVII can identify standard-issue UXO, even in cases where there are two targets in its field of view, and can discriminate them from clutter.

8017-07, Session 1

Inversion of dynamically repositioned multi-axis electromagnetic data for ordnance characterization

J. G. Keranen, G. Schultz, F. Shubiditze, J. Miller, L. Besaw, Sky Research, Inc. (United States)

The long-standing challenges associated with removing UXO and explosive remnants of war have led to a variety of methods for detection and discrimination of buried metallic objects using time-domain electromagnetic induction (EMI). In particular, recent work has shown that dipole polarizability tensor elements recovered from physics-based inversions can be very diagnostic in discriminating buried ordnance from non-ordnance. We present results of applying advanced processing to data from a dynamically repositioned multi-axis EMI instrument cued by digital geophysical surveys. Both magnetic dipole and normalized surface magnetic source (NSMS) models are used to resolve axi-symmetric targets of varying sizes and aspect ratios at different depths. The NSMS model can be considered as a generalized surface dipole model, with the single dipole model being a special limiting case. According to the NSMS model, an object's response to a sensor's primary magnetic field is modeled mathematically by a set of equivalent magnetic charges distributed over a surface surrounding the object. For discriminating UXO targets from clutter, we found that the total normalized magnetic source to be particularly useful. We assess the utility and veracity of dynamically sampled data acquired over a set of calibration and simulant targets. We also compare "on-the-fly" target localization methods combined with target parameterization derived from inversions. The combination of active target search methods and optimal sampling form an adaptive approach to target discrimination. Rapid target characterization codes are aggregated into a software package with particular focus on ease of use for non-expert users.

8017-08, Session 2

Live-site UXO classification studies via advanced EMI models

I. Shamatava, Sky Research, Inc. (United States); F. Shubitidze, Dartmouth College (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); J. P. Fernandez, A. Bijamov, Dartmouth College (United States)

First the data quality and the number of targets contributing to the signal are estimated using the JD technique. Once the number of targets is known, then the data is inverted and intrinsic parameters, such as the total ONVMS, are determined for each potential target using a standard non-linear optimization technique. These intrinsic parameters are grouped using the unsupervised Gaussian mixture approach. The potential targets of interests are: 37 mm projectile, M48 fuze, 105 mm projectile. For each group an anomaly is identified and ground truth is requested. Once the requested ground truth data is obtained, then each of the groups is classified. This paper reviews advanced EMI methods' data inversion, processing and discrimination schemes, and illustrates

the classification results scored by the Institute for Defense Analyses, for both the TEMTADS and MM sensors Camp Butner, NC cued data sets.

[This work is supported by the US Army Night Vision and Electronic Sensors Directorate (NVESD).]

8017-09, Session 2

Advanced UXO discrimination: resolving multiple targets and overlapping EMI signals

F. Shubitidze, Dartmouth College (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); I. Shamatava, J. P. Fernandez, Dartmouth College (United States); T. M. Grzegorczyk, Delpsi, LLC (United States); K. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States); A. Bijamov, Dartmouth College (United States)

Recently at live UXO sites, such as camp Sibert, Al, and former San Louis Obsipo, CA, various forward EMI models (i.e. dipole, normalized surface magnetic source) have demonstrated excellent UXO classification capabilities for well-isolated single targets using the next generation EMI data. However, the studies showed that the discrimination capability is considerably limited when sensors detect EMI signals from two or more targets simultaneously, i.e. overlapping EMI signals. Therefore, the obvious extension of current EMI data discrimination approaches is to accommodate overlapping EMI signatures is multiple targets data inversion and classification. One of the main difficulties for multi-target inversion is to estimate the number of targets (i.e. resolving multiple targets) that generate overlapping signals. In this work a joint diagonalization approach is employed with the next generation EMI sensors data for estimating the number of potential targets. These sensors provide multi-static response (MSR) data matrix. The studies showed that three eigenvalues in the MSR data matrix describe one target. In addition the eigenvalues' time dependence clearly exhibits the targets' classification features, which are used for creating initial targets diglist. Once the number of targets are known, then the objects' parameters are estimated using the non-dipole, physically complete EMI forward models called ortho-normalized volume magnetic sources (ONVMS) technique. In this work, excellent UXO classification performances are demonstrated for multi objects' (up to six targets) test-stand and UXO live site, at Former Camp Butner, NC, TEMTADS blind data sets

8017-10, Session 2

Frequency domain electromagnetic induction sensor data feature extraction and processing for improved landmine detection

S. L. Tantum, K. D. Morton, Jr., P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Frequency-domain electromagnetic induction (EMI) sensors have the ability 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. The basis function parameters can then be used as features for classification of the target as landmine or clutter. In this work, frequency-domain EMI sensor data feature extraction and processing is investigated, with a variety of physics-based models and statistical classifiers considered. Results for data measured with a prototype frequency-domain EMI sensor at a standardized test site are presented. Preliminary results indicate that extracting physics-based features followed by statistical classification provides an effective approach for classifying targets as landmine or clutter.

8017-11, Session 2

EMI sensor positioning using a beacon approach

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Discrimination of buried exploded ordnance by inversion of electromagnetic data requires accurate positioning of the sensor. There are many contaminated areas were dense forest or significant topography reduces the accuracy or precludes use of standard geo-location methods - such as satellite-based GPS and laser tracking systems (e.g., Robotic Total Station, RTS) - as these rely on line of sight. We tested and demonstrated the principle of an accurate, portable, local positioning system based on a beacon. The system was developed to survey with a Man-Portable Vector EMI sensor, the MPV. The magnetic moment of the MPV transmitter can be detected at a relatively large distance from the MPV. The primary field of the MPV transmitter is measured from a portable base station comprised of a 1.5 meter (m) horizontal boom with two vector receiver cubes that are similar to those on the MPV and are rigidly attached to either ends. Control tests showed that relative location and orientation could be recovered with sub-centimeter positional and one degree angular accuracy within a 5-m range and a 60-degree aperture (relative to the boom transverse direction), which is more than sufficient to cover any UXO anomaly. This level of accuracy satisfies the commonly accepted positional requirement for discrimination. The beacon positioning system can facilitate classification of munitions in any man-trafficable area and was successfully deployed at a field demonstration.

8017-81, Session 2

Multisensor system design dedicated to mine detection

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No abstract available

8017-12, Session 3

Synthetic aperture acoustic imaging of canonical targets with a 2-15 kHz LFM chirp

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Synthetic aperture image reconstruction is applied to indoor and outdoor acoustic recordings. Acoustic imaging is an alternate method having several military relevant advantages such as being immune to RF jamming, capability of standoff side and forward-looking scanning, low cost, weight, size and superior spatial resolution relative to 0.5 - 3 GHz ground penetrating radar technologies. Synthetic aperture acoustic imaging is similar to synthetic aperture radar but more akin to synthetic aperture sonar technologies owing to the nature of longitudinal or compressive wave propagation in the surrounding acoustic medium. This paper presents results obtained using a prototype system, consisting of a transceiver mounted on a carriage that travels along a 7-meter rail. The transceiver is a quasi mono-static microphone and audio speaker. The

speaker broadcasts a 2-15 kHz Linear Frequency Modulated (LFM) Chirp with a pulse repetition frequency (PRF) of 10 Hz and an inter-pulse period (IPP) of 50 milliseconds, while the microphone records sound reflected from the imaged scene, sampled at 44 kHz. Targets are positioned within the acoustic scene at slant range of three to seven meters while suspended in air, resting on grass, or weathered asphalt ground surfaces, and with intervening metallic chain link fencing. Acoustic image reconstruction results in means for literal interpretation and quantifiable analyses. A rudimentary technique characterizes acoustic scatter at the ground surfaces. Targets within the acoustic scene are first digitally spotlighted and further processed providing frequency and aspect-angle-dependent signature information.

8017-13, Session 3

Detection of unintended electromagnetic emissions from super-regenerative receivers

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The characteristics of unintended electromagnetic emissions from radio receivers are examined and we propose a novel method for detecting the presence of these emissions without a priori data or training. The chaotic properties of the internal oscillators from the radio receivers are modeled and used to detect the device emissions. A second-order self-similarity model is used to estimate the Hurst parameter as a detection threshold. The method is compared to a typical threshold method and is shown to be a significant improvement in the accuracy of detection. Upon detection, the received signal strength can be used to locate the device.

8017-14, Session 3

Ground target stimulaiton using a moving microwave source

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This effort is directed towards characterizing the response of a target placed on or near the ground to the radiation of a microwave source mounted on a moving vehicle. Because of the multipath problems inherent in measuring the electric field strength on or near the earth's surface, a theoretical model was constructed so that the effectiveness of the dynamic approach to actuating specific targets could be characterized. This process is repeated for a variety of microwave source speeds, vehicle to target aspect ratios and target positions on or above the ground plane.

Given a horizontally polarized beam driven by a horn antenna, the electric field strengths were calculated at different vehicle to target aspect ratios and at different heights on and above the ground plane for sand and clay soils. These values were then modeled in MATLAB to provide target stimulation for varied pulse chains. A model with independent pulse effects and a model based on cumulative effect of pulses were evaluated.

8017-15, Session 3

DS Sentry : an acquisition ASIC for smart, micro-power sensing applications

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Unattended ground monitoring that combines seismic and acoustic information can be a highly valuable tool in intelligence gathering; however there are several prerequisites for this approach to be viable. The first is high sensitivity as well as the ability to discriminate real threats from noise and other spurious signals. By combining ground sensing with acoustic monitoring this requirement may be achieved. Moreover, the DS Sentry provides innate spurious signal rejection by the "active-filtering" technique employed as well as embedding some basic statistical analysis. Another primary requirement is spatial and temporal coverage. Ideally, the perpetual monitoring of any expanse of area is coveted. Therefore, sensors should be densely deployed and consume very little power. Furthermore, sensors must be inexpensive and easily deployed to allow dense placements in critical areas. The ADVIS DS Sentry , which is a fully-custom integrated circuit that enables smart, micro-power monitoring of dynamic signals, is the crux of the proposed system. The core premise behind this technology is the use of an ultra-low power front-end for active monitoring in conjunction with a high-resolution, $\Sigma\Delta$-based analog-to-digital converter, which utilizes a novel noise rejection technique and is only employed when a threat has been detected. The DS Sentry can be integrated with seismic accelerometers and microphones and user-programmed to continuously monitor for signals with specific signatures such as impacts, footsteps, excavation noise, vehicle-induced ground vibrations, or speech, while consuming only microwatts of power. This will enable up to several years of continuous monitoring on a single small battery while concurrently mitigating false threats.

8017-16, Session 3

Threat detection in desert environment with passive millimeter-wave sensor

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A new method of IED creation uses an explosive device and control electronics surrounded by foam and covered in a thin layer of sand/dirt. The material characteristics of these IEDs make passive millimeter wave (pmmW) sensors a suitable candidate for countermeasures. The thin layer of sand/dirt that is applied to the outside of the foam is sub-wavelength and does not strongly interact with mmW radiation while many foam materials are transmissive at millimeter wavelengths. This results in the explosive device and control circuitry being exposed to detection. Metal and highly reflective materials produce strong contrast signals for mmW sensors due to the reflection of the 'cold sky' radiometric temperature. Mortar shells and other common explosives in IEDs will produce high contrast signals which can be detected by a pmmW sensor. Results are presented from a recent data collection event using a mock IED created at the University of Delaware. A mock desert scene was set-up using dirt from the Yuma Proving Grounds. Several large rocks, small mounds of dirt and footprints were also included as potential clutter. Images from the sensor clearly show a radiometrically cold object at the location of the mock IED. The root-sum-square radiometric temperature difference between the mock IED and dirt background was 12 K for radiation polarized vertically relative to the sensor and 10 K for radiation polarized horizontally relative to the sensor.

8017-17, Session 3

Laser neutralization of buried munitions

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This paper describes the results of the first phase of a planned two-phase

program to develop laser technology for rapid neutralization of buried mines and Improvised Explosive Devices (IEDs) from a safe standoff distance. The primary objective of this first phase is to demonstrate, via laboratory experiments, the capabilities of a breadboard laser system to "drill" through a minimum depth of 15 cm of earthen materials to defeat a buried mine/IED at a standoff distance greater than 20 m. The results of short range laboratory testing by 3 contractors are reported. The planned second phase of this program will consist of procuring a more capable 10 kW SM laser and performing field-testing at longer standoff ranges. The planned second phase of this program will consist of procuring a more capable 10 kW SM laser and performing field-testing at longer standoff ranges.

8017-18, Session 4

Automation for underwater mine recognition: current trends and future strategy

J. R. Stack, Office of Naval Research (United States)

The purpose of this paper is to define the future vision and outlay the technical strategy for automated underwater mine recognition. This technical strategy is founded on the principle of adapting the automation to changing context / environment and maximally leveraging the human expert when available. This paper begins by detailing the underwater mine recognition problem including typical data (with emphasis on imaging systems), common feature extraction techniques, and classification approaches. It also discusses the evolution of these techniques over time. The future vision is introduced by discussing an incremental roadmap for the evolution of the user experience. While this roadmap is aimed at near-full automation, it includes the intermediate steps necessary to gain trust from the user community and maximize the utility of the algorithm-human interactions. Afterwards, the technical strategy is outlaid focusing on the four core areas of performance estimation, adaptive automatic target recognition (ATR), contact correlation, and synthetic target insertion. At the heart of this technical strategy is the observation that model-based performance estimation must inherently compute parameters that are functions of the environment or context, and it must explicitly map them to algorithm performance. This observation enables a multitude of adaptation approaches based on explicitly linking these parameters to the algorithmic variables, models, and/or techniques. The novelty and unprecedented power of these adaptation approaches is that they are not relegated to only adapting a decision boundary in feature space; rather, they adapt the formation and maximize the saliency of the feature space itself. Specifically these adaptation techniques focus on optimizing the preprocessing, detection, and feature extraction stages to maximize discrimination. Multiple, independent sets of experimental results on initial approaches are presented to support this technical strategy. This paper concludes with observations on how this strategy may best support future autonomy in unmanned underwater systems.

8017-19, Session 4

Adaptive clutter removal from imagery and its impact on ATR with application to high-resolution sonar

G. J. Dobeck, Naval Surface Warfare Ctr. Panama City Div. (United States)

The Office of Naval Research has sustained a significant research effort in the area of automated sea-mine detection and classification (D/C). The thrust of this effort was five-fold: (1) reduce false alarms that slow mine clearance operations, (2) dramatically speed up post mission analysis so that the location of mines are reported to command and control in a timely fashion, (3) reduce the workload of operators who must look at volumes of sensor data, (4) increase probability of detection and classification against stealthy mines hidden in the complex littoral environment, and (5) supply robust real-time D/C algorithms for the MCM autonomous underwater vehicle (AUV) systems being developed to keep humans and assets out of harms way.

The high-resolution side-scan sonar and the high-frequency synthetic-aperture sonar are two important sensors used for sea mine detection and classification. The ability to discriminate bottom targets in imagery collected from these sonars is especially difficult in littoral environments where there is large-scale clutter and complex sea bottom textures; e.g., sand ripple or coral beds. Detection and classification would benefit from an adaptive denoising algorithm that would remove such background artifacts. This paper presents a Fourier-based denoising algorithm that removes features in the image that are of larger scale than the expected target size. The large support of the Fourier bases is used to capture and remove large-scale artifacts while leaving the target-size features nearly unchanged. Preliminary investigations have demonstrated excellent performance. The algorithm is computationally fast and suitable for real-time application. It is general in nature and can be applied to other types of imaging sensors; e.g., SAR.

8017-20, Session 4

SAS image segmentation using parameterized autocorrelation function models

J. T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States)

An algorithm for segmenting SAS seabed textures using features from parameterized autocorrelation function models is presented. The intensity autocorrelation function is modeled as a scaled Gaussian mixture. Parameters from the model are estimated via an Expectation Maximization algorithm for truncated data. These parameters are then fed to a supervised maximum likelihood segmentation method to separate various classes of textures. Results on simulated SAS images are presented.

8017-21, Session 4

Optimal frames for pattern recognition applications

J. C. Isaacs, Naval Surface Warfare Ctr. Panama City Div. (United States)

Frame methods, basis expansion methods, or kernel methods provide a higher-dimensional representation of a given data set within a feature space for discrimination applications. Frame pursuit addresses the problem of finding optimal frames to improve classification for pattern recognition applications. In this paper, the results of two stochastic optimization techniques applied to the optimal frame problem are presented. The cost function is an entropy measure. These techniques are tested here over eight publically available data sets. However, the results are shown for three of these sets. Empirical results demonstrate the utility of frame transformations for improving performance results in pattern recognition applications.

8017-22, Session 4

Statistical analysis and classification of acoustic color functions

J. D. Tucker, J. T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States)

Detection and classification of underwater objects in sonar imagery is a complicated problem due to various factors such as variations in operating and environmental conditions, presence of spatially varying clutter, variations in target shapes, compositions, and orientation.

Moreover, due to the enhanced sonar resolution bottom features can totally obscure a mine-like object. Recent studies have indicated that different bottom types exhibit non-Gaussian probability distributions depending on the grazing angle, sonar frequency and range for sonar imagery. Specifically, the K-distribution has shown to be a good assumption for the distribution of Synthetic Aperture Sonar (SAS) imagery. In this paper a new detection method for sonar imagery is developed for K-distributed background clutter using a finite mixture model (FMM) of K-distributions. The method for estimation of the parameters of the FMM and a generalized log-likelihood ratio test is derived. The detector is compared to the corresponding counterparts derived for the standard K, Gaussian, and Rayleigh distributions. Test results of the proposed method on a data set of synthetic underwater sonar (SAS) images is also presented. This database contains images with synthetically generated targets of different shapes inserted into real SAS backgrounds. Results illustrating the effectiveness of the FMM K-distributed detector are presented in terms of probability of detection, false alarm rates rates, and receiver operating characteristic (ROC) curves for various bottom clutter scenarios.

8017-23, Session 4

Seabed change detection in challenging environments

C. Matthews, D. Sternlicht, Naval Surface Warfare Ctr. Panama City Div. (United States)

Long used in airborne radar, image correlation Automatic Change Detection (ACD) is arguably the most sensitive technique for detecting changes in radar imagery. For image correlation to reliably detect the appearance of small man-made objects in sonar imagery, the overall inter-scene coherence between multi-temporal images must be maximized. The background of the two scenes must quantitatively be similar such that changes detected can be discriminated from inter-scene noise consisting of decorrelation due to variations in viewing geometry, system imperfections, and especially changes in the scene between imaging events. Synthetic Aperture Sonars (SAS) are well suited for this approach. They produce range-independent, fine resolution seafloor images out to hundreds of meters, and when mounted on actively navigated platforms capable of accurately repeating survey tracks (such as Autonomous Underwater Vehicles (AUVs)), radiometric inconsistencies between old and new data are minimized.

Analysis of the prominence or saliency of targets versus the non-stationary characteristics of the environment provides a high differential in the statistical variations between two co-located SAS images. After image co-registration and proper spectral filtering to account for geometric offsets, the backscatter variance measured between images can be used to define prominence of local repeat pass image components relative to the reference image. Through simulated and field data, it is shown that salient feature analysis should allow development of change detection techniques alerting to the presence of new objects, while ignoring temporal changes in sediment backscatter due to hydrographic processes (e.g. generation of ripples) - a method we call Time Invariant Saliency (TIS), outlined in figure 1. We anticipate that this ability to conduct automatic change detection in non-stationary environments will have wide application for MCM and port security.

8017-24, Session 5

Metrics of the eigenfunctions of the graph Laplacian for 3D shape matching

J. C. Isaacs, Naval Surface Warfare Ctr. Panama City Div. (United States)

Assuming that a 2D surface is a representation of a manifold embedded in 3-space then metrics of the eigenfunctions of the diffusion maps of that manifold represent the shape of that manifold with invariance to rotation, scale, and translation. Diffusion maps is said to preserve the local proximity between data points by constructing a representation for the underlying manifold by an approximation of the Laplace-Beltrami operator acting on the graph of this surface. This work examines 3D shape clustering problems using metrics of the projections onto the nodal sets of the eigenfunctions of the diffusion maps on a manifold for shape analysis of closed surfaces. Results demonstrate that the metrics allow for good class separation over multiple targets.

8017-25, Session 5

Data clustering and fusion using deformable structure Bayesian networks (DSBN)

K. Kampa, J. T. Cobb, J. C. Principe, A. Rangarajan, Univ. of Florida (United States)

Deformable Structure Bayesian Network (DSBN) is a Bayesian network whose joint probability p(X,Y,Z) includes both node variables (X,Y) and structure variables (Z), therefore, the random variables can be inferred concurrently. Consequently, the capabilities of probabilistic model and model selection are naturally combined in the same framework where we can do data clustering and fusion simultaneously. The objective function to be maximized is constructed by the structure likelihood given the evidence and the optimal parameter p(Y|Z) with the prior knowledge p(Z) and penalized by the model complexity function. For a given structure Z, the likelihood and the model parameters can be calculated efficiently using Belief propagation in E-step of the EM algorithm as we restrict the structure to be forest of trees. However, the structure space is very complicated, in order to find the best structure, the simulated annealing optimization framework and exhaustive search is employed over the structure space. In this paper, DSBN is restricted to 3-layer structure and each node is modeled by linear Gaussian given its parent. The posterior distribution at each root node is regarded as the fused information of its corresponding evidence, consequently, the most probable solution can be found from maximum a posteriori (MAP) solution with the uncertainty of the estimate in form of covariance matrix which is desired for variety of applications. Finally, we proposed an extension using mean-field variational approximation to speed up the algorithm. By constructing a similar but simpler distribution (a.k.a. variational distribution) where we can manipulate its parameters easily, the true posterior is approximated by the variational posterior.

8017-26, Session 5

Bayesian surprise metric for outlier detection in on-line learning

E. Hasanbelliu, K. Kampa, J. C. Principe, Univ. of Florida (United States); J. T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States)

Our previous work developed an online learning Bayesian framework (dynamic tree) for data organization and clustering. To continuously adapt the system during operation, we concurrently seek to perform outlier detection to prevent them from incorrectly modifying the system. We propose a new Bayesian surprise metric to differentiate outliers from the training data and thus help to selectively adapt the model parameters. The metric is calculated based on the difference between the prior and the posterior distributions on the model when a new sample is introduced. A good training datum would sufficiently but not excessively change the model; consequently, the difference between the prior and the posterior distributions would be reasonable to the amount of new information present on the datum. However, an outlier carries an element of surprise that would significantly change the model. In such a case, the posterior distribution would greatly differ from the prior resulting in a large value for the surprise metric. We categorize this datum as an outlier and other means (e.g. human operator) will have to be used to handle such cases. The surprise metric is calculated based on the model distribution, and as such, it adapts with the model. The surprise factor is dependent on the state of the system. This speeds up the learning process by

considering only the relevant new data. Both the model parameters and even the structure of the dynamic tree can be updated under this approach.

8017-27, Session 5

Low-noise magnetic sensing for marine munitions characterization

G. Schultz, Sky Research, Inc. (United States); S. Billings, Sky Research, Inc. (Australia); C. Bassani, J. Foley, R. Fonda, Sky Research, Inc. (United States)

Because the recovery of underwater munitions is many times more expensive than recovering the same items on dry land, there is a continuing need to advance marine geophysical characterization methods. To efficiently and reliably conduct surveying in marine environments, low-noise geophysical sensors are being configured to operate close to the sea bottom. We describe systems that are deployed from surface vessels via rigid or flexible tow cables or mounted directly to submersible platforms such as unmanned underwater vehicles. Development and testing of a towed configuration has led to a 4 meter wide hydrodynamically stable tow wing with an instrumented top-side assembly mounted on the stern of a surface survey vessel. An integrated positioning system combined with an instrumented cable management system, vessel and wing attitude and wing depth measurements provide sub-meter positional accuracy in up to 25 meter water depths and within 1 to 2 meters of the seafloor. We present the results of data collected during an instrument validation survey over a series of targets emplaced at measured locations. Performance of the system was validated through analyses of data collected at varying speeds, headings, and heights above the seafloor. Implementation of the system during live-site operations has demonstrated its capability to survey hundreds of acres of marine or lacustrine environment. Unique deployment concepts that utilize new miniaturized and very low noise sensors show promise for expanding the applicability of magnetic sensing at marine sites.

8017-28, Session 5

Active source electromagnetic methods for marine munitions

G. Schultz, F. Shubiditze, J. Miller, Sky Research, Inc. (United States)

The detection of munitions targets obscured in coastal and marine settings has motivated the need for advanced geophysical technologies suited for underwater deployment. Building on conventional marine electromagnetic theory and based on the use of existing electric and magnetic field sensing designs, we analyze the electromagnetic fields emitted from excited targets in the frequency range between 1 kHz and 1 MHz. We present evidence that employing electromagnetic modes that are higher in frequency relative to those typically used in ground-based sensing yields greater range and sensitivity for underwater surveys. We develop potential design strategies for implementing both magnetic (B) and electric (E) field sources and sensors in the marine environment, and determine optimal arrangements for a potential combined E- and B-field sensing system. The implementation of both 1D analytical and 3D numerical simulations yields the primary and secondary field distributions in representative underwater settings for various source-receiver arrangements. We study the electromagnetic field distributions from both electric (voltage-fed dipole) and magnetic field (encased and submerged induction coil) active sources. Application of these concepts provide unique and useful information about targets from the addition of electric field sensing alone as well as through the combination of electric and magnetic field sensing.

8017-29, Session 5

Investigating magnetic-field sensor configurations for underwater geo-location

F. Shubitidze, Dartmouth College (United States); G. Schultz, J. Miller, I. Shamatava, Sky Research, Inc. (United States)

In this work new magnetic field transmitter coils and receiver sensor configurations are presented for underwater geo-location. Studies are conducted using numerical code based on the method of auxiliary sources (MAS) to define a system based a low frequency magnetic fields that penetrate inside conducting media and their tensor gradients at a given point in space. It contains an active pulsed DC transmitter, tri-axial receivers, and a GPS. The active transmitter is coupled to a GPS that provides continuous geo-referencing of the transmitter position. An underwater UXO interrogation system (e.g., EMI or acoustic) has a set of tri-axial or total magnetic field sensor receivers that tracks the location of the interrogation system relative to the geo-referenced surface transmitter using low-frequency magnetic field measurements. In this work, the MAS is utilized for numerical analysis of coupling between the proposed new geo-location, underwater UXO interrogation systems and targets of interest. Namely, this work presents systematic studies on: a) magnetic field transmitter configurations to determine the best compromise between size, shape and practical implementation for the maximum range in underwater environments, b) tri-axial and total magnetic field receiver placements in order to accurately approximate the actively transmitted DC magnetic field tensor gradient from the spatial differences between receivers; c) variable noise sources (such as the air-water interface and coupling between target electromagnetic responses and the geo-location system) to estimate how the they influence the system's performance and location precision/accuracy. The theoretical investigations are validated with experimental data.

8017-30, Session 6

Coaxial line measurement and analysis of electromagnetic properties of soils for sensor applications

W. R. Folks, R. North, J. R. Kelley, A. Cunningham, J. McKenna, U.S. Army Engineer Research and Development Ctr. (United States)

We report complex permittivity, conductivity, magnetic susceptibility, and attenuation for soils collected from a typical site in a current theater of operations. Our experimental setup consists of three network analyzers along with custom-built sample holders and data reduction and analysis software. This system was developed to determine the electrical properties of soils over a wide frequency range from 100 Hz to 8 GHz. The lower frequencies are applicable to capacitive sensors for small shallow targets, while the higher frequencies are applicable to ground-penetrating radar (GPR) from 50 MHz to 2 GHz and beyond. S-parameter data is collected and reduced using a method, initially developed by Nicolson and Ross (1970) [1], for the determination of dielectric permittivity, magnetic permeability, and loss tangent from measured S-parameter data. After data reduction, results are fit to one of a number of models, for example, Debye, Cole-Cole, Cole-Davidson, or Lorentz, that allow for the determination of relation time and damping parameters. Experimental results are compared with site geology and mineralogy. Applications include detection of tunnels, land mines, unexploded ordinance (UXO), concrete reinforcements, and other shallow compact targets.

[1] A.M. Nicholson and G.F. Ross, Measurement of the intrinsic properties of materials by time-domain techniques. IEEE Trans. Instrum. Meas. 19 (1970), pp. 377-382.

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8017-31, Session 6

Performance of demining sensors and soil properties

K. Takahashi, H. Preetz, J. Igel, Leibniz Institute for Applied Geosciences (Germany)

Metal detector has commonly been used for landmine detection and ground-penetrating radar (GPR) is about to be used. Since both devices employ electromagnetic techniques, they are influenced by magnetic and dielectric properties of soil. To observe the influence, various soil properties as well as their spatial distributions were measured in four types of soil where a field test of metal detectors and GPRs took place. By analysing soil properties these four types of soil were graded based on the estimated amount of influence on the detection techniques. The classification was compared to the detection performance of devices obtained from the blind test and a clear correlation between the difficulty of soil and the performance was observed; detection and identification performance were degraded in difficult soil. Therefore, it was demonstrated that the performance of metal detector and GPR for landmine detection can qualitatively be assessed by geophysical analyses.

8017-32, Session 6

Effects of different soil types on strip-map SAR images using real-time impulse GPR system data

H. Nazli, M. Sezgin, TÜBITAK Marmara Research Ctr. (Turkey)

In this study, we present production of Strip-map Synthetic Aperture Radar (SAR) images using impulse GPR data gathered by ETMTS-2, and investigate effects of different soil types on SAR images. The SAR images of a buried object have been interpreted as tomographic reconstruction via inverse Fourier transformation and analyzed by current - field relations. In the first part of this study, The ETMTS-2 system data for a constant target have been collected in different soil pools known as dielectric constant, and reconstructed B-scan images from the received data. Secondly, time domain data collected from multiple observation points have been transformed 2D spectral domain and non uniform data on spectral domain have been interpolated to Cartesian grid by uniform interval. The SAR images have been reconstructed via 2D inverse FFT of interpolated data on ky-kz plane. Finally, it has been observed effects of the dielectric constants of soils on the SAR images and observed that resolution difference between B-Scan and SAR images on the real time data using ETMTS-2 system.

8017-33, Session 6

Simultaneous inversion of electromagnetic induction data for target and soil parameters

L. R. Pasion, K. Kingdon, J. Jacobson, Sky Research, Inc. (Canada); S. Billings, Sky Research, Inc. (Australia); D. W. Oldenburg, The Univ. of British Columbia (Canada)

At UXO remediation sites where the background geology response is small relative to the response of metallic targets, inversion of electromagnetic induction (EMI) data for the dipole polarization tensor can be an effective tool for discriminating between intact ordnance and scrap metal. In the presence of magnetic soil, sensor movement and surface topography can lead to sensor data anomalies that have similar size and shape of compact metallic targets. This spatially correlated noise from the presence of a geologic background greatly reduces the accuracy of dipole polarization estimates, and thus increases the probability of incorrect classification. In this presentation, we will outline a data processing approach that incorporates GPS and IMU information to model the small spatial wavelength features due to sensor movement. We will detail the two step procedure for simultaneously estimating parameters describing the amplitude and spatial variation of the geology and parameters characterizing a buried compact target. This method takes advantage of the differences in the spatial and temporal (or spectral) characteristics of the time (or frequency) domain response between magnetic soils and metallic targets. This method will be demonstrated using simulated and field data acquired with the Man Portable Vector (MPV) EMI sensor. We will present results from processing MPV data collected at the Defense Research and Development Canada test facility in Suffield, Alberta. We will focus on the ability to produce robust estimates of dipole parameters from data collected over steel and aluminum targets buried in a soil pit containing highly magnetic Cambodian soil.

8017-34, Session 6

High-resolution soil moisture mapping in Afghanistan

J. M. H. Hendrickx, J. B. Harrison, B. Borchers, New Mexico Institute of Mining and Technology (United States); J. R. Kelley, S. Howington, J. R. Ballard, Jr., U.S. Army Engineer Research and Development Ctr. (United States)

Soil moisture conditions have an impact upon virtually all aspects of Army activities and are increasingly affecting its systems and operations. Soil moisture conditions affect operational mobility, detection of landmines and unexploded ordinance, natural material penetration/ excavation, military engineering activities, blowing dust and sand, watershed responses, and flooding. This study further explores a method for high-resolution (2.7 m) soil moisture mapping using remote satellite optical imagery that is readily available from Landsat and QuickBird. The soil moisture estimations are needed for the evaluation of IED sensors using the Countermine Simulation Testbed in regions where access is impossible or difficult. The method has been tested in Helmand Province, Afghanistan, using a Landsat7 image and a QuickBird image of April 23 and 24, 2009, respectively. The objective of this study is to examine how the quality of the downscaled soil moisture maps can be improved by using different stratifications for the development of site-specific downscaling regression equations.

8017-35, Session 7

Principles and status of neutron-based inspection technologies

T. Gozani, Rapiscan Systems Labs. (United States)

Nuclear based explosive inspection techniques can detect a wide range of substances of importance for a variety of purposes. For national and international security is it mainly detection of nuclear materials, explosives and narcotics threats. For Customs services it is cargo characterization for shipment control and customs duties. For the military and other law enforcement agencies it could be the detection and/or validation of the presence of explosives mines, improvised explosive devices (IED) and unexploded ordnances (UXO).

The inspection is generally founded on the nuclear interactions of the neutrons with the various nuclides present and the detection of resultant characteristic emissions. These can be discrete gamma lines resulting from the thermal (n,γ) neutron capture process or inelastic neutron scattering (n,n'γ) occurring with fast neutrons.

The detection of nuclear materials, both fissionable (e.g., 238U) and fissile (e.g., 235U), are generally based on the fissions induced by the probing neutrons and detecting one or more of the unique signatures of the fission process. These include prompt and delayed neutrons and prompt and delayed gamma rays. These signatures are not discrete in energy (typically they are continua) but temporally and energetically significantly different from the background, thus making them readily distinguishable.

Return to Contents

The application of nuclear interrogation techniques greatly depends on operational requirements. For example explosive mines and IED detection is clearly one-sided inspection, which excluded transmission based inspection (e.g. transmission radiography) and greatly impacts others.

The principle, applications and status of neutron-based inspection techniques will be reviewed.

8017-36, Session 7

ESCALAD: a scanning landmine detector based on neutron backscattering

V. R. Bom, Technische Univ. Delft (Netherlands); A. M. Osman, R. M. Megahid, Egyptian Atomic Energy Authority (Egypt)

The neutron backscattering (NBS) technique is a well established method to find hydrogen in objects. In this "one sided" method fast neutrons are slowed down by the hydrogen and registered when they re-emerge from the object by a slow neutron detector.

NBS may be applied in land mine detection since land mines are abundant in hydrogen. The high operational speed of NBS makes it possible scan for mines moving at speeds up to 1 km/h. Additional advantages of NBS are the insensitivity to metal debris and to pebbles/stones in the ground and the ability to also find completely metal free mines. The NBS method must be applied on arid soils because of the sensitivity to hydrogen and can therefore be used to advantage in heavily mined areas like Egypt and the middle east countries, where about half of all mines in the world are found.

ESCALAD is a humanitarian scanning NBS demining device being developed in a collaboration between Egypt and the Netherlands. It employs imaging of the back scattered neutron radiation to separate counts from the soil by detection position and so greatly enhance the sensitivity of detection. An imaging system can also reject clutter p.e. due to variations in soil moisture level by ignoring signals shapes that are not mine-like and so improve the false alarm rate with respect to non-imaging point detectors.

We will show the ESCALAD detector, the development, construction and present status and the performances obtained during comparative demining device tests recently held in Egypt.

8017-37, Session 7

Portable and autonomous x-ray equipment for in-situ threatening materials identification by atomic effective number high-accuracy measurement

M. Iovea, M. Neagu, G. Mateiasi, O. Duliu, A. Caescu, M. SIMA, ACCENT PRO 2000 s.r.l. (Romania)

New portable and autonomous X-ray dual-energy Radioscopy equipment destined for bomb squad interventions that is capable of in-situ measurement of materials' Atomic effective number (Zeff) is presented. The system contains a 2D X-ray dual-energy detectors, manufactured based on linear array detector fast translation solution, a portable X-ray source and dedicated software running on a Laptop. By fast measurement of collected transmission data at two X-Ray energies spectrum, the system could directly compute the materials' Zeff values for various organic materials contained in the scanned object and then to identify them from a database list. The entire system calibration has been checked using explosive simulants with known Zeff values, the measurement accuracy of Zeff being around 2-3%. The ability of automate threats identification algorithm and various correction techniques are presented for an experiment with a hand-held luggage having various organic objects and explosive simulants inside.

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8017-38, Session 7

Defence R&D Canada-Suffield research on nuclear methods for detection of buried bulk explosives

J. E. McFee, A. A. Faust, Defence Research and Development Canada (Canada)

Defence R&D Canada Suffield has conducted research and development on nuclear methods for detection of bulk explosives since 1994. Initial efforts were directed at confirmation of the presence of bulk explosives in land mines and improvised explosive devices (IEDs). In close collaboration with a few key Canadian companies, methods suitable for vehicle-mounted or fixed position applications and those suitable as person- or small robot- portable use have been studied. Vehicle-mounted systems mainly employ detection of characteristic radiation, whereas person-portable systems use imaging of back scattered radiation intensity distributions. Two key design concepts have been reduction of personnel shielding by the use of teleoperation and custom design of sensors to address the particular problem, rather than adapting an existing sensor to the problem. This will be shown in a number recent research examples.

Among vehicle-mounted systems, recent research to improve the thermal neutron analysis (TNA) sensors, which were put into service with the Canadian Forces in 2002, will be discussed. Research on fast neutron analysis (FNA) and associated particle imaging (API), which can augment or replace TNA depending on the application, will be described. Monoenergetic gamma ray induced photoneutron spectroscopy is a novel method which has a number of potential advantages and disadvantages over TNA and FNA. Sources, detectors and geometries have been identified and modelling studies have suggested feasibility. Among person-portable systems, research on coded aperture X-ray backscatter imaging and neutron backscatter imaging (proximity and coded aperture) will be discussed. Experiments to detect culvert bombs using TNA and neutron backscatter imaging will be discussed.

8017-39, Session 8

Nuclear quadrupole resonance detection of explosives: an overview

J. B. Miller, U.S. Naval Research Lab. (United States)

Nuclear Quadrupole Resonance (NQR) is a spectroscopic technique closely related to Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI). These techniques, and NQR in particular, induce signals from the material being interrogated that are very specific to the chemical and physical structure of the material, but are relatively insensitive to the physical form of the material. NQR explosives detection exploits this specificity to detect explosive materials, in contrast to other well known techniques that are designed to detect explosive devices. The past two decades have seen a large research and development effort in NQR explosives detection in the United States aimed at transportation security and military applications. In this talk, I will briefly describe the physical basis for NQR before discussing NQR developments over the past decade, with particular emphasis on landmine detection and the use of NQR in combating IED's. Potential future directions for NQR research and development will be described.

8017-40, Session 8

Observations on military exploitation of explosives detection technologies

A. A. Faust, Defence Research and Development Canada (Canada); C. J. de Ruiter, TNO Defence, Security and Safety (Netherlands); A. Ehlerding, Swedish Defence Research Agency (Sweden); J. E. McFee, Defence Research and Development Canada (Canada); E. Svinsås, A. D. van Rheenen, Norwegian Defence Research Establishment (Norway)

Accurate and timely detection of explosives, energetic materials, and their associated compounds would provide valuable information to military commanders in a wide range of military operations: protecting fast moving convoys from mobile or static IED threats, during more deliberate countermine and counter-IED operations during route or area clearance, or in static roles such as hasty or deliberate checkpoints, critical infrastructure protection and support to public security. After ten years of operations in South West Asia, it would be worthwhile to assess the impact of this technology on the battlefield and in the fight against terror.

The detection of hidden explosive hazards is an extremely challenging problem, as evidenced by the fact that related research has been ongoing in many countries for at least seven decades and no general purpose solution has yet been found. Technologies investigated have spanned all major scientific fields, with emphasis on the physical sciences, life sciences, engineering, robotics, computer technology and mathematics.

This paper will present a limited, operationally-focused overview of the current status of detection technologies. Emphasis will be on those technologies that directly detect the explosive hazard, as opposed to those that detect secondary properties of the threat, such as the casing, associated wires or electronics. Technologies that detect explosives include those based on radiofrequency resonance absorption, nuclear radiation and terahertz radiation, as well as trace and biological detection techniques. Results from the authors' research groups and experiences shared by their respective military partners will be used to illustrate the practical applications.

8017-41, Session 8

Explosives (and other threats) detection using pulsed neutron interrogation and optimized detectors

D. A. Strellis, T. Gozani, M. Elsalim, Rapiscan Systems Labs. (United States)

We have previously reported results from a human-portable threat detection system based on neutron interrogation with program funding from the DOD Counternarcotics Office. We summarized our methodology for distinguishing threat materials such as narcotics, C4, and mustard gas in the myraid of backgrounds present in the maritime environment. We are expanding our mission for the Domestic Nuclear Detection Office (DNDO) to detect Special Nuclear Material (SNM) through the detection of multiple fission signatures without compromising the conventional threat detection performance.

The subject of this paper is the creative use of neutrons from pulsed neutron generators via the d(D,n)3He or d(T,n)alpha reactions with energies of ~2.5 and 14 MeV, respectively, for explosives (and other threats) detection with a compact form factor system. These fast neutrons or thermal neutrons (after successive collisions) can stimulate gamma-ray emission via the (n,n'gamma) inelastic scattering reaction and the (n,gamma) thermal capture reaction from explosive material hidden in a cavity of iron, wood, or iron/concrete. The focus of this paper will be the results of our trade-off investigations on system size and weight, system complexity, and explosive detection performance. Gamma-ray detectors of different types (NaI, CsI, LaBr3, SrI2, and plastic scintillator), sizes, efficiencies, resolutions, and induced-backgrounds in a neutron environment were studied. Measurements were conducted using both 2.5 and 14-MeV pulsed neutron generators to understand the trade-offs between neutron output, threat detection performance, and measurement time with the understanding that neutrons of different energies induce different threat signatures as well as backgrounds.

8017-42, Session 8

A non-imaging polarized terahertz passive system for detecting and identifying concealed explosives

M. A. Karam, D. Meyer, Northrop Grumman Navigation Systems (United States)

Existing terahertz (THz) systems for detecting concealed explosives are not capable of identifying explosive type which leads to higher false alarm rates. Moreover, some of those systems are imaging systems that invade personal privacy, and require more processing and computational resources. Other systems have no polarization preference which makes them incapable of capturing the geometric features of an explosive.

In this study a non-imaging polarized THz passive system for detecting and identifying concealed explosives overcoming the forgoing shortcomings is developed. The system employs a polarized passive THz sensor in acquiring emitted data from a scene that may have concealed explosives. The acquired data are decomposed into their natural resonance frequencies, and the number of those frequencies is used as criteria in detecting the explosive presence. If the presence of an explosive is confirmed, a set of physically based retrieval algorithms is used in extracting the explosive refractive index value from natural resonance frequencies and amplitudes of associated signals. Comparing the refractive index value against a database of refractive indexes of known explosives identifies the explosive type.

As an application, a system having a dual polarized radiometer operating within the frequency band of 0.62- 0.72 THz is presented and used in detecting and identifying person borne C-4 explosive concealed under a cotton garment. The system showed higher efficiencies in detecting and identifying the explosive.

8017-43, Session 9

Detection and identification of explosives hidden under barrier materials: What are the THz-technology challenges?

A. D. van Rheenen, M. W. Haakestad, Norwegian Defence Research Establishment (Norway)

We describe experiments where different explosives were hidden under common barrier materials, and THz radiation was used to detect and identify these explosives. Our THz system, a time-domain spectroscopy (TDS) system, is based on a femtosecond laser whose radiation is converted into THz radiation by a low-temperature grown GaAs photoconductive switch. A similar switch detects the reflected signal. The advantage of using a TDS system is that pulses reflected from the barrier and the actual explosive, arrive at different instances at the detector. This simplifies the separation of the barrier signature from the explosive signature, compared to a frequency domain system. However, partial temporal overlap between the two pulses makes it challenging to completely separate the spectral characteristics of the explosive from the characteristics of the barrier. Also, in addition to attenuating the THz-pulses, transmission through barrier materials may add spectral features to the reflected signal, hampering recognition of the explosive. On top of that, the explosive may have a rough surface, which reduces the strength of the reflected signal.

In this contribution we shall address these issues and discuss strategies that may be used to face these challenges.

8017-44, Session 9

Improved real-time processing of hyperspectral imaging data

R. Schweitzer, M. P. Nelson, R. J. D'Agostino, P. J. Treado, ChemImage Corp. (United States)

Proliferation of explosive threats is an escalating threat to civilian and military personnel. Sensor systems that can rapidly detect explosives at standoff distances in operationally relevant sensor configurations are achieving a state of robustness and reliability. These hyperspectral imaging sensors generate significant volumes of data that needs to be reduced to a manageable form on a timescale that's relevant to its intended use and that carries a high PD and a low PFA.

ChemImage has developed algorithms and software strategies that are designed to process this data to meet the required specifications. These development efforts are the foundation of a Real Time Toolkit (RTTK) that currently supports data from Raman, LIBS, SWIR, and RGB sensors. The RTTK addresses the following key elements:

1. Advanced algorithms that provide robust and accurate identifications, thereby minimizing the need for user input at the identification stage.

2. A highly intuitive user interface that allows the user to quickly comprehend the level of threat and make rapid decisions.

3. A robust hardware and software platform that performs the data processing at a real-time sensing tempo.

The algorithms and software take advantage of multiple sensors, spectral and spatial information, multiple scenes allowing the use of persistence based algorithms, and the use of software techniques that take advantage of advances in multi-core computer processing.

This presentation will describe several of the key algorithmic and software advances in detail as applied to data from a variety of CONOPS.

8017-45, Session 9

Stand-off detection of explosive particles by imaging Raman spectroscopy

M. Nordberg, H. Ellis, A. Ehlerding, H. Oestmark, T. Carlsson, Swedish Defence Research Agency (Sweden)

A multispectral imaging technique has been developed to detect and identify explosive particles, e.g. from a fingerprint, at stand-off distances using Raman scattering.

When handling IED:s as well as other explosive devices, residues can easily be transferred via fingerprints onto other surfaces e.g. car handles, gear sticks and suite cases. By imaging the surface using the multispectral imaging Raman technique the explosive particles can be identified and displayed using color-coding.

The technique has been demonstrated by detecting fingerprints containing DNT, TNT and ammonium nitrate at a distance of 12 m. For each measurement, an image sequence of 22 images was recorded and the spectral data from each pixel was compared with reference spectra of every substance. By using false color coding the pixels were marked with different colors corresponding to the detected substances in the fingerprint. Total detection time is one minute and for the moment the optical resolution is approximately 50 µm. The results indicate a great potential for multispectral imaging Raman spectroscopy as a stand-off technique for detection of single particle explosives.

8017-46, Session 9

Picosecond laser pulses improves sensitivity in standoff explosive detection

M. Akeson, L. Nilsson, P. Strömbeck, Portendo AB (Sweden)

Portendo has developed a world-leading technique of trace detection of explosives at standoff distance using Raman spectroscopy. The technology is further developed in order to enhance the sensitivity of the method further and be able to extend the field of applications. Raman scattering is a well-established technique able to detect substances down to single micrograms at standoff distances, however, one of the obstacles limiting the detection possibilities is interfering fluorescence, originating either from the substance itself or from the surrounding material. One main challenges when developing this technology further is thus to either omit the excitation of the fluorescent process altogether or to be able to separate the two processes and only detect the Raman signal.

Due to a large difference in the temporal behavior of the two processes - Raman scattering occurs in the order of femtoseconds while fluorescence has a lifetime in the order of nanoseconds or slower - one way to theoretically separate them is to limit the measurement to as short time as possible, cutting off most of the emitted fluorescence signal. The improvement depends on how much of the fluorescence is omitted without decreasing the Raman signal. Experimentally, we have verified the expected improvement in signal to noise ratio when using a laser with picosecond pulses instead of nanosecond pulses, which has resulted in an improvement in SNR of up to 7 times for bulk ANFO. These results verify the predicted signal enhancement and suggest higher sensitivity for trace detection at a distance in future systems.

8017-47, Session 10

ALIS deployment in Cambodia

M. Sato IV, 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.

8017-48, Session 10

Landmine detection by 3DGPR system

M. Sato IV, Y. Yokota, Tohoku Univ. (Japan); M. Grasmueck, Univ. of Miami (United States)

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.

8017-49, Session 10

Random GPR antennae height variations and mine detection performance

G. M. Milner, AARD, LLC (United States); M. Younger, BAE Systems (United States)

An extensive database of vehicle mounted GPR mine data acquired over a wide range of speed and surface roughness conditions are analyzed to determine the sensitivity of prescreen algorithms (local energy detection) and a variety of feature extraction algorithms (spatial features and frequency domain features) to random and rapid variations in antenna heights due to naturally occurring antenna bounce. Results are also described for data acquired during test designed to induce specific bounce profiles during data collections. Significant increases are observed in both false alarm rates and false alarm confidence values, and significant decreases are observed in mine detection probabilities at rougher test lane locations. Performance degradation is quantified as a function of the antenna vertical and horizontal velocities, and additional key defining antenna motion factors such as antenna trajectory or curvature. These factors are shown to impact specific algorithms uniquely, especially for the spatial pattern features. Perhaps the most significant antenna height factor was discovered to be rapid and large GPR amplitude changes due to the variations in antenna height and thus propagation loss. Finally, normalization techniques developed by BAE Systems are examined to correct for these GPR antenna bounce factors and are shown to be effective in most cases, particularly for some of the more severe induced bounce scenarios.

8017-50, Session 10

Detection of explosive hazards using spectrum features from forward-looking ground-penetrating radar imagery

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)

Buried explosives have proven to be a challenging problem for which the forward looking ground penetrating radar (FLGPR) has shown to be effective. This paper discusses an explosive hazard detection algorithm for a FLGPR. The algorithm applies the fast Fourier transform (FFT) to obtain spectrum features of anomalies in the FLGPR imagery. Results show that the spectral characteristics of explosive hazards differ from those of background clutter and are useful for rejecting false alarms (FAs). A genetic algorithm (GA) was developed to select a subset of these spectral features to produce a more generalized classifier. Furthermore, a k-nearest neighbor (k-NN) approach is employed in which targets and false alarms are used as training data to produce a two-class classifier. The experimental results of this paper use data collected by the US Army and show the effectiveness of spectrum based features in the detection of explosive hazards.

8017-51, Session 10

Context-aware detection of explosive hazards using frequency subband processing of forward-looking ground-penetrating radar

T. C. Havens, J. M. Keller, D. K. Ho, 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)

This paper proposes an effective anomaly detection algorithm for a forward-looking ground-penetrating radar (FLGPR). One challenge for threat detection using FLGPR is its high dynamic range in response to different kinds of targets and clutter objects. The application of a fixed threshold for detection in a full-band radar image often yields a large number of false alarms. We propose a method that uses both narrow-band and full-band radar processing, coupled with a context-dependent classifier. Full-band radar images provide a high degree of image resolution, while narrow-band images give a frequency signature for each detected object, which allows classifiers to distinguish targets from clutter. We address dynamic detection-environment factors by using a hierarchical context-dependent classification approach. Experimental results for our improved detection techniques are demonstrated on data sets collected at a US Army test site.

8017-52, Session 10

Layer segmentation of GPR images using relaxation labeling for landmine detection

M. A. Laffin, M. A. Mohamed, A. Etebari, NIITEK, Inc. (United States); M. W. Hibbard, CoVar Applied Technologies, Inc. (United States)

A method for segmenting deformable shapes of soil and ground layers in successive GPR image frames is described in this paper. Firstly, pre-processing operators are applied to enhance the quality of each image frame. Secondly, local histogram features are used to initialize membership probabilities of each pixel in the current image frame. Then, a segmentation algorithm based on relaxation labeling is applied to perform image segmentation. This algorithm uses information from previous and current image frames to perform layer identification by formulating the segmentation task as a probabilistic relaxation labeling process in which the current frame image is used for initializing pixel membership probabilities estimated from gray-level histograms. The previous frame image is used for estimating the compatibility values to be utilized for segmenting the current frame image using mutual information among neighboring pixels. By iteratively refining the membership probabilities of each pixel in the current image frame, in parallel, an enhanced segmentation is produced according to the refined probabilities. A distinguishing characteristic of this process is the ability to incorporate both temporal contexts (down-track history information encoded as compatibilities) and spatial contexts (current-scan pixel neighborhood information encoded as probabilities), concurrently. The segmented image is post-processed by further filtering operations and checking for highly unlikely decisions to produce the final segmentation.

8017-53, Session 11

The Viterbi algorithm as an approach for incorporating spatial information into air/ground interface inference

P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Rough surfaces present an impediment to the detection of buried threats with ground penetrating radar (GPR). Besides introducing artifacts in the sub-surface due to rough scattering, very rough or uneven surfaces can

make inference of the location of the ground response from GPR data difficult. Since many algorithms rely on the accurate localization of the air/ground interface, mistakes in ground location inference can cause significant increases in false alarm rates. Many different approaches to localizing the ground in a particular A-scan have been proposed, but sharing information across multiple A-scans to form a realistic, smoothly varying ground response over many spatial locations is a difficult problem that often requires computationally expensive approaches for adequate solutions. In this work we present an application of the well known Viterbi algorithm for accurate localization of the air/ground interface based on hypothesized locations from multiple nearby A-scans. Our implementation of the Viterbi algorithm enables principled incorporation of prior information into the ground tracking framework, and provides a solution capable of adapting computational complexity to the severity of the ground localization problem. Furthermore, the Viterbi algorithm can act as a meta-algorithm, allowing the implementation of different A-scan based ground detectors in different GPRs, for example. This work illustrates performance improvements for the Viterbi approach for ground localization using several radar systems.

8017-54, Session 11

DynAlign ground-tracking algorithm

B. Smock, P. Gader, J. N. Wilson, Univ. of Florida (United States)

Identifying which portion of a Ground-Penetrating Radar (GPR) image corresponds to the ground has several potential benefits, but has proven to be a difficult problem. In the ideal case, the ground can be identified by a single, dominant bounce in the radar return signal, but oftentimes interference can mask this signature or large objects near the surface can create a separate layer that is difficult to distinguish from the actual ground layer. The proposed DynAlign algorithm is able to handle a number of confounding situations and adapt online to different ground types using three main complementary ideas. First, the space of possible ground locations is reduced by imposing the constraint that the ground will look similar from one image to the next. Second, a space of likely ground locations is identified through optimal pair-wise alignment of neighboring channels' dominant features. Finally, the Viterbi algorithm is used with this and other information to determine the optimal ground surface layer across all channels. Testing results from a large, manually-truthed dataset will be presented.

8017-55, Session 11

Support vector data description for detecting the air-ground interface in ground-penetrating radar signals

J. J. Wood, J. N. Wilson, Univ. of Florida (United States)

In using GPR images for landmine detection it is often useful to identify the air-ground interface in the GRP signal for alignment purposes. A common simple technique for doing this is to assume that the highest return in an A-scan is from the reflection due to the ground and to use that as the location of the interface. However there are many situations, such as the presence of “nose clutter” or shallow sub-surface objects, which can cause the global maximum estimate to be incorrect. A Support Vector Data Descriptor (SVDD) is a one-class classifier related to the SVM which encloses the class in a hyper-sphere as opposed to using a hyper-plane as a decision boundary. We apply SVDD to the problem detection of the air-ground interface by treating each sample in an A-scan, with some number of leading and trailing samples, as a feature vector. Training is done using a set of feature vectors based on known interfaces and detection is done by creating feature vectors from each of the samples in an A-scan, applying the trained SVDD to them and selecting the one with the least distance from the center of the hyper-sphere. We compare this approach with the global maximum approach, examining both the performance on human “truthed” data and how each method affects false alarm and true positive rates when used as the alignment method in mine detection algorithms.

8017-56, Session 11

Ground tracking in ground-penetrating radar using Gaussian process and Bayesian inference

J. Ho, J. Bolton, B. Smock, Univ. of Florida (United States)

We propose a novel ground tracking algorithm using Gaussian process and Bayesian inference. Two of the most challenging aspects of the ground tracking are the background clutters and the sudden and abrupt ground motions. In the proposed method, the latter problem is managed using a flexible motion prediction scheme that can efficiently search and locate possible ground level over a large portion of the image. For the former problem, we model the background clutters using a Gaussian process, and the proposed algorithm applies Bayesian inference to estimate the ground once the presence of clutters and abrupt motion changes have been detected. We propose an efficient training method for computing regressions in this context, and we demonstrate experimentally that the algorithm can efficiently and accurately recover the ground under adverse external conditions.

8017-57, Session 11

Comparison of algorithms for finding the air-ground interface in ground-penetrating radar signals

J. J. Wood, J. Bolton, G. Casella, Univ. of Florida (United States); L. M. Collins, Duke Univ. (United States); P. Gader, T. C. Glenn, Univ. of Florida (United States); W. Lee, R. Mueller, NIITEK, Inc. (United States); B. Smock, Univ. of Florida (United States); P. A. Torrione, Duke Univ. (United States); J. N. Wilson, Univ. of Florida (United States)

In using GPR images for landmine detection it is often useful to identify the air-ground interface in the GRP signal for alignment purposes. A number of algorithms have been proposed to solve the air-ground interface detection problem, including some which use only A-scan data, and others which track the ground in B-scans or C-scans. Here we develop a framework for comparing these algorithms relative to one another and we examine the results. The evaluations are performed on data which have been categorized in terms of features that make the air-ground interface difficult to find or track. The data also have associated human selected ground locations, from multiple evaluators, that can be used for determining correctness. A distribution is placed over each of the human selected ground locations, with the sum of these distributions at the algorithm selected location used as a measure of its correctness. Algorithms are also evaluated in terms of how they affect the false alarm and true positive rates of mine detection algorithms that use ground aligned data.

8017-58, Session 12

Observations on syntactic landmine detection using impulse ground-penetrating radar

A. O. Nasif, K. J. Hintz, George Mason Univ. (United States)

In this paper, we discuss some results and observations of applying syntactic pattern recognition (SPR) methodology for landmine detection using impulse ground penetrating radar (GPR). In the SPR approach, the GPR A-scans are preprocessed using inverse filtering, after necessary signal conditioning, such as alignment and normalization, has been performed. The filtered signal is binarized using a peak detection method that is independent of the DC level of the signal. The 1's in the binarized signal represent the locations of the impedance discontinuities in range. During the training session, the characteristic (binary) strings for a particular landmine are found by looking at all the exemplars of that mine and selecting the string that yields the best detection results on all exemplars of a particular landmine type. These characteristic strings can be detected very efficiently using finite state machines (FSMs). Finally, the raw FSM detections are clustered for assigning weight to each detection, and discarding sparse detections. Given sufficient GPR resolution in range, the SPR method can be a robust solution for discriminating between non-metallic landmines and clutter since it is based on the internal impedance discontinuity profile of the target.

To evaluate the proposed methodology, the SPR scheme is applied to a set of impulse GPR data taken at a government test site. The results show that in most cases about 50%-80% of the mines can be detected, with a false alarm rate (FAR) of 0.05 per m^2. We briefly discuss the advantages of a fully coherent frequency-stepped radar over an impulse GPR.

8017-59, Session 12

Characterization of binary string statistics for syntactic landmine detection

A. O. Nasif, B. Mark, K. J. Hintz, George Mason Univ. (United States)

Syntactic landmine detection has been shown to be effective at detecting and classifying non-metallic landmines using impulse ground penetrating radar (GPR). In this approach, the GPR return is processed to extract characteristic binary strings for landmine and clutter discrimination. In our previous work, we discussed the preprocessing methodology by which the amplitude information of the signal can be effectively converted into binary strings in which the ones locate the impedance discontinuities in range. Our initial study of the false alarm rate (FAR) bounds using combinatorial enumeration showed that very low FARs may be achievable for such an approach.

In this work, we study the statistical properties of the binary string space. In particular, we develop a Markov chain model to characterize the observed bit sequence of the binary strings. The specification of the transition probabilities of the chain can be used to compute the likelihood of any given string. This formulation allows us to compute the performance metrics of interest for landmine detection, namely, probability of detection and FAR. We also develop an empirical method to study the landmine and clutter statistics, which can be used to estimate the parameters of the Markov chain. This method uses the collection of strings from sample training data to derive distributions of the distances between successive impedance discontinuities.

8017-60, Session 12

Ground-penetrating radar signal processing for the detection of buried objects

M. Walters, E. Garcia, Cornell Univ. (United States)

Ground penetrating radar (GPR) data is typically unintuitive and requires trained personnel to interpret due to the physics behind electromagnetic wave propagation, signal noise, measurement error and unwanted reflections caused by clutter. A consequence of this is that targets are often only identifiable after the return data has been analyzed with signal processing algorithms.

The eigensystem realization algorithm (ERA) and singular value decomposition (SVD) are two such algorithms that, when applied to two dimensional B-scan data, produce compact representations of the subsurface that may prove useful for target identification. These methods are typically robust in the presence of noise and uncertainty and decompose the data into discrete hierarchical components, which could prove to be useful in the development of automated robotic scanning platforms.

This work is focused on using the ERA and SVD to identify land mines, improvised explosive devices and buried structures. Targets can be identified by both periodically scanning the same path and looking for changes in the subsurface, or by matching the processed radar returns to libraries of target signatures. For example, when detecting newly constructed tunnels under secure borders, the former method is applicable. New structures or other freshly buried targets change the singular values and singular vectors of the SVD representation, and also alter the eigenvalues and eigenvectors produced by the ERA. When identifying targets from a fresh scan, the latter method can be used by identifying the SVD or ERA signatures unique to specific target types.

8017-61, Session 12

Adaptive Gaussian mixture models for pre-screening in GPR data

P. A. Torrione, K. D. Morton, Jr., New Folder Consulting, LLC (United States); L. Besaw, Applied Research Associates, Inc. (United States)

Most GPR-array based landmine detection systems implement “pre-screening” algorithms to processes the data generated by the antennae array and identify locations with anomalous signatures for more advanced processing. Many approaches to pre-screening have previously been proposed, but one video-based pre-screening algorithm, an online k-means approximation to an adaptive Gaussian mixture model (GMM), is particularly well-suited to application for pre-screening in GPR data due to its computational efficiency, non-linear nature, and relevance of the logic underlying the algorithm to GPR processing. In this work we explore the application of an adaptive GMM-based approach for anomaly detection from the video processing literature to pre-screening in GPR data.

8017-62, Session 12

Physics-based features for contextual factors affecting landmine detection with ground-penetrating radar

C. R. Ratto, K. D. Morton, Jr., L. M. Collins, P. A. Torrione, Duke Univ. (United States)

It has been established throughout the ground-penetrating radar (GPR) literature that environmental factors can severely impact the performance of GPR sensors in landmine detection applications. Over the years, electromagnetic inversion techniques have been proposed for determining these factors with the goal of mitigating performance losses. However, these techniques are often computationally expensive and require models and responses from canonical targets, and therefore may not be appropriate for some route-clearance applications. An alternative technique is context-dependent classification, in which decision rules are adjusted based on contextual shifts in features extracted from the GPR data. However, analysis of the performance of context-dependent learning has been limited to qualitative comparisons of contextually-similar GPR signatures and the overall improvement to the ROC curve, while the actual physical information being exploited has not been investigated thoroughly. In this work, physics-based features used in previous context-dependent approaches were extracted from simulated GPR data generated through Finite-Difference Time-Domain (FDTD) modeling. Statistical techniques where then used to predict several potential contextual factors, including soil dielectric constant, surface roughness, and subsurface heterogeneity. Results suggest that physics-based features of the GPR background may be indicative of some physical properties of the environment, and context-dependent classification based on these features can exploit information regarding these potentially-important environmental factors.

8017-63, Session 13

Multiple instance learning for landmine detection using ground-penetrating radar data

A. Manandhar, K. D. Morton, Jr., L. M. Collins, P. A. Torrione, Duke Univ. (United States)

Multiple Instance Learning (MIL) is a type of supervised learning method in which labels are available for sets of samples, but not for individual samples and the goal of learning is to classify new sets of samples as they become available. Such a framework is useful in ground penetrating radar (GPR)-based landmine detection problem since pre-screener alarms correspond to sections of GPR data which can be modeled as sets of data from several depth-bins Furthermore, for GPR-based landmine detection, target/non-target labels are relatively easy to provide at the alarm level, but are difficult to obtain at the individual depth-bin level. Several methods have previously been proposed to solve the MIL problem. In this work, various MIL algorithms applicable to the landmine detection problem in GPR data are analyzed and the results are compared with non-MIL methods. This work also further develops an approach known as the Adaptive p-Posterior Mixture Model (PPMM), which uses mixture models followed by kernel methods to solve the MIL problem. Results from several different approaches to MIL including the new proposed modification to Adaptive PPMM will be compared for processing GPR data.

8017-64, Session 13

Contextual learning in ground-penetrating radar data using Dirichlet process priors

C. R. Ratto, K. D. Morton, Jr., L. M. Collins, P. A. Torrione, Duke Univ. (United States)

In landmine detection applications, the inevitable fluctuation of environmental and operating conditions can limit the performance of sensors based on ground-penetrating radar (GPR) technology. As these conditions vary, the classification and fusion rules necessary for achieving high detection and low false alarm rates may change. Therefore, context-dependent learning algorithms that exploit contextual variations of GPR data to alter decision rules have been considered for improving the performance of landmine detection systems. Past approaches to contextual learning have used both generative and discriminative methods to learn a probabilistic mixture of some type, such as a Gaussian mixture, fuzzy c-means clustering, or a mixture of random sets. However, in these approaches the number of mixture components is pre-defined, which could be problematic if the number of contexts in a data collection is uncertain. In this work, a generative context model is proposed which requires no a priori knowledge in the number of mixture components. This was achieved through modeling the contextual distribution in a physics-based feature space with a Gaussian mixture, while also incorporating a Dirichlet process prior to model uncertainty in the number of mixture components. This Dirichlet process Gaussian mixture model (DPGMM) was used in the previously-developed Context-Dependent Feature Selection (CDFS) framework for fusion of multiple landmine detection algorithms. Experimental results suggest that when the DPGMM was incorporated into CDFS, the degree of performance improvement over conventional fusion was greater than when a conventional fixed-order context model was used.

8017-65, Session 13

Exploiting spectral content for image segmentation in GPR data

P. Wang, K. D. Morton, Jr., L. M. Collins, P. A. Torrione, Duke Univ. (United States)

Ground-penetrating radar (GPR) sensors provide an effective means for detecting changes in the sub-surface electrical properties of soils, such as changes indicative of landmines or other buried threats. However, most GPR-based pre-screening algorithms only localize target responses along the surface of the earth, and do not provide information regarding an object's position in depth. As a result, feature extraction algorithms are forced to process data from entire cubes of data around pre-screener alarms, which can reduce feature fidelity and hamper performance.
In this work, spectral analysis is investigated as a method for locating subsurface anomalies in GPR data. In particular, a 2-D spatial/frequency decomposition is applied to pre-screener flagged GPR B-scans. Analysis of these spatial/frequency regions suggests that aspects (e.g. moments, maxima, mode) of the frequency distribution of GPR energy can be indicative of the presence of target responses. After translating a GPR image to a function of the spatial/frequency distributions at each pixel, several image segmentation approaches can be applied to perform segmentation in this new transformed feature space. To illustrate the efficacy of the approach, a performance comparison between feature processing with and without the image segmentation algorithm is provided.

8017-80, Session 13

Comparative analysis of clutter suppression techniques for landmine detection using ground-penetrating radar

M. Sezgin, TÜBITAK Marmara Research Ctr. (Turkey)

No abstract available

8017-67, Session 14

Detection of buried mines and explosive objects using dual-band thermal imagery

J. J. Lepley, M. T. Averill, SELEX Galileo Ltd. (United Kingdom)

Thermal imagery detects material and thermal properties of the scene that can be interpreted to provide information on the presence of buried or surface-laid IED threats. Surface signatures above buried objects include: changes in surface moisture content, altered soil porosity resulting from the emplacement and alteration of the physical mixture of the surface soil through the disturbance of silicate particles that exhibit Restrahlen discontinuities.

We have developed a dual-band thermal imager (CONDOR II) capable of imaging in both the Medium (3-5μm) and Long band (8-12μm) at full TV resolution and frame rates on a common focal plane array. The two bands each respond differently to the thermal black-body and emissivity of the materials in the scene; by selectively processing the information present in the two bands we extract information on the physical nature of the materials being imaged.

We described the development of a statistical technique to process the information present in the two bands to extract the different physical properties recorded within each band. The information, once processed and re-laid over the original, demonstrates an enhanced visibility of surface signatures that is resilient to changing lighting conditions over the diurnal cycle. We present the development of a statistical classifier used to detect targets on independently trained images with a high probability of detection and low false negative rates. The paper also includes work on processing techniques to further mitigate the impact of false positives through the selective processing of image regions and contextual interpretations of the scene content.

8017-69, Session 14

Investigation of the potential use of hyperspectral imaging for stand-off detection of person-borne IEDs

C. C. Cooksey, D. W. Allen, National Institute of Standards and Technology (United States)

Advances in hyperspectral sensors and algorithms in numerous fields of research have opened up new possibilities and may also improve the detection of person-borne IEDs. While portions of the electromagnetic spectrum, such as the x-ray and terahertz regions, have been investigated for this application, the spectral region of the ultraviolet (UV) through shortwave infrared (SWIR) (250 nm to 2500 nm) has received little attention. The purpose of this work was to investigate what, if any, potential there may be for exploiting the spectral region of the UV through SWIR for the detection of hidden objects under the clothing of individuals. The optical properties of both common fabrics and threat objects were measured. The approach, measurement methods, and results are described in this paper, and the potential for hyperspectral imaging is addressed.

8017-71, Session 14

Characterizing optical properties of IED surface signatures

J. J. Staszewski, Carnegie Mellon Univ. (United States); C. A. Hibbitts, G. O'Marr, A. C. Goldberg, The Johns Hopkins Univ. (United States)

Burial of explosive hazards creates soil disturbances that remain visible for a not fully determined duration can be detected via unaided and technologically-aided vision. This presentation reports progress made in further documenting the phenomena of soil disturbances for detection purposes.

Prior work has shown that optical signatures of temperate well-developed soil disturbances produced by landmine emplacement persist for several weeks. Results identified visual cues that characterize the signatures, their changes over time and exposure in the natural environment, and contrasts in the perceptual salience of signatures on the bandwidths sampled over time.

The goals of the current effort were to generalize and extend these findings to IEDs and test under different soils types and weather conditions. Simulated IEDs were buried in sandy-clay soil at a secure test site during the summer.

Imagery was collected before and after target emplacement and again two weeks later. Disturbed and surrounding undisturbed surfaces were sampled using shortwave Infrared unfiltered (0.9 - 1.7 μm) and filtered (1.55 - 1.7 μm), dual band mid-IR (3.8 - 4.2 μm and 4.5 - 5 μm), longwave imaging FTIR (spectral range: 7.5 -13 μm), visible-SWIR point spectroscopy in the 0.35 - 2.4 μm range, and high-resolution (<1mm accuracy) laser scanning of the surface topography.

Results show (a) changes for better and worse in signature salience over time within bands (b) contrasts in salience across bands within time periods, and (c) enhanced signature salience produced by selectively fusing data from different bands. Discussion addresses phenomenological bases of results and their methodological implications for efforts to exploit the optical phenomena of disturbed soils to detect buried explosive hazards.

8017-72, Session 14

Automatic detection of targets in medium-wave infrared imagery using adaptive background mixture models

C. J. Spain, J. M. Keller, M. Popescu, K. E. Stone, Univ. of Missouri-Columbia (United States)

Infrared cameras can be used to image unpaved roads containing buried explosive hazards where detection relies upon differences between settled and disturbed soil in addition to thermal emissivity. We use a variation of the mixture of Gaussians (MOG) modeling technique to separate potential hazards from benign background regions. Objects detected in IR-image space are then projected into Universal Transverse Mercator (UTM) coordinates where hits on a single object from multiple frames are clustered using mean-shift. The clustering aggregates the hits from multiple frames into a single point for scoring. The MOG method has been used successfully in the past to model backgrounds in imagery taken from fixed cameras with slow changing backgrounds. The use of MOG with Medium Wave infra-red cameras mounted on a moving platform creates some unique problems whose solutions we address in this paper. Experimental results are demonstrated on data sets collected at a US Army test site.

8017-73, Session 15

Detection of targets in forward-looking infrared imaging using a multiple instance learning framework

M. Popescu, K. E. Stone, J. M. Keller, Univ. of Missouri-Columbia (United States)

In this paper we describe a method for generating cues of targets present in the field-of-view of an infrared (IR) camera installed on a moving vehicle. A typical two class classifier requires the building of an image library containing manually extracted examples of both types of objects, i.e., targets and non-targets. This approach, usually tedious on static images, becomes intractable when using video sequences taken from moving vehicles due to the variable object appearance caused by perspective. To avoid manual segmentation of video sequences, we employ a multiple instance learning (MIL) framework that allows training of a two class classifier just by specifying if a frame contains targets or not.

The proposed method has three steps. First, for each frame of a training run, we generate a set of possible points of interest using a corner detection algorithm. Second, for the same training run, we tag each frame as positive (targets present) or negative (non-targets present, only). Each hit is described using the local binary pattern (LPB) features computed at its image location. The generated hits, together with their frame tag, are used by the MIL training framework to generate a set of target LPB prototypes. Although many regular classifiers may be trained using MIL, in this paper we used a simple approach based on the nearest prototype. In the last step, we used the computed prototypes to classify the corner hits detected in a test video sequence.

To validate our approach, we present results obtained on 6 runs gathered with a long wave infrared (LWIR) camera mounted on a moving vehicle.

8017-74, Session 15

Sensor fusion approaches for EMI and GPR-based subsurface threat identification

P. A. Torrione, K. D. Morton, Jr., New Folder Consulting, LLC (United States); L. Besaw, Applied Research Associates, Inc. (United States)

Despite advances in both electromagnetic induction (EMI) and ground penetrating radar (GPR) sensing phenomenologies, neither sensor alone provides a panacea for detecting the myriad of possible buried objects that threaten the lives of soldiers and civilians. However, while neither GPR nor EMI sensing alone can provide optimal detection across all target types, the two approaches are highly complementary. As a result, many fielded landmine systems currently make use of both sensing modalities simultaneously and fuse the results from both sensors to improve detection performance of targets from multiple target classes (e.g. high metal/low metal, antipersonnel/anti-tank). Despite this, little work has focused on comparing different approaches to sensor fusion and machine learning for combining data from these orthogonal phenomenologies. In this work we explore a wide array of pattern recognition techniques for algorithm development and sensor fusion. Results with the ARA Nemesis landmine detection system suggest that non-linear and non-parametric classification algorithms provide significant performance benefits for single-sensor classifier development, but that fusion of multiple algorithms can be performed satisfactorily using simpler parametric approaches, such as logistic discriminant classification.

8017-75, Session 15

Vehicle mounted video-based change detection for novel anomaly detection

P. A. Torrione, K. D. Morton, Jr., C. R. Ratto, L. M. Collins, Duke Univ. (United States)

Vehicle mounted forward looking video-based processing has the potential to identify and flag objects of interest ahead of a vehicle before the objects become immediate threats to the system. However video understanding and processing is a difficult task, and adaptive background-based approaches to anomaly detection in video data can result in very large amounts of data flagged and presented to system operators. When multiple sorties take place over the same routes, it may be possible to leverage information from several passes to form a library of previously encountered “anomalous” objects, and use this list of previously encountered objects to either suppress or modify alarms from additional alarms due to the same objects. This kind of change-detection processing requires the system to be aware of its current spatial location relative to other data collections on the same routes. In this work we explore an approach to video stream alignment that has direct applications for change detection in forward looking sensing. Our current results indicate that it is possible to infer a system’s relative position in terms of data from another system’s pass down the same route without making use of global positioning information, and with limited computational complexity.

8017-76, Session 15

Algorithm fusion in forward-looking longwave infrared imagery for buried explosive hazard detection

D. T. Anderson, J. M. Keller, O. Sjahputera, Univ. of Missouri-Columbia (United States)

In this paper, we propose a new way to fuse confidence maps acquired from multiple algorithms running on multiple platforms in the context of forward looking explosive hazard detection of buried targets. Several algorithms, such as a bank of size contrast filters, FFT-based spectral features, corner detection with multiple instance learning on LBP features, and change detection are explored for an infrared and ground-penetrating radar system. Next, a fuzzy measure is learned for Fuzzy Integral-based fusion of the individual confidence maps. Experimental results are demonstrated for the system based on field data measurements from a US Army test site.

8017-77, Session 15

Validating spectral-spatial detection based on MMPP formulation

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Spectral, shape or texture features of the detected targets are used to model the likelihood of the targets to be potential mines in a minefield. However, some potential mines can be false alarms due to the similarity of the mine signatures with natural and other manmade clutter signatures. Therefore, in addition to the target features, spatial distribution of the detected targets can be used to improve the minefield detection performance. In our recent published SPIE paper, we evaluated minefield detection performance for both patterned and unpatterned minefields in highly cluttered environments, using both target features and target spatial distributions simultaneously that define Markov Marked Point Process (MMPP). The results have suggested that proper exploitation of spectral/shape features and spatial distributions can indeed contribute to improve the performance of patterned and unpatterned minefield detection. Also, the ability of the algorithm to detect the minefields in highly cluttered environments shows the robustness of the developed minefield detection algorithm based on MMPP formulation. Moreover, the results show that the MMPP minefield detection algorithm performs significantly better than the baseline algorithm employing spatial point process with false alarm mitigation. Since these results were based on the simulated data, it is not clear that the MMPP detection algorithm has fully achieved its best performance. To validate its performance, an analytical solution for the minefield detection problem will be developed, and its performance will be compared with the performance of the simulated solution. The analytical solution for the complete minefield detection problem is intractable due to a large number of detections and the variation of the number of detected mines in the minefield process. Therefore, an analytical solution for a simplified detection problem will be derived, and its minefield performance will be compared with the minefield performance obtained from the simulation in the same MMPP framework for different clutter rates.

8017-78, Session 15

Using predictive distributions to estimate uncertainty in classifying landmine targets

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Typical classification models used for detection of buried landmines estimate a singular discriminative output. This classification is based on a model or technique trained with a given set of training data available during system development. Regardless of how well the technique performs when classifying objects that are ‘similar’ to the training set, most models produce undesirable (and many times unpredictable) responses when presented with object classes different from the training data. This can cause mines or other explosive objects to be misclassified as clutter, or false alarms.

Bayesian regression and classification models produce distributions as output, called the predictive distribution. This paper will discuss predictive distributions and their application to characterizing uncertainty in the classification decision, from the context of landmine detection. Specifically, experiments comparing probability of detection produced by Relevance Vector Machines and Gaussian Processes will be described. We will demonstrate that predictive variance can be used to determine the uncertainty of the model in classifying an object (i.e. the classifier will know when it’s unable to reliably classify an object). The experimental results suggest that degenerate covariance models (such as the Relevance Vector Machine) are not reliable in estimating the predictive variance. This necessitates the use of the Gaussian Process in creating the predictive distribution.

8017-79, Session 15

Buried explosive hazard detection using forward-looking long-wave infrared imagery

K. E. Stone, J. M. Keller, M. Popescu, C. J. Spain, Univ. of Missouri-Columbia (United States)

Trainable size-contrast filters, similar to local dual-window RX anomaly detectors, utilizing the Bhattacharyya distance are used to detect buried explosive hazards in forward-looking long-wave infrared imagery. The imagery, captured from a moving vehicle, is geo-referenced, allowing projection of pixel coordinates into (UTM) Universal Transverse Mercator coordinates. Size-contrast filter detections for a particular frame are projected into UTM coordinates, and peaks are detected in the resulting density using the mean-shift algorithm. All peaks without a minimum number of detections in their local neighborhood are discarded. Peaks from individual frames are then combined into a single set of tentative hit locations, and the same mean-shift procedure is run on the resulting density. Peaks without a minimum number of hit locations in their local neighborhood are removed. The remaining peaks are declared as target locations. The mean-shift steps utilize both the spatial and temporal information in the imagery. Scoring is performed using ground truth locations in UTM coordinates. The size-contrast filter and mean-shift parameters are learned using a genetic algorithm which minimizes a multiobjective fitness function involving detection rate and false alarm rate. Performance of the proposed algorithm is evaluated on multiple lanes from a recent collection at a US Army test site.

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8018-01, Session 1

Biological aerosol background characterization

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To provide useful information during military operations, or as part of other security situations, a biological aerosol detector has to respond within seconds or minutes to an attack by virulent biological agents, and with low false alarms. Within this time frame, measuring virulence of a known microorganism is extremely difficult, especially if the microorganism is of unknown antigenic or nucleic acid properties. However, measuring "live" characteristics is an option as only viable organisms are potentially infectious. Fluorescence based instruments have been designed to optically determine if aerosol particles have viability characteristics. Still, such commercially available biological aerosol detection equipment needs to be improved for their use in military and civil applications. Air has an endogenous population of microorganisms that may interfere with alarm software technologies. To design robust algorithms, a comprehensive knowledge of the airborne biological background content is essential. For this reason, there is a need to study ambient live bacterial populations in as many locations as possible. Doing so will permit collection of data to define diverse biological characteristics that in turn can be used to fine tune alarm algorithms. To avoid false alarms, improving software technologies for biological detectors is a crucial feature requiring considerations of various parameters that can be applied to suppress alarm triggers. This NATO Task Group will aim for developing reference methods for monitoring biological aerosol characteristics to improve alarm algorithms for biological detection. Additionally, they will focus on developing reference standard methodology for monitoring biological aerosol characteristics to reduce false alarm rates.

8018-02, Session 1

Characterization of laser-induced fluorescence from background aerosols in a maritime environment

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The increase in the availability of biological warfare agents combined with the uncertain geopolitics climate tends to put the biological threat as one of today's challenges. An efficient standoff biological warfare detection system providing a 'detect-to-warn' capability would be an important asset for both defence and security communities. Defence R&D Canada (DRDC) has developed, by the end of the 90s, a standoff bioaerosol sensor based on intensified range-gated spectrometric detection of Laser Induced Fluorescence (LIF). This sensor called SINBAHD demonstrated the capability to detect and characterize bioaerosols from a stand-off position. The sensor sensitivity and false alarm rate will greatly depend on the background characteristics since these later will dictate the threshold levels to be used.

SINBAHD was used to characterize the background aerosols in a maritime environment close to Halifax, Canada in May 2008. The characterization of the LIF signal from the background aerosols included spectral, temporal and spatial aspects over 8 nights of continuous data collection. The local environmental conditions in addition to the aerosol concentration and particle size distribution were recorded during the entire trial period. From the 64 LIF trials, only five showed specific spectral features. The spectral variability was encountered either at short range, thus closer to the shore, or during a night having a specific prevalent wind direction. Indeed, the detected anomalies were in most cases directly related to the climatic conditions. The integrated LIF signal was also processed to assess the use of LIF intensity to identify aerosol anomalies in a maritime environment.

8018-03, Session 1

Changes in fluorescence spectra of bioaerosols measured in a laboratory reaction chamber to simulate atmospheric transport

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Real-time detection and characterization of micron-sized airborne particles is important to the early detection of bio-threat agents and environmental monitoring. A number of bioaerosol sensors have been developed during the last decade exploiting various biological, chemical, and physical properties of the targeted bioaerosols. At present most sensors suitable for early warning of airborne bio-threat agents are based on fluorescence and elastic scattering of the aerosol particles. Therefore, it is important to understand the fluorescence properties of background and target bioaerosols in atmospheric environment, and especially how these properties might change during atmospheric transport and chemical aging.

A laboratory reaction test chamber and single particles UV laser-induced-fluorescence (UV-LIF) spectrum measurement system has been developed to monitor the changes of biological aerosols in simulated atmospheric environments, with particular emphasis on the effect of solar radiation, exposure to ozone, and water uptake (hygroscopicity) on UV-LIF spectra of single particles. In this study samples of E. coli, B. thuringiengis, Yersinia rohdei, and Ovalbumin, were aerosolized, injected into a rotating-drum aerosol chamber, and exposed to ozone (a dominant oxidant in urban air pollution) in the dark. During the experiment the UV-LIF spectra of single particles (1-3 µm, excited by a single laser pulses at 263 nm) were monitored at regular intervals over several hours (up to 24 hours). Ozone concentrations were typically kept high (0.5 to 9 ppm) during the whole measurement period. Preliminary measurements reveal that the fluorescence emission peak around 330 nm, which is primarily due to the presence of the amino acid tryptophan in the proteins, appears to decrease somewhat in intensity and become slightly blue-shifted. Further, the fluorescence shoulder around 400 nm-550 nm, which is likely due to the presence of nicotinamide adenine dinucleotide (NADH) and/or residual growth materials, undergoes a relatively increase in intensity. Further experiments are planned for studying the changes in the size and fluorescence of various bio-aerosols under more complex conditions: ie, with exposure to simulated sunlight, increased humidity, and temperature.

8018-04, Session 1

Ground truth methods for optical cross-section modeling of biological aerosols

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Standoff detection of detection of biological warfare agents (BWAs) is an important field because the effectiveness of agents can be greatly

reduced with fast detection and response. Under the Joint Biological Standoff Detection System (JBSDS) program, LIDAR systems have demonstrated some capacity to meet the needs of a fast-response standoff biological detection method for simulants in open air conditions. These systems are designed to exploit various cloud signatures, such as differential elastic backscatter, fluorescence, and depolarization in order to detect BWAs. However, because the release of BWAs in open air is forbidden, methods must be developed to predict candidate system performance against real agents for Agent Performance Assessments (APAs). In support of such efforts, the Johns Hopkins University Applied Physics Lab (JHU/APL) has developed a modeling approach to predict the optical properties of agent materials from relatively simple, BSL3-compatible bench top measurements. JHU/APL has fielded new ground truth instruments (in addition to standard particle sizers, such as the APS or GRIMM) to more thoroughly characterize the simulant aerosols released in recent field tests at Dugway Proving Ground (DPG). These instruments include the Scanning Mobility Particle Sizer (SMPS) made by TSI inc, the Ultraviolet Aerodynamic Particle Sizer (UVAPS) made by TSI inc, and the Aspect Aerosol Size and Shape Analyser (Aspect) made by Bristol Industrial and Research Associates Limited. The SMPS was employed as a means of measuring small-particle concentrations for more accurate Mie simulations; the UVAPS, which measures size-resolved fluorescent intensity, was employed as a path toward fluorescent cross section modeling; and the Aspect, which measures particle shape, was employed as a path towards depolarization modeling. Fielding these instruments enabled better characterization of the cloud, which led to a better understanding of the field test results and improved the aerosol signature models.

8018-05, Session 1

Optimal classification of standoff bioaerosol measurements using evolutionary algorithms

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Recently, there has been an increased interest in technologies for detection and classification of biological agents. Early warning systems based on standoff detection of biological aerosols require real-time signal processing of a large quantity of high-dimensionality data, challenging the systems' efficiency in terms of both computational complexity and classification accuracy. Hence, optimal feature selection is essential in forming a stable and efficient classification system. This involves finding optimal signal processing parameters, characteristic spectral frequencies and other data transformations in large magnitude variable space, stating the need for an efficient and smart search algorithm. Evolutionary algorithms are population-based optimization methods inspired by Darwinian evolutionary theory. These methods focus on the application of selection, mutation and recombination on a population of competing solutions and optimize this set by evolving the population of solutions each generation. We have employed the genetic algorithm in the search for optimal feature selection and signal processing parameters for classification of biological agents. The experimental data were achieved with a spectrally resolved lidar based on ultraviolet laser induced fluorescence, and included several releases of 5 common stimulants. The genetic algorithm tested is seen to outperform benchmark methods involving enumerative, analytic, sequential and random methods like support vector machines, Fisher's linear discriminant, principal component analysis, sequential forward feature selection and random search, with significantly improved classification accuracy compared to the best classical method.

8018-06, Session 1

On the information content of linear and circular depolarization signatures of bioaerosols

G. A. Roy, Defence Research and Development Canada (Canada); X. Cao, Royal Military College of Canada (Canada); R. Bernier, Les Instruments Optiques du St-Laurent Inc. (Canada)

Cao et al.1 published a paper where differentiating bioaerosols (pollens) appeared feasible when linear depolarization ratio signature at multiple wavelengths could be obtained. The measurements were performed at 4 wavelengths. The bioaerosols were disseminated in a controlled environment and the discrimination analysis was based on Mahalanobis distances. Poor discrimination was obtained for single wavelength measurement while acceptable and good discrimination was reported for two and three wavelengths. This innovative work has raised the following question: to which extent does the addition of circular polarization signature to the existing linear polarization increase the overall discrimination capability? In order to answer that question the measurements of Cao et al. were repeated for linear and circular depolarization ratios.

We demonstrate experimentally that the linear and circular depolarization ratios are related to each other via a known simple theoretical mathematical expression in the case of randomly oriented particles. Hence, by measuring one, you obtain the other and consequently there is no additional information that is gained by doing measurements with the two polarization states. This suggests that there is no need for full Mueller matrix measurement systems for detection and discrimination of bioaerosols.

[1] Xiaoying Cao, Gilles Roy and Robert Bernier, "Lidar polarization discrimination of bioaerosols", Opt. Eng. 49, (10 Nov 2010).

8018-07, Session 2

Tracking legionella in air generated from a biological treatment plant: a case study of the outbreak of legionellosis in Norway

J. M. Blatny, Norwegian Defence Research Establishment (Norway)

Three outbreaks of Legionnaires' disease were reported in the Fredrikstad/Sarpsborg community, Norway, in 2005 and 2008 caused by the Legionella pneumophila serogroup 1 ST15 and ST462. The wet scrubber at Borregaard Ind. Ltd. was identified as the source of the outbreak. Later, results showed that the aeration ponds, a part of the biological treatment plant at Borregaard Ind. Ltd., were the main amplifiers and primary disseminators of the outbreak strains, as the outbreak strains are not able to survive in air scrubber liquid media more than two days of incubation at the scrubber's operating conditions. The aeration ponds contained Legionella bacteria up to 1010 CFU/L and investigations were performed to analyze if legionellae could be dispersed as aerosols from the ponds and further transported by the wind. Computational fluid dynamics (CFD) was used a priori to estimate the aerosol pathways and to determine suitable air sampling locations. L. pneumophila was identified up to 200 meters downwind from the ponds. The highest concentration level of viable Legionella spp. was identified directly above the aeration ponds (3300 CFU/m3). Wind-tunnel measurements, CFD simulations and real-life measurements showed that the aerosol plume generated from the aeration pond remained narrow and that the 2µm and 18µm aerosols were mainly deposited < 200 meters in distance from the ponds. The maximum aerosol concentration level appeared to be <10 meters above ground level. The dilution of the aerosol plume seemed to be greater in the near-field analysis due to increased mixing caused by the building structures < 150 meters from the ponds. Our study provides further insight to the dispersion of airborne microorganisms that may be human pathogens released from man-made environments important for occupational as well as public health.

8018-08, Session 2

Characterizing phylogenetic diversity in airborne bacterial populations in China

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Considering the importance of its potential implications for human health, agricultural productivity, and ecosystem stability, surprisingly little is known regarding the composition or dynamics of the atmosphere's biological aerosol community. Using Phylochips, a microarray designed for comprehensive identification of bacterial organisms, we examined samples collected in Xianghe, China from July-September 2008. Aerosols were collected on Nuclepore filters downstream of a PM10 impactor. Samples were scheduled for 8-hour collection windows and 48-hour back-trajectories were calculated using NOAA's Hysplit Model. The 300+ samples were categorized by month and direction of their back-trajectory. DNA extraction was carried out on the pooled samples in a quantitative manner to allow for comparison between the amount of extracted material and the amount of initial total aerosol mass. On average, 8% of the original total aerosol sample was measured to be nucleic acid via Nanodrop, but that value ranged from 2-20%. PCR was utilized to achieve the necessary amount of 16s rRNA to hybridize to the Phylochips. Within an individual month, samples originating from similar land types and about equidistant to the sampling location exhibited similar diversity, whereas samples originating from much further distances and from different land types included phyla unique to that location. We also observed variability in the phyla from the same origin from one month to the next. The biological diversity found from the Phylochips reinforces the notion that air samples carry a biological record of their history.

8018-09, Session 2

Bacterial identification using kinetics of fluorescence staining

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Bacterial infectious diseases remain one of the major health hazards nation- and worldwide. The expedience of detection and identification of bacterial pathogens determines how early the diagnosis is, and hence, what the treatment and the outcome of the illness would be. We will present an unprecedented use of the dynamics of fluorescence staining for the development of assays for detection and identification of bacterial species. Using a novel microfabrication technology to prototype microfluidic devices, we studied the kinetics of fluorescence staining at the single-cell level in a massively parallel manner. We measured the kinetics of bacterial staining with cyanine and thioflavin dyes and investigated their photophysical properties. We focused our studies on different bacteria species which are of clinical importance, and which can be handled in biosafety level II labs. We demonstrated that the kinetics of fluorescence staining contains a wealth of information for identification of bacterial species. We believe that utilizing several stains (vs. one stain), producing different kinetic profiles for the different bacteria, will result in fluorescence kinetics "fingerprint" patterns for each of the species. While speed is crucial for the diagnosis of bacterial infections, current cell-staining methods, which offer expedience and relative simplicity, inherently provide Boolean outcomes. The breaking of century-old traditions of Boolean bioanalyses reflects the innovative nature of the assays based on the dynamics of staining.

8018-10, Session 2

Selective biomarker detection in saliva and serum using peptide functionalized field-effect transistors

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Current state of the art analysis of biomarkers in biological fluids such as saliva, serum, and urine is based on a central lab concept using radioimmunoassay and chromatography methods. There is a growing need for selective and sensitive detection assays that can be used at the point of care or for continuous monitoring of individuals. This work details the efforts for developing a platform sensing technology for real-time analysis of multiple biomarkers in biological fluids. Biological recognition elements (BRE), such as peptides, have been developed to specifically bind a human performance target of interest, Orexin A. Orexin A is a neuropeptide that crosses the blood/brain barrier and is indicative of cognition, alertness, fatigue, and post traumatic stress disorder. Molecular modeling using protein docking and molecular dynamics software has confirmed the binding interactions with the BRE and target neuropeptide. Integrating the BRE peptide onto a zinc oxide field effect transistor (ZnO FET) allows for electronic signal transduction of the binding event. This scheme has resulted in selective detection of Orexin A at levels of atto-molar in water, femto-molar in saliva, and nano-molar in serum. Selective detection was determined by scrambling both the target and recognition peptides (separately) with little to no sensor detection compared to the positive controls.

8018-11, Session 2

A distributed national network for label-free rapid identification of emerging pathogens

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Typical bioterrorism prevention scenarios assume well-known and well-characterized pathogens like anthrax or tularemia, which are serious public concerns if released into food or water supplies. Common governmental contingencies include rapid response to these biological threats with predefined treatments and management operations. However, bioterrorist attacks may follow a far more sophisticated route. With the widely known and immense progress in genetics and availability of molecular biology tools worldwide, the feasibility of malicious modifications of pathogenic genomes is very high. Common non-pathogenic microorganisms could be transformed into dangerous, debilitating pathogens. Known pathogens can also be modified to avoid detection because organisms are traditionally identified on the basis of their known physiological or genetic properties. In the absence of defined primers a laboratory using genetic biodetection would be unable to quickly identify a modified microorganism using methods such as PCR. Our concept includes developing a nation-wide database of signatures based on biophysical (such as elastic light scattering properties and/or Raman spectra) rather than genetic properties of bacteria, paired with a machine-learning system for emerging pathogen detection. We envision a system approach emphasizing ease of implementation using a standardized collection of phenotypic information and extraction of biophysical features of pathogens. Owing to the label-free nature of the proposed detection modalities the system would be also less costly than any genotypic approach. Examples will be provided of label-free detection and classification of pathogenic bacteria in a nonexhaustive framework, that is, without knowledge about all the possible classes that can be encountered.

8018-12, Session 3

Gamma/neutron analysis for SNM signatures at high-data rates (greater than 10^7 cps) for single-pulse active interrogation

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We are developing a high data gamma/neutron spectrometer suitable for active interrogation of special nuclear materials (SNM). We have tested the system at Naval Research Laboratory's Mercury high pulsed power facility at distances approaching 10 meters from a depleted uranium (DU) target. We have found that the gamma-ray field in the target room "disappears" 10 milliseconds after the x-ray flash, and that gamma ray spectroscopy will then be dominated by isomeric states/beta decay of fission products. When a polyethylene moderator is added to the DU target, a time dependent signature of thermal neutrons is created causing nuclear reactions in the DU and poly. We observe this signature in gamma-spectra measured consecutively in the 0.1-1.0 ms time range. These spectra contain the Compton edge line (2 MeV) from capture in hydrogen, and a continuous high energy gamma-spectrum from capture or fission in the DU.

8018-13, Session 3

Over-water testing of the neutron imaging camera

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We describe the performance, angular and spectral resolution, of the 30×30×7 cm3 Neutron Imaging Camera (NIC) prototype measured in static and dynamic over-water tests. The NIC is based on the Three-Dimensional Track Imager (3-DTI) technology developed at GSFC for gamma-ray astrophysics applications. The 3-DTI is a scalable, large volume time-projection chamber that provides omni-directional, 400 um pitch, 3-D tracking of charged particles. The neutron sensitive gas mixture of the NIC is a mixture of methane (CH4) and carbon disulfide (CS2) at 400 torr. The energy and incident directions of fast neutrons, En > 0.1 MeV, are reconstructed from the momenta of recoil protons resulting from neutron-proton elastic scattering in the NIC volume. These tests demonstrated that the NIC is a viable, helium-3 free neutron imaging technology. This work is funded by ONR, Code 35.

8018-14, Session 3

Detection of thermal neutrons using gadolinium-oxide-based nanocrystals

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Colloidal nanocrystals have attracted tremendous interest over the last few years for a wide range of applications. So far, however, their potential as possible nuclear radiation detectors has not been generally realized. Yet, compared to commonly used neutron detectors, nanocrystalline approach is much more attractive due to its significantly lower cost, relative ease of colloidal synthesis of high quality nanocrystals with controlled composition, and superior optical, chemical, and mechanical properties of nanocrystals compared to their bulk counterparts. These properties are significantly enhanced by unique configurations of core-shell nanocrystals that do not have their bulk correspondent. Another advantage of the nanocrystals, of specific relevance to neutron detection, is that they can be embedded into a transparent polymer host without causing optical scattering, and the host can serve the multiple functions of preventing agglomeration of highly concentrated nanocrystals, making the detector mechanically robust, as well as moderating incoming neutrons, improving interaction probability and detection sensitivity. This paper will present a novel concept for detection of thermal neutrons based on lanthanide oxide nanocrystals containing gadolinium, an element with by far the highest thermal neutron capture cross section among all stable isotopes. Colloidal synthesis and structural/optical characterization of the nanocrystals will be described, including transmission electron microscopy, energy dispersive spectroscopy, dynamic light scattering, steady state UV-visible optical absorption and photoluminescence spectroscopy, and photoluminescence lifetime measurements. The results of neutron detection experiments will be reported.

8018-15, Session 3

An air fluorescence imaging system for the detection of radiological contamination

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On-site detection and measurement of the activity and extent of alpha (α) contamination presents a significant challenge to radiation detection personnel. Due to the short range of these particles, conventional detection techniques involve bringing a probe within a few centimeters of the suspect area. Performing a thorough survey of an area is time consuming, painstaking, and potentially dangerous, as personnel may be exposed to harmful radiation. Conventional detectors also have fragile Mylar windows which are highly prone to breakage. The instrumentation under development employs a novel approach; instead of detecting the radiation directly, it detects radiation-induced air fluorescence surrounding the contaminated area. Optical imaging is used to determine the spatial extent of the contamination, providing a much more rapid, accurate and robust tool for in-situ contamination measurements. A mobile, near-field, wide-angle, fast (F#/1) optical system has been designed and constructed to detect and image this radiation-induced air fluorescence. It incorporates large-area position-sensitive photo-multiplier tubes, UV filters, a specially constructed fast electronic shutter and an aspherical phase mask to significantly increase the instruments depth-of-field. First tests indicate that a 0.2 μCi source can be detected in less than 10 seconds at a standoff distance of 1.5 meter. The presentation will describe the optical system and summarize its performance characteristics.

8018-16, Session 3

Tl-based wide-gap semiconductor materials for x-ray and gamma-ray detection

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Gamma-ray detection is important for high-energy physics, nuclear spectroscopy, nondestructive testing, gamma-ray astronomy, and medical imaging. Currently there are a number of semiconductor materials including Ge, CdTe, CdZnTe, Se and HgI2 having significant impact on gamma radiation detection. For room temperature operation, semiconductor materials with band gap high than 1.5 eV are potential candidates since the dark current is negligible. Compound semiconductor materials with high atomic numbers of the central element, appropriate band gaps, high densities are sought after for radiation detection at room temperature. In this study, we report on the investigation of several Tl-based ternary semiconductor materials with high average atomic numbers for gamma ray detection. The materials were prepared by the modified Bridgman method. We evaluated the band gap energy, dielectric constant, and absorption coefficient of the semiconductor materials from UV-Vis-near IR transmission and reflection spectra ranging from 300-1500 nm. The mobility lifetime products

were determined from photoconductivity measurements. Tl6I4Se has mobility-lifetime products of 7.1x10^(-3), 5.9x10^(-4) cm^2/V, for electron and hole carriers, respectively, and comparable to those of CdZnTe. We measured the room temperature detector response of the high Z semiconductors to x-ray and γ ray radiation. Using a 57Co source, Tl6I4Se detector has a well resolved spectral response and peak FWHM comparable to that of Cd0.9Zn0.1Te.

8018-17, Session 3

Portable high-speed data acquisition system for x-ray and gamma radiation detection

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A high-speed, portable radiation detection system that is sensitive to X-ray and gamma radiation has been developed. The system includes a microcontroller for analog-to-digital conversion and data processing, external memory for data logging, a silicon-based sensor for radiation detection, and shaping circuitry for pulse height analysis. The system utilizes removable and expandable memory for the collection of real time information about the environment being tested. The memory can be easily removed and is compatible with multiple computer formats for further data analysis. Initial testing shows that the system is capable of sampling speeds up to 18 MHz while maintaining data transfer to external memory.

The system can be operated in either a high-speed mode or averaging mode. High speed mode is intended for use in low intensity environments and is capable of detecting individual radiation events. Averaging mode is designed to be used in high intensity environments where the average radiation intensity is of importance.

X-ray detectors are widely used in medical imaging and chemical composition measurements which require precise energy resolution, but these systems are typically very expensive and not necessary for every application. The developed system offers a unique and relatively inexpensive standalone solution that can perform both pulse height analysis with moderate energy resolution and average intensity measurements.

8018-18, Session 3

Compton imaging with a planar semiconductor system using pulse shape analysis

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Homeland security agencies have a requirement to be able to locate and identify radionuclides. One possible solution is the use of a Compton camera [1,2]. A prototype Compton camera imaging device for homeland security applications is under development at the University of Liverpool in partnership with AWE. The device will be capable of imaging gamma rays with energies between 60 and 1500keV. This prototype is based upon the existing SmartPET [3] detector system consisting of two 60x60x20mm high purity germanium double sided strip detectors. Compton cameras offer higher detection efficiency in comparison with conventionally collimated imaging devices, such as a gamma cameras or coded aperture systems.

State of the art data acquisition electronics are being used to undertake measurements with the SmartPET system, allowing pulse shapes to be stored for every event. Pulse shape analysis [4] can then be utilised to determine the interaction positions within the detector more accurately than via detector segmentation. This enhanced knowledge of the interaction position within the detectors results in an improved Compton image resolution. A comparison of Compton images generated with and without pulse shape analysis techniques will be presented, highlighting the impact of this approach on image quality. The full potential of this system shall be quantified in terms of position resolution in the detector and image resolution in the reconstructed image. The ability of these technologies to identify radioactive sources in the field will be discussed.

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[2] Mihailescu, L., NIM Volume 570 Issue 1, Pages 89-100, 2007

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[4] Kroll, T., NIM Volume 463 Issue 1, Pages 227-249, 2001

8018-63, Poster Session

The ChemSight: an open-path, multichemical detector for security applications

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The performance of an open-path multi-chemical detector designed for continuous, long line-of-sight monitoring is described. The detector system is comprised of an infrared source that projects a collimated broad-spectrum beam towards a detector, which can be located up to 45 m away from the source. The detector spectrally analyzes the beam with an array of room-temperature pyroelectric detectors integrated with bandpass filters. When chemicals intercept any portion of the beam path, they are detected by a unique detection and identification algorithm, which uses non-linear techniques to match the measured IR absorption spectrum against signatures stored in the detector's on-board, remotely updatable library. Using this algorithm, multiple chemicals can be detected and identified.

The sensor and algorithm were extensively tested in the laboratory and multiple field deployments, including continuous operation trials exceeding 18 months in duration at major transportation centers, public buildings, and chemical storage facilities. In laboratory tests, the detector was presented with different chemicals at known optical densities in a gas containment cell. Different environmental conditions were simulated by varying the relative humidity of the air in gas containment cell and introducing interferent gases. The laboratory tests were used to establish minimum detection sensitivities, false positive, and false negative detection rates. Field test data was used to evaluate false negative and false positive rates, and field operation characteristics. These tests demonstrated a 1 ppm-m level sensitivity for most chemicals, a false positive rate of approximately 1 per year, and no false negatives to field test challenges.

8018-64, Poster Session

Threat representative droplet generation and surface interaction analysis

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Inkjet droplet dispensers are non-ideal for disseminating small droplets of thickened material because of orifice size constraints and requirements for heating viscous materials. Alternatively, we are utilizing a direct-displacement droplet dispenser to generate droplets and have been successful in disseminating free-falling droplets of ca. 5 - 100 nL using neat materials (viscosities of 1 - 20 cP) and droplets of ca. 100 nL using glycerol/water solutions of up to 500 cP at room temperature. A goniometer/tensiometer is being used to analyze the surface interaction of the free-falling droplets generated by the direct-displacement droplet dispenser. The advanced goniometer system is able to capture images of the impact and time dependent droplet morphology on the surfaces of interest and is able to calculate the average contact angle and droplet volume as a function of time. The goniometer/tensiometer is also able to analyze the materials themselves, and can calculate the surface/air interfacial tension of the materials tested, as well as the energetics of the various surfaces. By coupling these instruments, a threat-representative droplet of viscous material can be created on demand and the behavior of the droplet on a surface can be monitored as a function of time. This capability can be applied to many fields, such as: contamination and toxicity modeling, surface persistence calculations, and the determination of the limit-of-detection of surface contamination detectors against CWA droplets on representative surfaces. This will be an invaluable system to gather pertinent threat information and may lead to more effective and reliable technology for the modern warfighter.

8018-65, Poster Session

Investigation of standoff explosives detection via photothermal/photoacoustic interferometry

P. S. Cho, Celight, Inc. (United States); R. M. Jones, ITT Advanced Engineering & Sciences (United States); T. Shuman, Fibertek, Inc. (United States); D. J. Scoglietti, ITT Advanced Engineering & Sciences (United States); G. Harston, Celight, Inc. (United States)

Progress in standoff detection of surface-bound explosives residue using photothermal and photoacoustic (PT/PA) imaging and spectroscopy has been reported recently. Photothermal/photoacoustic interferometry (PTI), a variation of the aforementioned techniques, is a candidate for standoff detection as a result of its non-contact and non-destructive approach. In PTI, the PT/PA effects produced by explosives' direct absorptions of infra-red laser excitation are measured by an overlapping focused probe laser beam. The return back-scattered/reflected probe laser beam is collected and coupled into a single-mode optical fiber. The PT/PA-induced perturbation on the return probe laser, in the form of phase or amplitude modulation or both, is detected interferometrically. The resulting quadrature signals are digitized and processed to recover the minute PT/PA dynamics against background noise producing an absorption spectrum of the surface-borne explosive residue. The CW probe laser, operating in the 1550-nm range, and the constituents of the coherent detection system are commercial off-the-shelf components. A commercial tunable quantum cascade laser with output pulse energies up to 50 nJ was employed to generate the PT/PA perturbation in the 8.8-10.2 m range where the atmospheric absorption is negligible. PTI spectral data collected for three types of solid explosives deposited on a non-absorbing surface: HMX, RDX, and PETN, with the probe laser system 5 meters away from the explosives targets, will be presented. In addition, investigation of non-direct-absorption induced by stimulated Raman scattering (SRS) process in solid samples will be described. We believe this is the first standoff solid explosives detection via both SRS and PT/PA techniques.

8018-66, Poster Session

Explosives detection in the marine environment using UUV-modified immunosensor

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Port and Harbor Security has rapidly become a point of interest and concern with the emergence of new improvised explosive devices (IEDs). The ability to provide physical characterization at these entry points has led to an increased effort in the development of unmanned underwater vehicles (UUVs) equipped with sensing devices. Traditional sensors used to identify and locate potential threats are side scan sonar and acoustic methods. At the Naval Research Laboratory (NRL), we have developed an immunosensor capable of detecting trace levels of explosives that has been integrated into a REMUS payload for use in the marine environment. Laboratory tests using a modified PMMA microchannel device with immobilized monoclonal antibodies specific for TNT and RDX have been conducted yielding detection levels in the low parts-per-billion (ppb) range. New designs and engineered improvements in microfluidic devices, fluorescence signal probes, and UUV internal fluidic and optical components have been investigated and integrated into the unmanned underwater prototype. Results from recent field demonstrations using the prototype UUV immunosensor will be discussed. The immunosensor in combination with acoustic and other sensors could serve as a complementary characterization tool for the detection of IEDs, unexploded ordnances and other potential chemical or biological threats.

8018-67, Poster Session

Detection of TATP precursor acetone at trace levels using rf sputtered SnO_2 thin film-based sensors

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Emerging threats of improvised explosive devices (IEDs) and homemade explosives (HMEs) have created a demand for reliable and unambiguous recognition of constituent analytes. Triacetone triperoxide (TATP), a cyclic peroxide based explosive has become a weapon of choice [1] in the hands of resourceful urban insurgents mainly because of ease of manufacture with readily available precursor constituents (acetone and concentrated hydrogen peroxide). Failure of conventional EDDs due to absence of nitrogen compounds coupled with the fact that TATP exhibits no significant absorption in UV region and does not demonstrate fluorescence has confined its detection to IR and Raman spectroscopy besides some enzyme-based tests and mass spectrometry [2]. Hence there is an urgent need for highly sensitive technique with a fast response speed that can detect presence of TATP at extremely low vapour pressure and purposely camouflaged physically or under cross-contamination with interfering compounds.

In the present work trace level (20 ppm) acetone (precursor of TATP) sensing characteristics of rf sputtered semiconducting SnO2 thin films having embedded Pt interdigital electrodes have been investigated. Specifically a fast response speed of 10 seconds is noted and sensing characteristics of bare SnO2 and catalyst-SnO2 hetero-structures are compared. Innovative catalyst dispersal technique is shown to enhance sensitivity as also reduce response times with simultaneous application of Fermi-level energy control and Spillover mechanisms. Novel sensing hetero-structures with reversible acetone detection capabilities are shown to provide a feasible alternative for real-field operation along with remote detection with limited sample size.

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8018-69, Poster Session

Fluorescence/scattering lidar for short-range standoff detection of biological agents

Z. Mierczyk, K. Kopczyński, M. Zygmunt, J. Mlynczak, J. Wojtanowski, M. Kwasny, M. Z. Kaliszewski, A. Mlodzianko, M. Wlodarski, A. Gietka, P. Knysak, T. Drozd, M. Muzal, M. Mularczyk-Oliwa, A. Bombalska, J. Mierczyk, Military Univ. of Technology (Poland)

The operation principle of the presented LIDAR (Light Detection and Ranging) is based on the Laser Induced Fluorescence (LIF) and Scattering phenomena presented in biological agents if excited by UV radiation. The system emits UV radiation at 375 nm and collects

scattering and fluorescence at 400 - 450 nm.

Fluorescence of biological particles and scattering signal are detected by three photomultiplier tubes (PMTs) for night detection or by multichannel photomultiplier tube (MCPMT) with narrow bandwidths for day detection. The use of different optical filters in front of the PMTs enables to choose the specific emission bandwidth. The signals from PMTs or MCPMT are analyzed by dedicated electronic system where information of the presence of the dangerous substances is worked out. The application of new light sources based on laser diode technology allows miniaturization of the device and reduction of energy consumption. Thanks to its short range of detection (up to 300m) and low weight the system can be hand-held which enables applications to military operations in urban environment as well as monitoring large area public buildings (airports, shopping centers). The sensors is able to detect bacteria, spores and fungi which can be dangerous for people's health causing some diseases.

8018-70, Poster Session

Gas image enhancement based on morphology and adaptive time-domain filtering

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3~14 micron are the fingerprint regions of most gases. Therefore mid-wave or long-wave infrared thermal imager is commonly applied in gas detection. As the gas signal detected by the thermal imager is often weak, a narrowband filter with its central frequency matching with the gas absorption peak can be employed to enhance gas signal by increasing the radiation energy ratio of gas to background. However, the utility of filter weakens background radiation and amplifies noise in the image. With further influence of low gas concentration and heterogeneity of infrared focal plane arrays, the image has numerous drawbacks including loud noise, weak gas signal, low Signal-to-Noise ratio, gridding, dead points and electronic ripple wave interference, all of which are particularly evident in continuous image sequences. In order to solving the abovementioned problems, we take into account the characteristics of the leaking gas image and propose a enhancement method based on the morphology with the adaptive time-domain filtering. The gas concentration near the leakage source is high but decreases rapidly with the distance increasing from the leakage source. Therefore, the leaking and diffusing gas is a dynamic and transient target. However, it's believed that the gas concentration around the leakage source is stable and the pixel value is relatively even. Thus dilation gas region along direction of gas diffusion can greatly enhance the visibility of the leakage area. Morphological filtering algorithm can not only dilate the gas region, but also effectively remove the noise, smooth the contour, and achieve an independent operation on the gas existence domain based on segmentation of gas and background. The adaptive time-domain filtering method which operates on continuous image sequences is a hybrid method combining the recursive filtering and median filtering methods. This method segments gas and background according to a selected threshold, removes speckle noise according to the median and removes background domain using weighted difference image but retains gas moving domain, to improve the contrast between gas and background. Results show that the gas infrared region is effectively popped out and the Signal-to-Noise ratio is improved.

8018-71, Poster Session

Smart radiation monitor for airport baggage screening

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This work presents specially designed radiation monitoring system for baggage screening on conveyors at airports and border crossing points. The system was developed in order to detect radioactive and special nuclear materials in cargo and thereby increasing the homeland security.

Border monitoring equipment plays a key role in preventing illicit trafficking. The IAEA Illicit Trafficking Database[ ], reports over 250 confirmed radioactive incidents since July 2006.

The obtained sensitivity results of the system and an analytical analysis of the system algorithm contribution to the detection performances are presented. This comprehensive system consists of highly sensitive gamma and neutron detectors, electronic data processing unit, computer interface and unique algorithms for improving the detection level.

Several categories of instrumentation were defined to deal with illicit trafficking. The conveyor monitor copes with the detection level determined by the standard for Radiation Portal Monitors.

This type of device inherent greater sensitivity than hand held monitors for continuous monitoring of the baggage flow.

The system's electronic unit interfaces with the conveyor control system for both, receiving the conveyor operation status and for providing an output signal for stopping the conveyor in case of alarm. This interface and implemented algorithm enable us to maintain low false alarm rate and to improve detection level by taking the background variation in consider. The on-line computer software provides the user with friendly interface for analyzing the archived data. Further significant improvement of the detection level is achieved by implementing an advanced algorithm based on the detector reading profile versus time.

8018-73, Poster Session

Rotationally resolved infrared spectra of the explosive bouquet compounds in C-4 explosives

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The explosive material known as Composition C4, or simply C4, is an RDX based military grade explosive. RDX itself possesses a negligible vapor pressure at room temperature suggesting it is not a good target for conventional instruments designed to detect vapor phase chemical compounds. Recent research with canines has indicated that a better approach for detecting explosive vapors such as C4 might be to focus on a characteristic mixture of impurities associated with the material. These characteristic mixtures of impurity vapors are referred to by canine researchers as the explosive bouquet and are fairly unique to the specic energetic material. In this paper, we will examine and report infrared spectral signatures for the known compounds comprising the explosive bouquet for C4 based explosives including isobutylene, 2-ethyl-1-hexanol and cyclohexanone.

8018-20, Session 4

Visible/near-infrared hyperspectral sensing of solids under controlled environmental conditions

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We describe the use of a wind tunnel for conducting controlled passive hyperspectral imaging experiments. In recent years, passive hyperspectral detection of solids, minerals and ores has emerged as a very useful technique, for example for classifying land types, mineral deposits, and agricultural practices. Such techniques are also potentially useful for detecting explosives, solid-phase chemicals and

other materials of interest from a distance so as to provide operator safety. The Pacific Northwest National Laboratory operates a wind tunnel facility that can generate and circulate artificial atmospheres whereby certain environmental parameters can be controlled such as lighting, humidity, temperature, aerosol burdens, and obscurants. By selecting the appropriate fore optics and sample size, one can conduct meaningful experiments under controlled conditions at relatively low cost when compared with typical instrument deployments. We will present recent results describing optimized sensing of solids over tens of meters distance using both visible and near-infrared cameras, as well as the effects of certain environmental parameters on data retrieval.

8018-21, Session 4

Fluorescence lifetime imaging system for the remote sensing of hazardous materials

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This paper describes the development an demonstration of a stand-off fluorescence lifetime imaging (SeePhase) system for the remote, real time identification and measurement of chemical and biological fluorescent markers in the field that are indicative of hazardous distress. The fluorescence lifetime of the target fluorophores is measured using the principle of "frequency-domain" or "phase-locked" detection, a method that is insensitive to the excitation or fluorescence emission light intensity levels as well as insensitive to any background stray light. The remotely detected lifetime signals are processed using fast software algorithms and displayed in real time in a spatially resolved 3-dimensional fluorescent lifetime image of the field. As world governments have become more attentive to the potential threat of chemical and biological weapons, a premium has been place on technologies capable of reliably identifying airborne threats. The SeePhase system will be applicable to the military for the protection of war-fighters as well as in civilian and government institution for first-time responders and civilian protection.

8018-22, Session 4

Optical constants of neat liquid-chemical warfare agents and related materials measured by infrared spectroscopic ellipsometry

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There is an ongoing need in the standoff detection communities for reliable complex indexes of refraction of chemical warfare agents and related materials in the infrared. Understanding the liquid phase optical properties of these materials is essential to the development of remote sensing capabilities of the chemical agents in aerosol droplet form. We studied various liquids using a novel vertical attenuated total reflection (ATR) liquid sampling assembly in conjunction with Infrared Variable Angle Spectroscopic Ellipsometry (IR-VASE), to determine the infrared optical constants of several bulk liquids related to chemical warfare. The index of refraction, n, and the extinction coefficient, k, of isopropyl methylphosphonofluoridate (Sarin or GB), isopropyl alcohol (IPA) (a precursor of GB), and dimethyl methylphosphonate (DMMP)-a commonly employed simulant for GB, measured by our vertical ATR IR-VASE setup are closely matched to those found in other studies. We also report the optical constants of cyclohexyl methylphosphonofluoridate (GF), 2-(diisopropylamino)ethyl methylphosphonothioate (VX), bis-(2-chloroethyl) sulfide (HD), and 2-chlorovinyl dichloroarsine (L, Lewisite). In this study we demonstrated that the ATR IR-VASE technology, which has been used to investigate a variety of organic liquids, affords an appropriate and accurate measurement of the complex indices of refraction for the chemical warfare agents and agent simulants. Despite their high toxicities and diverse characteristics, optical properties of hazardous liquid compounds in the infrared region can be readily measured by this technique without the need for more complicated experimental and mathematical approaches.

8018-23, Session 4

Active infrared multispectral imaging of chemicals on surfaces

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Active infrared multispectral imaging is a promising technique for the standoff detection and mapping of chemicals on surfaces. The technique involves measuring the reflectance from a surface as a function of illumination wavelength in the long-wave infrared (LWIR) and analyzing the multispectral images for evidence of distinctive absorption features. In this work, the phenomenology of LWIR reflectance from contaminated surfaces was measured using a quantum-cascade laser (QCL) that tunes from 9.1 to 9.8 microns and a HgCdTe focal-plane array (FPA) with custom read-out integrated circuit (ROIC). Diethyl phthalate (DEP), a chemical simulant for VX, was applied to a variety of surfaces such as diffusely reflecting gold, concrete, asphalt, and sand, and multispectral images were taken at standoff distances ranging from 0.1 to 5 meters. The presence of the chemical simulant was measurable for all surfaces and the optical signatures were found to be dominantly characterized by either absorption in the chemical or by reflection at the air/chemical interface. The measured results compare favorably with theoretical calculations. We also demonstrate the unique on-chip processing capabilities of the custom ROIC used in this work by generating differential-reflectance images of contaminated objects moving at speeds of more than 1 m/s. These experiments confirm that active multispectral imaging is a powerful technique that warrants further investigation for the standoff detection and mapping of contaminated surfaces.

8018-24, Session 4

Polarimetry and infrared spectroscopy in the detection of low-volatility chemical threats

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Recent advances in our non-contact detection of G- and V-series nerve agents are presented. Various configurations of polarization modulation infrared reflection-absorption spectroscopy (PMIRRAS) have been used to investigate the applicability of PMIRRAS to detecting low-volatility chemical threats on surfaces. Experimental investigations have been augmented with theoretical models of polarimetric infrared spectroscopy.

8018-25, Session 4

Characterization of next-generation commercial surface-enhanced Raman scattering (SERS) substrates

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Surface-enhanced Raman scattering (SERS)-based techniques are increasingly used for Army, first responder and defense relevant applications. Commonly SERS is used for the identification and characterization chemical and biological hazards, energetic materials and medical applications. SERS, like most Raman-based techniques is a valuable analytical method to use in theatre as it offers many advantages. SERS advantages include easy sample identification and characterization, little to no sample preparation, application in many environments, no interferences from water, ability to be used with a variety of laser sources, and reliance on specific vibrations within the molecule from which a sample specific spectrum can be generated. Despite all of these advantages, the ubiquitous use of SERS remains challenging due to the lack of a commercially available reproducible, high sensitivity and uniform substrates. In this paper we report on the characterization of next generation commercial substrates, and demonstrate their application to an Army relevant target.

8018-26, Session 5

A two-pulse, pump probe method for short-range, remote standoff detection of chemical warfare agents

S. E. Bisson, T. A. Reichardt, T. J. Kulp, Sandia National Labs., California (United States)

Remote standoff detection of surface contamination is currently a problem of importance to many homeland security and military defense missions. Low-volatility chemical warfare agents are of particular concern due to their persistence and extreme toxicity. Methods that can rapidly screen in real-time a suspected contamination area while simultaneously reducing the potential for operator contact are highly desired. At present, methods based on contact swiping with subsequent laboratory analysis are employed, however, these methods typically cover a limited surface area, require time consuming post laboratory analysis and place the technician in close proximity to the agent.

The broadest class of low-volatility chemical warfare agents are based on high molecular weight organo-phosphates which contain the common PO group. Unfortunately, large organophosphates are not easily amenable to rapid, remote standoff detection by conventional methods such as laser induced fluorescence or gas phase infrared absorption. As the objective of this work is to evaluate methods for rapid screening of contaminated surfaces, positive identification of the particular agent is not required. Thus, detection of either molecular PO or atomic phosphorous associated with the agent may be sufficient. In this work, we explore a two-pulse, pump-probe method that ablates the analyte from the surface that subsequently produces molecular PO. The photofragment PO or P is then probed by a second low energy (~10µJ) laser. This approach has the advantage of producing species that are easily detectable by laser induced fluorescence and that for screening applications the photofragments have a high degree of association with organophosphates.

8018-27, Session 5

Standoff chemical detection using quantum cascade lasers and photoacoustic sensing

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In recent years good progress has been made in the area of chemical detections, especially with the advance of quantum cascade lasers (QCLs) and photoacoustic spectroscopy (PAS). However, most of the demonstrated methods of detection are localized techniques and require that the samples be contained in a photoacoustic cell for testing and measurement. We report in this paper the feasibility of standoff chemical detection using QCL and PA technique. In our experiment, we use a QCL with an emission wavelength near 7.9µm, an electret condenser microphone, and isopropanol (IPO) vapor as a safer experimental substitute of the explosive, RDX. With the IPO bottle open, a constant flow of IPO vapor is formed at the opening and the vapor is trapped inside a T-shape piping. The QCL is running at pulsed mode with a repetition rate of 1 kHz and duty cycle of 50%. The microphone is placed around 15 centimeters away from the IPO vapor. An acoustic signal is generated and can be detected by the microphone directly without any help of filter or amplifier. The generated acoustic signal is proportional to the laser pulse energy and inversely proportional to the distance to the sample. After adding filters, amplifiers, and sound reflectors to the system and increasing the laser power, the standoff detection distance shall be able to increase greatly. We are in the process to improve the sensitivity and detection distance.

8018-28, Session 5

LIBS spectroscopic classification relative to compressive sensing

S. T. Griffin, E. Jacobs, O. Furxhi, The Univ. of Memphis (United States)

Laser Induced Breakdown Spectroscopy (LIBS) utilizes a diversity of standard spectroscopic techniques for classification of materials present in the sample. Pre-excitation processing sometimes limits the analyte to a short list of candidates. Prior art demonstrates that sparsity is present in the data. This is sometimes characterized as identification by components. Traditionally, spectroscopic identification has been accomplished by an expert reader in a manner typical for MRI images in the medicine. In an effort to automate this process, more recent art has emphasized the use of customized variations to standard classification algorithms. In addition, formal mathematical proofs for compressive sensing have been advanced. Recently the University of Memphis has been contracted by the Spectroscopic Materials Identification Center to advance and characterize the sensor research and development related to LIBS. Applications include portable standoff sensing for improvised explosive device detection and related law enforcement and military applications. Reduction of the mass, power consumption and other portability parameters is seen as dependent on classification choices for a LIBS system. This paper presents results for the comparison of standard LIBS classification techniques to those implied by Compressive Sensing mathematics. Optimization results and implications for portable LIBS design are presented.

8018-29, Session 5

Standoff detection applying laser-induced breakdown spectroscopy at the DLR laser test range

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The DLR laser test range at Lampoldshausen is designed for a wide field of laser application studies at central European atmospheric conditions. Micrometeorological measurements are performed simultaneously and nearby to the laser propagation path. The infrastructure is very suitable for the developement of laser based stand-off detection systems of biological, chemical, and explosive hazardous substances. In a first approach, laser-induced breakdown spectroscopy (LIBS) has been introduced for investigation of surface contaminents at distances up to 130 m. A basic LIBS set-up and LIBS results of selected samples using different excitation wavelengths from IR to UV are presented for detection at different distances.

A Nd:YAG laser beam was focussed by a Cassegrain type telescope onto different samples. The light of the generated plasma plume was collected by a Newtonian telescope, analysed and detected by a broadband CCD-spectrometer system. The Nd:YAG laser yields pulse energies up to 800 mJ at a wavelength of 1064 nm and a pulse width of 8 ns. Optionally the second and third harmonics can be extracted at reduced energy. LIBS spectra produced on gold layers as thin as 5 nm deposited on silicon wafers were recorded for test of detection sensitivity and comparison of wavelengths effects. In addition, black powder as ordinary substance representing explosives was detected by LIBS technology. Spectra were recorded in single and repetitive pulsed scheme of the Nd:YAG laser at various daylight and atmospheric conditions.

8018-30, Session 6

Mid-infrared optical fiber Fourier transform infrared spectrometer

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The need for small, robust, and highly selective sensors for both military and homeland security requirements is driving the development of portable and less expensive detectors for hazardous materials. Infrared spectroscopy exhibits high selectivity because the infrared vibrational transitions correlate to the molecular structure and functional groups within the molecule. Small FTIR systems exist as COTS items; however, these systems still require a moving mirror to generate the interferogram. A more desirable approach is to build a solid state system with no precision moving parts as required by a typical moving mirror interferometer. This work will describe the design aspects of an optical fiber based mid-infrared FTIR and focus specifically on the use of an optical fiber supercontinuum source for efficient coupling of light into the system.

8018-31, Session 6

Hollow-core fiber optics for mid-wave and long-wave infrared spectroscopy

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We describe the development and testing of hollow core glass waveguides (i.e., fiber optics) for use in Mid-Wave Infrared (MWIR) and Long-Wave Infrared (LWIR) spectroscopy systems. This wavelength region from 3 to 12 microns is useful for detecting trace chemical compounds indicative of weapons of mass destruction (WMD), and fiber optics are a key enabling technology needed to improve the utility and effectiveness of detection systems. Hollow glass waveguides have the advantage over solid-core chalcogenide fibers in that they are less fragile, do not produce cladding modes, and do not require angle cleaving or anti-reflection coatings to minimize laser feedback effects. In addition, hollow waveguides have been proven to effectively deliver Gaussian beams with low loss in the MWIR and LWIR regions. This paper focuses on recent developments in hollow waveguide technology geared specifically for infrared spectroscopy, including a reduction in both length dependent and bending losses while maintaining relatively high beam quality. Results will be presented from tests conducted using Quantum Cascade Lasers (QCL's) operating in the LWIR range centered at about 10 microns. When used with an aperture to spatially filter the output of a QCL, the waveguides are shown to effectively deliver the beam with relatively low loss (e.g., 0.5 dB/m) and relatively high beam quality. Alternatively, without a spatial filter, the waveguides are also shown to effectively mode-filter the raw beam exiting the QCL, in effect damping out the higher order modes, as well as, converting the elliptical output beam into a more circular profile.

8018-32, Session 6

Design, synthesis, and processing of novel infrared chalcogenide glasses for ultra-sensitive nanocavity photothermal chem-bio detection

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Nano-cavity enhanced photothermal spectroscopy is a novel technique we have recently proposed for ultra-sensitive detection of chemical and biological species (toxic gases, aerosols, spores, etc.) in the gas phase. While conventional infrared spectroscopy directly measures the optical absorption due to the target molecular species, photothermal spectroscopy detects photothermal heat generation as a consequence of infrared absorption. We illustrate that through simultaneous spatial localization of optical and thermal interactions in a planar integrated nano-cavity, the detection sensitivity is dramatically improved by > 104 compared to state-of-the-art, and ppt-level limit of detection can be attained without pre-concentration.

Key to the nano-cavity photothermal detection is the use of novel infrared-transparent chalcogenide glass alloys for optical resonant cavity fabrication. Through composition engineering, these glasses feature a photothermal material figure-of-merit more than two orders of magnitude higher compared to conventional photonic materials such as silica and silicon. We show that high-quality chalcogenide glass thin films can be deposited via thermal evaporation over large areas with high uniformity. We further demonstrate Si-CMOS backend-compatible fabrication of planar photonic devices in these glass materials. Record cavity quality factors up to 5 × 105 have been achieved in planar chalcogenide glass resonant cavities, leading to high photothermal detection sensitivity.

8018-33, Session 6

Demonstration of microcantilever-based sensor array with integrated microfluidics

G. P. Nordin, R. R. Anderson, S. J. Ness, W. Hu, T. M. Gustafson, D. C. Richards, J. W. Noh, S. Kim, Brigham Young Univ. (United States)

Microcantilevers configured as sensors have been shown to have high sensitivity for biological, chemical, explosive, and environmental sensing applications. We have recently developed a new in-plane photonic transduction mechanism that scales to simultaneously read out hundreds of microcantilevers on a single chip. Experimental characterization has demonstrated readout sensitivity as good as the best achieved by the laser reflection method typically used in atomic force microscopes (AFMs). By functionalizing individual microcantilevers with different molecular receptors, an array of microcantilevers can function as a label-free, high sensitivity, multiplexed sensing platform. Moreover, integration with microfluidics having integrated pumps and valves offers the opportunity to perform such sensing operations with small fluid volumes (~0.5 μL). In this presentation we detail the design and characterization of microcantilever sensor arrays with integrated microfluidics for biosensing applications. We also discuss a new on-chip high speed pump that enables rapid sensing with small sample volumes, and a new flow-dependent transient response that we use for microcantilever characterization.

8018-34, Session 7

Coordinated sensor cueing for chemical plume detection and tracking

C. Hawthorne, A. S. Watkins, S. J. Marshall, N. Abraham, A. Jensenius, The Johns Hopkins Univ. Applied Physics Lab. (United States)

This paper presents a system for detecting and tracking a chemical plume using multiple, mobile chemical standoff sensors. The system employs a distributed data fusion algorithm for processing detections (both organic and received) and sending cues to other sensors connected by a wireless mesh network. The data fusion algorithm was located at each sensor in the network on a JoaC (JCID on a Chip) hardware platform. The chemical sensors are JSLSCADs (Joint Services

Lightweight Standoff Chemical Agent Detector) which detect and classify chemical agents using Fourier transform infrared (FTIR) spectroscopy. Results from a field test performed at Dugway Proving Grounds in October 2010 are presented.

8018-35, Session 7

Enhanced chemical weapon warning via sensor data fusion

M. Flaherty, Torch Technologies (United States)

Torch Technologies Inc., is actively involved in CBRN sensor networking and data fusion via multi-year efforts with Dugway Proving Ground (DPG) as well as the Defense Threat Reduction Agency (DTRA) working in conjunction with the Edgewood Chemical Biological Center (ECBC). The objective of these efforts is to develop innovative concepts and advanced algorithms that enhance our national Chemical Warfare (CW) defense warning capabilities via the fusion of traditional and non-traditional CW sensor data. Under Phase I, II, and III SBIR contracts with DPG, Torch developed the Advanced Chemical Release Evaluation System (ACRES) software to support CW sensor specific data fusion. ACRES fuses non real-time heterogeneous test range sensor data and estimates optimal Gaussian model-based cloud states for chemical simulant cloud releases. The ACRES cloud state estimation process provides a sensor fusion based characterization of CW agent cloud transport and dispersion dynamics, including time projections with uncertainties, by fusing point concentration (PC) measurements, standoff sensor concentration pathlength (CL) measurements, and meteorological data. Under Phase I and II SBIRs with DTRA, ACRES provided the initial framework from which to develop the Cloud state Estimation in a Networked Sensor Environment (CENSE) real-time sensor network data fusion architecture. Under the DTRA effort, Torch is developing CENSE to implement and test innovative concepts for real-time network data fusion of CW and non-CW sensor data via integration of fusion nodes within the Potomac Fusion Inc., Fusion Exploitation Framework (FEF). This approach aligns itself with the DTRA/ECBC MARS-JFP Advanced Technology Demonstration effort which the CENSE framework supports.

8018-36, Session 7

Sensor fusion for chemical plume detection, classification, and tracking

A. S. Watkins, J. D. Barton, C. Hawthorne, The Johns Hopkins Univ. Applied Physics Lab. (United States)

The Chemical/Biological Detection Early Warning System (CBDEWS) is a multi-modal sensing approach to chemical and biological detection and warning. The system employs a diverse set of standoff sensors (including LIDAR, IR, and acoustic) and UAV-borne point sensors for the purpose of providing sufficient warning and actionable information in response to a chemical or biological event. This paper describes the data fusion algorithm which fused individual detections from all sensors in terms of both plume location and classification. Additionally, all sensors where cued to areas of interest in the field of regard based on detections and their fused result. The fusion algorithm employs grid-based recursive Bayesian estimation to compute an estimate of the plume's location and classification over a discrete spatial grid. Data fusion and plume tracking results from field tests performed at Dugway Proving Grounds are presented.

8018-37, Session 7

Modeling of photoacoustic vapor sensors using a multiphysics approach

E. L. Holthoff, P. M. Pellegrino, U.S. Army Research Lab. (United States)

Photoacoustic spectroscopy (PAS) is a useful monitoring technique that is well suited for trace gas detection. This method routinely exhibits detection limits at the parts-per-million (ppm) or parts-per-billion (ppb) level for gaseous samples. PAS also possesses favorable detection characteristics when the system dimensions are scaled to a micro-system design. One of the central issues related to sensor miniaturization is the geometry of the photoacoustic cell. Current work utilizes COMSOL Multiphysics software to develop a model for the characterization of a photoacoustic cell that has provided favorable vapor detection capabilities in a sensor platform. The model is used to predict the acoustic resonance frequency of the cell and the results are compared to experimental data.

8018-38, Session 8

Dynamic sensor deployment for the monitoring of chemical releases in urban environments (DYCE)

J. J. Lepley, SELEX Galileo Ltd. (United Kingdom)

The ability to analyse the chemical composition or quality of air samples in a controlled environment is easily demonstrated, but the problem becomes extremely complex when translated to an unconstrained outdoor environment. Here the sensors are faced with the need to identify very low particle counts, often in the presence of high levels of benign pollutants and rapidly changing turbulent meteorological conditions.

The DYCE project has been set up to address the needs of military and blue light responders in providing a rapid, reliable on-scene analysis of the dispersion of toxic airborne contaminants following their malicious or accidental release in an urban or industrial environment.

The system comprises a small network of portable ad-hoc deployable sensor nodes that are able to monitor and react to changing local conditions and chemical data to enable end-users to dynamically optimise their locations. Each node is built around the SELEX GALILEO Hydra platform fitted with solid state meteorological sensors and a Nexsense-C Field Asymmetric Ion Mobility Spectrometry (FAIMS) based chemical detector. The FAIMS detector provides a capability to rapidly detect and identify chemical warfare agents and toxic industrial chemicals.

This paper presents an overview of the project and results on methods to:

- Identify and locate the source of the contaminant release.

- Monitor and estimate the dispersion characteristics of the plume.

- Monitoring localised changing environmental conditions and understanding their repercussions on the mission.

- Deployment planning to optimise the data gathering mission given a constrained asset base.

8018-39, Session 8

Remote quantification of smokestack total effluent mass flow rates using imaging Fourier-transform spectroscopy

J. L. Harley, K. C. Gross, Air Force Institute of Technology (United States)

A Telops Hyper-Cam midwave infrared (1.5-5.5 μm) imaging Fourier-transform spectrometer (IFTS) will be used to estimate industrial smokestack total effluent mass flow rates (kg/hr) by combining spectrally-determined species concentrations with flow rates estimated via analysis of sequential images in the raw interferogram cube. Recent measurements of the coal-burning smokestack were made with the IFTS at a stand-off distance of 350 m. Approximately 200 hyperspectral data cubes were collected on a 128 (W) x 64 (H) pixel sub-window (11.4 x 11.4 cm^2 per pixel) at high spectral resolution (0.5/cm). Strong emissions from H_2O, CO_2, CO, SO_2, and NO were observed in the spectrum. A

single-layer plume radiative transfer model will be used to estimate gas concentrations; results will be compared with in situ measurements. The turbulent nature of the flow field results in instantaneous fluctuations in scene radiance; these fluctuations lead to brightness patterns which are captured in the DC-level imagery. A simple analysis of sequential imagery will be presented which enables an estimation of the flow velocity. This brightness pattern velocity estimation method applied to IFTS measurements of a laboratory blower afforded a velocity estimate of 783±5 cm/s which compared favorably with 800±24 cm/s as measured by an anemometer.

8018-40, Session 8

iCATSI: a multi-pixel imaging differential standoff chemical detection sensor

L. M. Moreau, F. Prel, ABB Analytical Measurement (Canada); H. Lavoie, Defence Research and Development Canada (Canada); C. B. Roy, C. A. Vallieres, ABB Analytical Measurement (Canada); J. Theriault, Defence Research and Development Canada (Canada)

iCATSI is a combination of the CATSI instrument, a standoff differential FTIR optimised for the characterisation of chemicals and the MRi, the hyperspectral imaging spectroradiometer of ABB Bomem based on the proven MR spectroradiometers.

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 object of interest. The instrument is capable of sensing in the VLWIR (cut-off near 14 μm) to support research related to standoff chemical detection.

Overview of the capabilities of the instrument and results from tests and field trials will be presented.

8018-41, Session 8

Chemical agent detection with low-resolution scanning FTIR sensors

E. R. Larrieux, D. Manolakis, MIT Lincoln Lab. (United States); F. M. D'Amico, U.S. Army Edgewood Chemical Biological Ctr. (United States)

Standoff detection of chemical warfare agents is necessary when physical separation is required to put people and assets outside the zone of severe damage. An important class of standoff sensors for chemical plumes is based on the principles of passive infrared (IR) spectroscopy. Typical standoff sensors utilize passive imaging spectroscopy in the long wave infrared (LWIR) atmospheric window (8 - 13um). The LWIR region is well suited for gas-sensing applications because of the relative transparency of the atmosphere at these wavelengths and the presence of uniquely identifying features for a wide range of chemicals. In contrast to high-resolution hyperspectral imaging sensors, which almost simultaneously provide a large number of spatially registered spectra, low-resolution scanning spectrometers provide a small number of spectra by sampling the area surrounding a chemical plume. The limited amount of background training data and their spatial-temporal nonstationarity, pose a unique challenge to the development of algorithms designed to exploit low-resolution scanning FTIR spectrometer data. The purpose of this paper is to analyze data from the JSLSCAD and low-resolution Aerospace scanning FTIR sensors to investigate the effects of limited background training data, background nonstationarity, and registration on the performance of chemical detection algorithms.

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8018-42, Session 8

Characterization of aerosol-containing chemical simulant clouds using a sensitive, thermal infrared imaging spectrometer

J. L. Hall, J. Qian, M. L. Polak, C. S. Chang, The Aerospace Corp. (United States); F. M. D'Amico, U.S. Army Edgewood Chemical Biological Ctr. (United States); S. J. Kolodzey, U.S. Army Research, Development and Engineering Command (United States)

A sensitive, ground-based thermal imaging spectrometer based on the SEBASS design has been deployed to the Army's Dugway Proving Ground to remotely monitor explosively-released chemical simulant clouds from stand-off ranges of several kilometers. The sensor has 128 spectral bands covering the 7.8 to 13.5 micron region. Data analysis has focused on the nighttime releases, in which low altitude temperature inversions restrict the vertical motion of the dispersing cloud. The 1-mrad pixel size and low noise (< 0.1K NEDT) of this sensor permits detailed probing of the spatial and spectral content of these clouds. Initial data processing using our SAGE (Scene-based Algorithm for Gas Estimation) algorithm showed anomalously low detection strengths for pixels located in the center of the clouds. This was caused by severe mis-modeling of the measured spectra because the spectra were distorted by scattering of high-elevation-angle sky radiance by aerosols or dust in the clouds. These new spectral characteristics persisted for long times. The predicted lifetime of small aerosol droplets, due to rain-out and evaporation, is much shorter. This suggests that the scattering is primarily caused by dust, not aerosols, in the clouds. These results have significant implications for stand-off detection of chemical clouds containing significant amounts of aerosols or dust. On one hand it is clear that detection algorithms must properly account for the scattered radiation component, and on the other this scattering gives rise to an enhanced "delta-T" for detection.

8018-43, Session 9

Signal processing for the detection of explosive residues on varying substrates using laser-induced breakdown spectroscopy

K. D. Morton, Jr., P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Laser induced breakdown spectroscopy (LIBS) can provide rapid, minimally destructive, chemical analysis of substances with little to no sample preparation. Therefore, LIBS is a viable technology for the detection of substances of interest in fielded scenarios. Of particular interest to military and security operations is the detection of explosive residues on various surfaces. It has been demonstrated that LIBS is capable of detecting residues of this type, however, the surface or substrate on which the residue is present can alter the observed spectra. Standard chemometric techniques such as principal components analysis and partial least squares discriminant analysis have previously been applied to data collections of this type, however, it has been observed that the classification techniques developed on such data perform best against residue/substrate pairs that were included in model training. Therefore, previously seen residues may not be correctly detected if they are presented on a previously unseen substrate. In this work, we explicitly model LIBS spectra resulting from the residue and substrate to attempt to separate the response from each of the two components. This separation process is performed jointly with classifier design to ensure that the developed classifier is able to detect residues of interest without being confused by varying substrates. We demonstrate that the proposed classification algorithm provides improved robustness to variations in substrate compared to standard chemometric techniques for residue detection.

Return to Contents

8018-44, Session 9

Fabrication and testing of a standoff trace explosives detection system

R. D. Waterbury, J. B. Rose, D. Vunck, T. B. Blank, F. Vilardi, K. R. Pohl, A. Ford, T. McVay, E. L. Dottery, Alakai Defense Systems, Inc. (United States)

Improvised explosive devices (IEDs) are the number one threat to coalition forces in Afghanistan. Operational assessments indicate standoff trace detection of explosives, home made explosives, and explosive precursors may aid the counter-IED fight.

A standoff, trace, checkpoint explosives detection system (CPEDS) for reducing the IED threat has recently been fabricated and government field tested. The system incorporates multi-wavelength Raman and laser induced breakdown spectroscopy (LIBS) modalities into a single unit for trace detection of explosives during military operations. Newly developed spectrometers, custom and off-the-shelf components and other required sensors all integrated with a custom graphical user interface for producing simplified, real-time detection results are also included in the system. All equipment is housed in a military ruggedized shelter for potential deployment in-theater for signature collection and operational assessment.

In September 2010, the system underwent a Military Utility Assessment (MUA) for use by soldiers in Fort Leonard Wood Missouri. The system was operated by Soldiers in an operational environment during the MUA. Results from government double-blind technical testing, as well as the construction of the CPEDS system and its potential deployment capabilities, will be presented in the current work.

8018-45, Session 9

Multiple-excitation-wavelength resonance-Raman explosives detection

B. Yellampelle, M. Sluch, West Virginia High Technology Consortium Foundation (United States); S. A. Asher, Univ. of Pittsburgh (United States); B. E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

Deep-ultraviolet resonance Raman spectroscopy (DUVRRS) is a potential candidate for stand-off detection of explosive traces due to: 1) resonant enhancement of Raman cross-section, 2) ^(-4)-cross-section enhancement, and 3) fluorescence and solar background free signatures. For trace detection, these signal enhancements more than offset the small penetration depth due to DUV absorption. A key challenge for stand-off sensors is to distinguish explosives, with high confidence, from a myriad of unknown background materials that may have interfering spectral peaks. To address this, we have investigated a new technique that simultaneously detects Raman spectra from multiple DUV excitation wavelengths. Due to complex interplay of resonant enhancement, self-absorption and laser penetration depth, significant amplitude variation is observed between corresponding Raman bands with different excitation wavelengths. These variations with excitation wavelength provide a unique signature that complements the traditional Raman signature to improve specificity relative to single-excitation-wavelength techniques. We have measured these signatures for a wide range of explosives using amplitude-calibrated Raman spectra, obtained sequentially by tuning a frequency-doubled Argon laser to 229, 238, 244 and 248 nm. For nearly all explosives, these signatures are found to be highly specific. An algorithm is developed to quantify the specificity and sensitivity of this technique. To establish the feasibility of this approach, a multi-wavelength DUV source, based on Nd:YAG harmonics and hydrogen Raman shifting, and a compact, high throughput DUV spectrometer, capable of simultaneous detection of Raman spectra in multiple spectral windows, are being investigated experimentally.

8018-46, Session 9

Remote detection of explosives using Raman spectroscopy

J. E. Fulton, Jr., Naval Surface Warfare Ctr. Crane Div. (United States)

Stand-off detection of potentially hazardous small molecules at sufficient distances that allow the user to be safe has many applications, including explosives and chemical threats. The Naval Surface Warfare Center, Crane Division, with EYZtek, Inc. of Ohio, developed a prototype stand-off, eye-safe Raman spectrometer. With a stand-off distance greater than twenty meters and scanning optics, this system has the potential of addressing particularly difficult challenges in small molecule detection. An overview of the system design and desired application space is presented.

8018-47, Session 9

Deep-UV Raman measurements of energetic materials

S. A. Asher, D. Tuschel, L. Wang, 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.

8018-48, Session 9

Ultraviolet resonance Raman spectroscopy of nitroaromatic compounds for standoff detection applications

E. D. Emmons, S. D. Christesen, A. W. Fountain III, J. A. Guicheteau, U.S. Army Edgewood Chemical Biological Ctr. (United States)

Ultraviolet resonance Raman spectroscopy is a potentially valuable tool for standoff detection of trace quantities of explosives. Due to the large enhancements in the Raman cross sections that can be obtained, the detectable concentrations are significantly reduced. Nitroaromatic molecules are known to exhibit resonance Raman enhancement upon excitation with wavelengths between 200-300 nm, due to electronic resonance with the nitro groups. For example, nitrobenzene (NB) and 2,4,6-trinitrotoluene (TNT) have strong resonance Raman enhancement when excited at 262 nm. The effect of positional isomerism in nitroaromatic molecules is being examined by studying the different isomers of nitrotoluene (2-, 3-, and 4-nitrotoluene), dinitrobenzene (1,2-; 1,3-; and 1,4-dinitrobenzene), and dinitrotoluene (2,3-; 2,4-; 2,6-; and 3,4-dinitrotoluene) that are available commercially. The UV resonance Raman spectra of these molecules as well as their absolute Raman cross sections are being obtained using various excitation wavelengths in the UV (262 nm, etc.). The ability of UV resonance Raman spectroscopy to selectively discriminate between the different isomers will be examined, in order to determine how well the technique can elucidate small changes in a molecule. Since UV resonance Raman spectroscopy probes both the electronic and vibrational states of a molecule, it has the potential to be more selective than conventional non-resonant Raman spectroscopy. Changes in vibrational mode frequencies, intensities, and resonance enhancement factors and their trends for the different isomers will be discussed.

8018-49, Session 9

Optimal dynamic detection of explosives

D. S. Moore, Los Alamos National Lab. (United States); H. A. Rabitz, Princeton Univ. (United States)

The detection of explosives is a notoriously difficult problem, especially at stand-off, due to their (generally) low vapor pressure, environmental and matrix interferences, and packaging. We are exploring Optimal Dynamic Detection of Explosives (ODD-Ex), which exploits 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 to explosives signatures while dramatically improving specificity, particularly against matrix materials and background interferences. These goals are being addressed by operating in an optimal non-linear fashion, typically with a single shaped laser pulse inherently containing within it coherently locked control and probe sub-pulses. Recent results will be presented.

8018-50, Session 9

Chemical and explosives point detection through opaque containers using spatially offset Raman spectroscopy (SORS)

P. W. Loeffen, C. Tombling, M. Bloomfield, Cobalt Light Systems Ltd. (United Kingdom); P. Matousek, Cobalt Light Systems Ltd. (United Kingdom) and Rutherford Appleton Lab. (United Kingdom)

Spatially Offset Raman Spectroscopy (SORS) is a novel technique used to identify the chemical Raman signature of threat materials within a few seconds through common non-metallic containers, including those containers which do not yield to inspection by conventional backscatter Raman. In particular, some opaque plastic containers and coloured glass bottles can be difficult to analyse using conventional backscatter Raman because the signal from the contents is often overwhelmed by the much stronger Raman signal and/or fluorescence originating from the container surface. SORS overcomes these difficulties and generates clean Raman spectra from both the container and the contents with no prior knowledge of either. This is achieved since two or more Raman measurements are made at various offsets, each containing different proportions of the fingerprint signals from the container and content materials. Using scaled subtraction, or multivariate statistical methods, the two orthogonal signals can be separated, thereby providing a clean Raman spectrum of the contents without contamination from the container. Consequently, SORS promises to significantly improve threat detection capability and decrease the false-alarm rate compared with conventional Raman making it very suitable as an alarm resolution methodology (e.g. at airports). In this presentation, the technology and method are described and the latest results presented in the development of SORS as a screening technology. SORS is highly influenced by optimisation and recent experimental findings are presented in the context of maximising the information from SORS, improving threat detection and minimising the false-alarm rate. This project is funded under the Innovative Research Call in Explosives and Weapons Detection (2010) initiative, a cross-government programme sponsored by a number of government departments and agencies under the CONTEST strategy.

8018-51, Session 9

Investigating a drop-on-demand microdispenser for standardized sample preparation

E. L. Holthoff, M. E. Hankus, P. M. Pellegrino, U.S. Army Research Lab. (United States)

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. A quartz crystal microbalance and Raman spectroscopy are used to investigate droplet and sample uniformity and reproducibility. Results are compared to samples prepared using a dropcast method.

8018-52, Session 9

A mass spectrometer-based explosives trace detector

J. A. Syage, K. A. Hanold, A. Vilkov, Syagen Technology, Inc. (United States)

We have developed an explosives trace detector (ETD) based on mass spectrometry (MS). The first application is for air cargo screening and uses a swab for sample collection off of objects such as packages and a thermal desorber to vaporize and deliver the collected sample to the MS detector. A similar MS system was previously used in a personnel screening portal system (called the Guardian). The MS is based on quadrupole ion trap time of flight (QitTof) MS and operates at 60 Hz in MS mode and 30 Hz in MS/MS mode. The system employs rapid switching dual polarity ionization and detects upwards of 26 compounds simultaneously with MS/MS molecular confirmation. The MS system has several important performance characteristics necessary for high-speed, high-accuracy detection. These include a high volume inlet, high ion trap capacity, high repetition rate in order to achieve positive/negative ionization as well as MS survey and MS/MS confirmation scans. The QitTof also allows over 2 orders of magnitude higher ion capacity than conventional ion traps increasing the dynamic range and greatly reducing saturation effects due to massive doses of sample.

8018-53, Session 9

Multi-colorimetric sensor array for detection of explosives in gas and liquid phases

N. Kostesha, T. S. Alstrøm, Technical Univ. of Denmark (Denmark); C. Johnsen, K. A. Nielsen, J. O. Jeppesen, Univ. of Southern Denmark (Denmark); J. Larsen, A. Boisen, M. H. Jakobsen, Technical Univ. of Denmark (Denmark)

Terrorism is some of the worst problems of all mankind, and its destructive impact on society is developing in complexity. New technology must be developed to detect easily a variety of hidden explosives and explosive derivatives. The Xsense project has at the Technical University of Denmark is a multidisciplinary effort to develop a handheld sensor for detection traces of explosives relevant for defense and security applications.

Colorimetric-sensing technique is one of the promising analytical methods which can be used in detection and identification of explosives (DNT, RDX, TATP and HMX) in the presence of various volatile organic compounds at different temperatures in both gas and liquid phases. The technology relies on an array of up to 384 chemically responsive

compounds immobilized on a solid support. A change in a color signature indicates the presence of unknown explosives and/or molecules of interest. Each chosen compound is selected to react chemo-selectively with the analyte of interest, while others are carefully added to take care of false positives. Images are obtained using an ordinary flatbed scanner or using a low magnification microscope equipped with a cooled color CCD camera. As a result we have a unique digital image of the colorimetric array before and after exposure which composes a unique fingerprint for each analyte. The colorimetric sensor array can detect other chemical compounds belonging to various classes: amines, alcohols, arenes, ketones, aldehydes, and acids. In the practical use the array can be modified for sensing of poisonous chemicals, toxins, illegal compounds, drugs, and narcotics.

8018-54, Session 10

NIR spectroscopy with multivariate calibration and lock-in amplification to detect chemicals concealed behind fabrics

A. Saleem, C. Canal, D. Hutchins, The Univ. of Warwick (United Kingdom)

The detection of specific chemicals using NIR spectroscopy is reported, where the chemical is concealed behind a layer of clothing fabric or packaging material. This concealment modifies the spectrum of a particular chemical when recorded in a diffuse reflection or through-transmission experiment at ranges of a few meters. The subsequent analysis to identify a particular chemical has involved employing calibration models using traditional bilinear modelling methods such as principle components regression (PCR) and partial least squares regression (PLSR). Additionally, detection has been attempted with good results using neural networks trained with Bayesian learning algorithm used in conjunction with Levenberg-Marquardt optimization. The latter technique serves to overcome nonlinearities in the calibration/ training dataset, affording more robust modelling. Finally, lock-in amplification of spectral data has been carried out using software-based algorithms implemented in the LabVIEW environment. This serves to improve detection in noisy environments by enhancing signal-to-noise ratio. The work has been shown to allow detection of specific chemicals such as hydrogen peroxide that could be used to constitute improvised explosives concealed behind a single intervening layer of fabric material or placed within packaging material.

8018-55, Session 10

Development of standoff detection of trace explosives by infrared photo-thermal imaging

C. A. Kendziora, R. Furstenberg, M. R. Papantonakis, V. Q. Nguyen, U.S. Naval Research Lab. (United States); J. L. Stepnowski, Nova Research, Inc. (United States); R. A. McGill, U.S. Naval Research Lab. (United States)

We are developing a technique for the stand-off detection of trace explosives using infrared (IR) photo-thermal imaging. In this approach, compact IR quantum cascade lasers tuned to strong absorption bands in the trace explosives illuminate a surface of interest. An IR focal plane array 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. By varying the incident wavelength slightly, we show selectivity between TNT and RDX. Using a sequence of lasers at different wavelengths, we increase both sensitivity and selectivity while reducing the false alarm rate. A complete test and analysis can be performed in less than 1 second. We emphasize results with cooled detectors and examine the advantages of filtering the collected light signal. We are designing a prototype system for outdoor testing at longer stand-off distances. 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).

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8018-56, Session 10

Enhanced vapor signature of explosive materials using infrared laser excitation

M. R. Papantonakis, R. Furstenberg, C. A. Kendziora, R. A. McGill, J. Grosser, U.S. Naval Research Lab. (United States)

The low vapor pressure of many explosive materials presents a challenge for non-contact sampling of trace residues. We present a technique to augment the vapor signature of explosive materials using infrared light tuned to an absorption mode of the material. A quantum cascade laser is used to heat the sample and create a plume of the explosive material, and a commercial ion mobility spectrometer is used to validate the signal enhancement. We find that the technique works from all tested substrates, though the thermal and spectroscopic properties of the substrate affect the degree of the enhancement.

8018-57, Session 10

The limit of detection for explosives in spectroscopic differential reflectometry

T. A. Dubroca, K. Vishwanathan, M. Friedman, R. E. Hummel, Univ. of Florida (United States)

In the wake of the recent terrorist attacks, such as the 2008 Mumbai hotel explosion or the December 25th 2009 “underwear bomber”, our group has developed a technique (US patent #7368292) to apply differential reflective spectroscopy to the problem of detecting explosives in order to detect terrorist threats. Briefly, light (200-500 nm) is shone on a surface such as a piece of luggage at an airport. Upon reflection, the light is collected with a spectrometer combined with a 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 for explosive detection techniques is the limit of detection. This limit is defined as the amount of explosive material necessary to produce a signal to noise ratio of three. We present here, several methods to evaluate the limit of detection of our technique. In particular we discuss how the definition of noise and signal affect such a limit. Finally, we present our sample preparation method and experimental set-up specifically developed to measure the limit of detection for our technology. This results in a limit ranging from 100 nano-grams to 10 micro-grams depending on the method and the set-up parameters used, such as the detector-sample distance.

8018-58, Session 10

Empirical model for the temporally resolved temperatures of post-detonation fireballs for aluminized high explosives

J. M. Gordon, K. C. Gross, G. P. Perram, Air Force Institute of Technology (United States)

A physics-based, low-dimensionality, empirical model is developed to characterize the time varying temperature profile from post-detonation

combustion fireballs of aluminized novel munitions. Fourier-transform infrared signatures with a temporal resolution of 12 milliseconds are collected from field detonations RDX based aluminized high explosives surrounded by an aluminized plastic-bonded spin-cast liner all inside a steel tube. The rate of change of temperature in the post-detonation combustion fireballs are modeled using a radiative cooling term and a double exponential combustion source term. Confidence in the physical meaning of the fit parameters is established through comparison with expected theoretical values and correlations to expected physical phenomena. Optimized nonlinear least-squares fit of the numerical solution of the empirical model to the temperature data shows the largest fit residuals on the order of 20-60 degrees Kelvin for events with peak temperatures of 1600- 2000 Kelvin. A Pearson correlation coefficient of 0.96 is found between calculated heat of combustion and model predicted heat of combustion. The model reveals a correlation coefficient of 0.77 between the constant rate of ascendancy of a detonation fireball and the total integrated temperature in the same. The present empirical model provides another optical forensic tool with which to robustly classify detonation events.

8018-59, Session 10

A novel infrared hyperspectral imager for passive standoff detection of explosives and explosive precursors

J. Theriault, E. Puckrin, H. Lavoie, F. Bouffard, Defence Research and Development Canada (Canada); P. Lacasse, AEREX avionique inc. (Canada); A. Vallières, V. Farley, M. Chamberland, Telops (Canada)

Fourier-transform infrared (FTIR) spectroscopy is one of the most powerful methods for material characterization. Many remote sensing techniques based on this method have been developed for civilian applications, such as atmospheric sensing and pollution monitoring. 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. This standoff detection capability does not currently exist. DRDC Valcartier recently initiated the development and field-validation of a novel R&D prototype, MoDDIFS (Multi-Option Differential and Imaging Fourier Spectrometer) to address and solve this security vulnerability.

Passive FTIR spectroscopy has been successfully demonstrated in measuring chemical concentrations in smokestack plumes. An outstanding question remains whether typical concentrations of relevant target explosives and precursor chemical vapors emanating from buildings are sufficiently high to be detectable. However, preliminary simulations and measurements on TATP and precursors performed at DRDC Valcartier indicate that typical concentration levels may be detected using a highly-sensitive optimized sensor. Therefore, the MoDDIFS was specifically designed to exhibit the required sensitivity and to detect explosive-related vapors leaking from windows, oven ventilation systems, central air systems and possibly chimneys. 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 an imaging capability of the Hyper-Cam advanced IR imager developed by Telops with a differential CATSI-type sensor. Differential polarization measurements will substantially mitigate the spectral clutter arising in the measurement due to the natural variability associated with the background sky radiance.

This paper presents the MoDDIFS sensor methodology and first investigation results that were recently obtained.

8018-60, Session 10

Compact, wide-field DRS explosive detector

E. C. Schundler, D. L. Carlson, R. M. Vaillancourt, J. Rentz Dupuis, C. R. Schwarze, OPTRA, Inc. (United States)

OPTRA is developing a compact, wide field standoff diffuse reflectance spectrometer for trace explosive detection from a safe standoff. This system is comprised of two key components: a Risley scanner and an infrared tunable laser based spectrometer. The Risley scanner is a mature technology, which uses a pair of matched prisms to steer a laser beam anywhere inside a cone. The compact size, low operating power, and large field of view of the Risley scanner make it the ideal solution for rapidly scanning the laser over the field. The infrared tunable laser spectrometer utilizes a low-cost quartz crystal tuning fork (QCTF) in place of a traditional infrared detector. The large Q-factor of the QCTF enables high sensitivity, low noise detection of explosive signatures even for low concentrations and large standoffs. By coupling this demonstrated technology with a mature Risley scanner design, the field can be scanned both spatially and spectrally. Pairing this data with sophisticated algorithms results in a map of explosives in the field. This paper presents OPTRA's breadboard spectrometer design along with the TNT and RDX spectra it produced.

8018-61, Session 10

Explosive and pharmaceutical mid-and long-wave IR spectra by laser-induced breakdown spectroscopy

A. P. Snyder, U.S. Army Edgewood Chemical Biological Ctr. (United States); C. S. Yang, Battelle Memorial Institute (United States); A. C. Samuels, U.S. Army Edgewood Chemical Biological Ctr. (United States); S. B. Trivedi, Brimrose Corp. of America (United States); E. Brown, U. H. Hommerich, Hampton Univ. (United States)

Traditional laser-induced breakdown spectroscopy (LIBS) interrogates the UV-VIS-near-IR spectrum for atomic emissions of metal atoms in a sample. LIBS has been used primarily to interrogate the alkali, alkaline, and carbon atoms of substances. Sample discrimination relies on the distribution of metal atoms. Multivariate data analysis is usually used for data reduction. We report LIBS spectra where the spectral peaks reflect the organic moieties in the substance and utilize the mid- and long-wave IR spectral regions. If a percentage of the original material is ablated or fragmented, rather than atomized, large fragment species should be observed. A Q-switched Nd:YAG laser at 1.064 microns was used with ZnSe lenses for 5-12 micron emission detection. InSb and MCT detectors were used for the mid-IR and long wave IR regions, respectively. The appearance of spectral peaks in the IR proves that intact molecular entities and/or large fragments survive the LIBS plasma event. We investigate NH4ClO4, NH4NO3, and (NH4)2SO4 explosives and commercial pharmaceuticals such as Tylenol, Excedrin, Anacin, and Nitroquick (heart treatment) tablets along with acetylsalicylic acid (aspirin) and acetaminophen active ingredients. The mid- to long-wave IR spectra, obtained with separate detectors, provide very similar (visual) spectral features when compared to that of the standard database IR spectra of the respective samples. Point (centimeters) and remote (1 meter) distances were used.

8018-62, Session 10

Liquid explosive detection in bottle by near infrared

H. Itozaki, D. Shirotani, H. Akaba, Osaka Univ. (Japan); S. Morimoto, Kubota Corp. (Japan)

Terrorist used liquid explosives with hydrogen peroxide in London attach in 2005. Since water and hydrogen peroxide have similar physical properties, it is difficult to distinguish between the two. There are some detectors for hydrogen peroxide such as Raman scattering and ion mobility analyzer, but they have some limitation to be applied to the security check. Therefore bottles cannot be brought in the security region in the airport even now. Here, a liquid scanner has been developed using near infrared technology to modify this strict limitation rule. This scanner can detect hydrogen peroxide in a bottle, distinguishing to drinks. Near infrared with wavelength of between 0.5 to 1 micron is illuminated from bottom of a bottle. Returned light with some information of water content was collected at the center of the bottle was analyzed as spectrum. If the content of the bottle is dangerous liquid such as gasoline, oil, acid, hydrogen peroxide so on, this scanner indicates existence of dangerous liquid. It takes less than a few seconds. It can also indicate concentration of hydrogen peroxide. It will be used at the security gate in the airport so on. This has been tested practically in the Kansa international airport in Osaka, Japan. It worked well without any error alarm. It is expected to be installed in the airport and passengers will bring their own carried bottles into the security region in the airport.

Conference 8019: Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense X

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8019-01, Session 1

Situational awareness and informed decision-making for law enforcement responders

G. C. Tillery, National Institute of Justice (United States)

No abstract available

8019-05, Session 2

Cyber security state-of-the-art and challenges and opportunities for the future

P. K. Khosla, Carnegie Mellon Univ. (United States)

No abstract available

8019-06, Session 3

Immune security network model based on multi-agents coevolution

J. Su, Harbin Univ. of Science and Technology (China)

Immune network was a dynamic system about time and it could realize self-adjusting by using remember function and learning function. It could automantically detect abnormal behavior. This paper improved performance of multi-agent using immune technology and built an immune security network model based on multi-agents coevolution to realize abnormal behavior detecting and self-balance of distributed network. To settle the problem of slow convergence and easy to fall into premature, article immune detection algorithm is improved, including detector improving, chromosome coding, fitness function improving and matching computing improving. Comparing with the tradition intrusion detection method based on pattern matching, the initiative identifying ability to variant of known intrusion and unknown intrusion is improved and self-adaptation is improved.

8019-07, Session 3

Visualization techniques for malware behavior analysis

A. R. A. Gregio, Univ. Estadual de Campinas (Brazil); R. D. Coelho dos Santos, Instituto Nacional de Pesquisas Espaciais (Brazil)

The current information security threat is malicious code (malware, such as worms, trojans and bots) spread, a increasingly problem lately due to Internet popularization specially among non-technical users, and their lack of basic training -- for example, social networks and peer-to-peer systems are being used to spread malware, and we can count on the fact that new approaches of Internet interaction will bring new malware spread techniques. Thus, there are many variants of malware and it is important to study their behavior in order to identify and classify them. One simple approach to study malware behavior is through its execution in controlled environments (running special monitoring software), identifying then the actions performed by it on the target systems. Using system call hooking techniques we can intercept the malware and its subprocesses' system -- basically all the operations it performs -- recording its interactions with the target operating system. Some of these operations are file creation, modification and deletion; processes creation and termination; registry key modifications; network activities, etc. The recording of these operations generate a chain of events or signature that can be used to characterize and identify the malware being studied and to compare them with signatures of other known malware. An effective way to analyse and compare different malware signatures is through visualization (timelines, activity graphs). In this paper we present a simple approach to convert the malware behavior into activity graphs and show some visualization techniques that can be used to analyse malware behavior, individually or grouped.

8019-08, Session 3

Visual analytics for computer network defense

J. M. Beaver, R. M. Patton, X. Cui, C. A. Steed, Oak Ridge National Lab. (United States); M. Schultz, Univ. of Maryland, Baltimore County (United States)

Effective visual analysis of computer network defense (CND) information is challenging due to the volume and complexity of both the raw and analyzed network data. A typical CND is comprised of multiple niche intrusion detection tools, each of which performs a unique analysis of the network data and produces a unique alerting output. The state-of-the-practice in the analysis of CND data is the prevalent use of custom-developed scripts by Information Technology (IT) professionals to retrieve, organize, and understand potential threat events. We propose a new visual analytics framework, called the Oak Ridge Cyber Analytics (ORCA) system, for CND data that allows an operator to interact with all detection tool outputs simultaneously. Aggregated alert events are presented in multiple coordinated views with timeline, cluster, and swarm model analysis displays. These displays are complemented with both supervised and semi-supervised machine learning classifiers. The intent of the visual analytics framework is to improve CND situational awareness, to enable an analyst to quickly navigate and analyze thousands of detected events, and to combine sophisticated data analysis techniques with the interactive visualization such that patterns of anomalous activities may be more easily identified and investigated.

8019-09, Session 3

Comparative evaluation of anomaly detection algorithms for local maritime video surveillance

B. L. Auslander, K. M. Gupta, Knexus Research (United States); D. W. Aha, U.S. Naval Research Lab. (United States)

A variety of anomaly detection algorithms have been applied to surveillance tasks for detecting threats with some success. However, selecting and applying these algorithms to a particular task (e.g., involving local maritime surveillance) remains problematic. A new genre of anomaly detection algorithms that use local density-based approaches has performed well in some domains. However, they have not been applied to local maritime surveillance. Furthermore, the reasons for the performance differences of anomaly detection algorithms on problems of varying difficulty have not been analyzed. We address these two issues by comparing the performance of families of global and local anomaly

detection algorithms on tracks extracted from local maritime surveillance videos. Obtaining anomalous maritime data can be difficult or even impractical. Therefore, to compare these algorithms, we use a model to generate this data to vary and control the degree of task difficulty and to focus on situations that distinguish these algorithms' behaviors. Our evaluations reveal that global algorithms outperform local algorithms when the tracks are unstructured and have large variations, while local algorithms perform at par or better than global algorithms when these variations are small.

8019-10, Session 3

Image quality assessment using color appearance model

M. G. Milanova, T. A. Bennett, J. R. Talburt, Univ. of Arkansas at Little Rock (United States); B. H. Tsou, Air Force Research Lab. (United States); S. Kaya, H. Xu, Univ. of Arkansas at Little Rock (United States)

With the emergence and explosion of surveillance applications there is an increasing necessity for effective methods to evaluate image/video quality. Video Quality Assessment (VQA) methods fall into two categories: 1) subjective assessment by humans and 2) objective assessment by algorithms. In theory, a perception-based objective image quality metric can quantify the subjective quality of a distorted image without having human subjects rate the picture. Usually the success of assessing image /video relies on the selection of an appropriate set of features which can be measured and used to characterize video information. To model the human visual system (HVS), features are extracted in the spatial temporal and chromatic domain. Researchers have found that the features which incorporate (simulate) HVS processing lead to higher correlation with subjective scores performed by human observers.

The most deployed color appearance model is the CIELAB. In this color representation color values are linearized with respect to perceptual color differences. This means that a change in a measured color value will produce the same relative change in the visual properties. In the CEI Lab color model, the 'L' represents luminescence, 'a' is the magenta contrast, and 'b' is the yellow contrast. This approximation to the human vision system improves upon the discovery of the relationship between objectively derived image features and the grader's response to an image's quality.

In this study, we develop a novel image/ video quality metrics, Color-SSIM (saliency-based structural similarity index) and Color-VIF, based on color CEFLAB model. Luminance and contrast features are extracted from the color image. The structural similarity index (SSIM) and the visual information fidelity (VIF) in pixel domain are modified. We compare our results with the results using SSIM for image/video quality assessment. The main drawback of the SSIM algorithm in the spatial domain is that it is highly sensitive to the translation, rotation and scaling of images. To solve this problem, work has been done to develop a complex wavelet SSIM (CW-SSIM) algorithm for working in the transform domain and capturing non-structured image distortions that are usually caused by movements of image acquisition devices. CW-SSIM methods work only when the amount of translation, scaling, and rotation is small compared to the wavelet filter size. This problem can be solved using multi scale SSIM. Our results show that our technique is more correlated with human subjective perception.

8019-11, Session 3

TERRA: efficient video mark-up and analytics

S. F. Page, D. R. Myatt, Waterfall Solutions Ltd. (United Kingdom)

This paper describes the ongoing development of the TERRA application by Waterfall Solutions Ltd. (WS), which is a high-throughput video analytics tool designed to be highly flexible to user requirements. One of the known pitfalls associated with video analytics is the lack of sufficient user interaction within existing systems, often leading to system unreliability due to an unacceptably high level of false alarms. Therefore, instead of aiming to produce a fully automated system, TERRA emphasizes the importance of having a human user in the loop, and consequently concentrates on providing information in an intuitive and efficient a manner as possible. Primarily, the program is designed for collating, marking-up, analyzing and presenting image and video data. The application allows the cataloguing of media with custom-defined metadata tags to allow efficient searching and sorting within the database. For a given video sequence, data tagging may be entered manually or produced via an appropriate processing plug-in that automatically analyses the imagery, thus improving operator throughput. Available processing plug-ins encapsulating existing WS algorithms include image enhancement, object detection and tracking, change detection, classification and behavioural analysis, thus allowing usage on a wide variety of commercial and military applications. The resultant detections/tracks may then have reticules or other graphic annotations (such as overlaid text) added using an intuitive timeline-based user interface. The annotated processing results may then be exported to a video for use in a presentation.

8019-12, Session 3

Toward intelligent decision support for security staff: evaluation of an interactive resource management system based on a CMDP model

J. Hild, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); J. Ott, Karlsruher Institut für Technologie (Germany); E. Peinsipp-Byma, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

State-of-the-art surveillance and reconnaissance of large enclosed properties obligate security staff to handle threat situations according to printed security instructions and regulations which are based on legal requirements. As the surveillance resources (security personnel, sensors) are typically limited, this can be a challenging situation for the resource management in case of situations where multiple threats have to be handled at the same time. The security manager faces a complex decision and optimization problem: To which of the property's sectors should the resources be allocated in order to provide the safest threat states for the property as a whole over time?

Our objective is to create an intelligent decision support system (DSS) which provides a recommendation for resource allocation. For this purpose our approach uses a continuous-time Markov decision process (CMDP) to model the optimization problem. The recommendation is obtained from a heuristics for solving the CMDP approximately. The man-machine interface (MMI) of the DSS displays the recommendation to the security manager. To enhance situation awareness, the MMI in addition displays the current threat situation of the property as a "risk map".

For evaluation, we adopted the CMDP-model to a concrete property. The participants had to handle expert-reviewed threat scenarios, one time using the intelligent decision support, one time without it. The results show that the intelligent decision support benefits a more "cost-saving" handling of the threat scenarios. In addition, with respect to load and acceptance, almost all participants preferred to perform the resource allocation task using the intelligent decision support.

8019-13, Session 3

Entropy based heavy tailed distribution transformation and visual analytics for monitoring massive network traffic

K. J. Han, Air Force Research Lab. (United States); M. Hodge, Rochester Institute of Technology (United States); V. Ross, Air Force Research Lab. (United States)

There is an enormous cost in collecting, storing, and analyzing network traffic datasets. A difficult problem in handling network traffic data is that one is not able to analyze efficiently a huge amount of network traffic data with the current network traffic monitoring technologies. There has been an increased interest in data mining based approaches for monitoring network traffic. The major difficulty of data mining is that it is computationally expensive to find correlations between attributes in massive network traffic datasets. It is desirable to perform statistical processing on reduced datasets instead of the original full datasets. In general, network traffic data has a heavy-tailed probability distribution. Heavy tailed network traffic characterization and visualization are important and essential tasks to the Quality of Services. However, due to the difficulty of parameter estimation, heavy tailed distributions are limited in their ability to characterize real-time network traffic. The Entropy-Based Heavy Tailed Distribution Transformation (EHTDT) has been developed to convert the heavy tailed network traffic data distribution into a transformed probability distribution. In practice, the entropy distribution of the transformed probability distribution exhibits a linearity parameter that allows one to characterize real-time network traffic data. Advantage of the EHTDT transform converts such a heavy tailed distribution into a transformed probability distribution more amenable to characterize and aggregate overdispersion of network traffic. Results of applying the EHTDT for innovative visual analytics to real network traffic data are presented.

8019-14, Session 3

Increasing the security at vital infrastructures: automated detection of deviant human behavior

G. Burghouts, R. den Hollander, K. Schutte, S. Landsmeer, E. den Breejen, J. Marck, TNO Defence, Security and Safety (Netherlands)

Amsterdam, The Netherlands, 27th of May 2010. The national security authorities call out to secure the area around the central train station. 150 Security officers, both military and police, are instructed to guard the area and to report people of whom the behavior is deviant. Here, ‘deviant’ is relative to what is normal at a train station, with all its commuters.

At TNO, psychologists have compiled a list of deviant behaviors. Some are very subtle and therefore better observed by human professionals. Others are hard to observe in the midst of the crowd, for instance, deviant walking patterns.

For these cases, we have developed visual analytics. Our approach starts with tracking people, including re-tracking a person after occlusions. From the tracking and bounding box, more detailed behavioral indicators are extracted, using both whole-body and patch-based features. Our visual analytics software is able to signal deviant trajectories, aggression, and suspicious interactions between people.

We have experimented with the four hours of video data that were recorded at Amsterdam Central Station. The data is very challenging: 100s of people, partially visible, many trajectories, similar clothes. In this presentation, we will show our tracking algorithm, behavioral features and the inference of which behaviors are deviant. We show our recent work that multiple indicators together are discriminative: the ‘0+0+0=1’ principle. Our results discover persons who are avoiding the police, taking photos where this is not allowed, persons exchanging something, and waiting without taking the train.

8019-15, Session 3

Joint situation awareness frameworks and informed decision making for federal and civil authorities

A. Lenz, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8019-16, Session 4

Fast track, fast tech: challenges and opportunities for homeland security

S. F. Hallowell, Transportation Security Lab. (United States)

No abstract available

8019-17, Session 5

Measurement of the reflectivity and absorptivity of liquids, powders, and solids at millimeter wavelengths using dielectric detection by a resonator-post fixture between parallel conducting plates

J. C. Weatherall, SRA International, Inc. (United States); J. Barber, Battelle (United States); C. S. Brauer, B. T. Smith, Transportation Security Lab. (United States)

No abstract available

8019-18, Session 5

Development of a contrast phantom for active millimeter-wave imaging systems

J. Barber, Battelle Ventures, L.P. (United States); J. C. Weatherall, SRA International, Inc. (United States); C. S. Brauer, B. T. Smith, Transportation Security Lab. (United States)

No abstract available

8019-19, Session 5

Characterization of peroxide-based explosives using Raman spectroscopy

C. S. Brauer, Transportation Security Lab. (United States); J. Barber, Battelle (United States); J. C. Weatherall, SRA International, Inc. (United States); B. T. Smith, Transportation Security Lab. (United States)

No abstract available

8019-20, Session 5

Explosive detection technologies for aviation checkpoints

T. Grant, Transportation Security Lab. (United States)

No abstract available

8019-21, Session 5

Optimization of dynamic sampling of trace explosives off of shoes

S. R. Lukow, Transportation Security Lab. (United States); M. Staymates, J. Grandner, National Institute of Standards and Technology (United States); I. Cho, Nova Research, Inc. (United States)

The development of shoe screening technology is of utmost interest given the inconvenience of removing shoes at aviation checkpoints. Among the several technologies in various stages of technical maturity, trace based explosive detection systems show promise owing to their superb sensitivity. However, in order to achieve such low limits of detection in field applications, trace systems must demonstrate an efficient sampling process to dislodge explosive residues from the surface of interest and transport particles and vapor into the system. Without effective sampling, sensitivity can be compromised drastically. In an attempt to assist the development of effective sampling systems, two efforts focused specifically on sampling of trace residues on shoes were recently completed. The first effort focused on optimizing collection of explosive residues on shoes via a contact brush approach, while the latter accomplished the same with an emphasis on non-contact approaches employing air jets and air blades. Both efforts explored variables that affected aspects of sample collection, and worked toward an optimal configuration with an iterative approach. Lessons learned from this process will be used to develop future shoe screeners that are based on trace detection.

8019-22, Session 5

Opportunities with DHS Science & Technology: Research and Development (R&D) Partnerships Group

T. Cellucci, U.S. Dept. of Homeland Security (United States)

No abstract available

8019-23, Session 6

Human motion analysis and modeling

B. Kocher, J. M. Cathcart, A. M. Thomas, Georgia Tech Research Institute (United States)

Georgia Tech has investigated methods for the detection and tracking of personnel in a variety of acquisition environments. This research effort focused on a detailed phenomenological analysis of human physiology and signatures with the subsequent identification and characterization of potential observables. As a fundamental part of this research effort, Georgia Tech collected motion capture data on an individual for a variety of walking speeds, carrying loads, and load distributions. These data formed the basis for deriving fundamental properties of the individual's motion and supported the development of a physiologically-based human motion model. Subsequently this model aided the derivation and analysis of motion-based observables, particularly changes in the motion of various body components resulting from load variations. This paper will describe the data acquisition process, development of the human motion model, and use of the model in the observable analysis. Video sequences illustrating the motion data and modeling results will also be presented.

This work was supported, in part, under a grant from the US Army Research Office.

8019-24, Session 6

Human motion analysis and characterization

J. M. Cathcart, A. M. Thomas, B. Kocher, Georgia Tech Research Institute (United States)

Georgia Tech has investigated methods for the detection and tracking of personnel in a variety of acquisition environments. This research effort focused on a detailed phenomenological analysis of human physiology and signatures with the subsequent identification and characterization of potential observables. Both aspects are needed to support the development of personnel detection and tracking algorithms. As a fundamental part of this research effort, Georgia Tech collected motion capture data on an individual for a variety of walking speeds, carrying loads, and load distributions. These data formed the basis for deriving fundamental properties of the individual's motion and the derivation of motion-based observables, and changes in these fundamental properties arising from load variations. Analyses were conducted to characterize the motion properties of various body components such as leg swing, arm swing, head motion, and full body motion. This paper will describe the data acquisition process, extraction of motion characteristics, and analysis of these data. Video sequences illustrating the motion data and analysis results will also be presented.

This work was supported, in part, under a grant from the US Army Research Office.

8019-25, Session 6

Classification of people walking and jogging/running using multimodal sensor signatures

T. Damarla, J. M. Sabatier, U.S. Army Research Lab. (United States)

In this paper, we address the issues involved in detecting and classifying people walking and jogging/running. When the people are walking, sensors observe the signals for a longer period compared to the case in which people are jogging. To identify fast-moving people, one must make the decision based on the few telltale signals generated by a person jogging: a higher impact of a foot on the ground, which can be monitored by seismic sensors; the panting noise observed through an acoustic sensor; or a higher Doppler from an ultrasonic sensor, to name few. First, we investigate the phenomenology associated with seismic signals generated by a person walking and jogging. Then, we analyze both acoustic and ultrasonic signatures to distinguish the characteristics associated with them. Finally, we develop the algorithms to detect and classify people walking and jogging. These algorithms are tested on data collected in an outdoor environment.

8019-26, Session 6

Magnetometer-enhanced personal locator for tunnels and GPS-denied outdoor environments

S. Kwanmuang, J. Borenstein, L. V. Ojeda, Univ. of Michigan (United States)

This paper describes recent advances with our earlier developed Personal Dead-reckoning (PDR) system for GPS-denied environments. The PDR system uses a foot-mounted Inertial Measurement Unit (IMU) that also houses a three axis-magnetometer. In earlier work we developed methods for correcting the drift errors in the accelerometers, thereby allowing very accurate measurements of distance traveled. In addition, we developed a powerful heuristic method for correction heading errors caused by gyro drift. The heuristics exploit the rectilinear features found in almost all man-made structures and therefore limit this technology to indoor use only.

In recent work we integrated a three-axis magnetometer with the IMU using a Kalman Filter. While it is well known that the ubiquitous magnetic disturbances found in most modern buildings render magnetometers almost completely useless indoors, these sensors are nonetheless very effective in pristine outdoor environments and in most tunnels.

The present paper describes the integrated magnetometer/IMU system and presents detailed experimental results. Specifically, the paper reports results of an objective test conducted by Firefighters of California's CAL-FIRE. In this particular test, two firefighters in full operational gear and one civilian hiked up a two-mile long mountain trail over rocky, sometimes steeply inclined terrain, each wearing one of our magnetometer-enhanced PDR systems but not using any GPS. During the hour-long hike the average position error was about 20 meters for all

three PDR systems.

An animated trajectory plot is available at:

http://www.engin.umich.edu/research/mrl/video/StoneWall1280x720.wmv

8019-27, Session 7

Validation of Escherichia coli capture on portable microchips for point-of-care applications

U. Demirci, Harvard Medical School (United States)

Multiple pathogens, such as Escherichia coli (E. coli) can cause sepsis, which may be lethal to in combat-burned patients during referral for further treatment. In addition, bacterial contamination can lead to food poisoning in military or civilian food supply, highlighting the need for rapid detection of E. coli in blood and food samples. Here, we fabricated a functionalized microchip to capture E. coli and we validated it using blood and spinach samples. The microchip was functionalized with anti-E. coli antibody on the channel surface. To validate the surface chemistry, a model strain of E. coli (BL21) was transformed with GFP-expressing plasmids. The GFP-expression E. coli captured by the microchip were imaged under a fluorescence microscope and counted manually. The results demonstrated that the number of captured GFP-expression E. coli was correlated with initial sample concentrations. In addition, the microchip was able to capture E. coli from blood and spinach samples. In conclusion, we have fabricated a microfluidic device that captured E. coli from blood and spinach samples. The results indicate that this platform technology could also be potentially adapted for detection of other pathogens to monitor bacterial infection in combat-burned patients and detect food contamination at the point-of-care.

8019-28, Session 7

Monitoring wildlife behavior for the detection of imminent threats

C. S. Bendall, Space and Naval Warfare Systems Ctr. Pacific (United States)

No abstract available

8019-29, Session 7

Bioinspired flow and acoustic sensor

J. Tao, X. Yu, J. Berrilla, Case Western Reserve Univ. (United States)

This paper describes the fabrication of a flow and acoustic sensor. The sensor features a hairy structure inspired by aquatics. The design and optimization of sensor geometry was conducted to achieve the highest sensitivity. A few advanced fabrication technologies were employed for sensor fabrication. These include the use of advanced lithographic technology for sensor electrode deposition. The sensor was polarized under high voltage gradient and was subsequently evaluated under controlled laboratory conditions in a micro wind tunnel. The results of sensor performance are discussed in this paper.

8019-30, Session 8

Photonics sensor-based rifle mini-fire control system

S. Rajic, Oak Ridge National Lab. (United States)

No abstract available

8019-31, Session 8

Classification of acoustic gunshot signatures using a nonparametric Bayesian signal model

K. D. Morton, Jr., P. A. Torrione, L. M. Collins, New Folder Consulting, LLC (United States)

The classification of firearms from their acoustic signatures has many potential benefits for a variety of military and police security operations. Most approaches to acoustic gunshot classification can be characterized as frame based feature classification approaches, where the time-domain acoustic signal is partitioned into a set of frames from which characterizing features are extracted and used to classify the signals. Although this approach can be quite successful, performance is highly dependent upon the relationship between the selected frame size and the signals under consideration. In this work we consider a statistical model for time-domain gunshot signatures which eliminates the need for both data partitioning and the selection of characterizing features. Each class of acoustic signals is modeled as a hidden Markov model (HMM) with autoregressive (AR) source densities. Each AR model specifies a set of spectral and energy characteristics of the signal while the HMM characterizes the transitions between these states. The model is constructed using nonparametric Bayesian techniques to allow model inference to learn the number of states within the HMM and the AR order of each state density. The model thus selects the number of unique spectral components and the complexity of each of these components from the set of training data, limiting model over-fitting and eliminating the need to optimize performance over these parameters. We demonstrate that classification using the proposed statistical model performs comparably to existing techniques without requiring user specified features, thus allowing the same statistical models to be used on future datasets without modification.

8019-32, Session 8

Delay-and-sum beamforming for direction of arrival estimation applied to gunshot acoustics

A. L. L. Ramos, Buskerud Univ. College (Norway) and Univ. of Oslo (Norway); S. Holm, Univ. of Oslo (Norway); S. Gudvangen, Buskerud Univ. College (Norway); R. Otterlei, Posicom AS (Norway)

Sniper positioning systems described in the literature use a two-step algorithm to estimate the sniper's location. First, the shockwave and the muzzle blast acoustic signatures must be detected and recognized, followed by an estimation of their respective direction-of-arrival (DOA). Second, the actual sniper's position is calculated based on the estimated DOA via an iterative algorithm that varies from system to system. The overall performance of such a system, however, is highly compromised when the first step is not carried out successfully. Field tests have shown that detecting and estimating the DOA of the muzzle blast is a rather difficult task in real life situations. This is particularly true for long range detection in noisy environments and absorbing terrains, e.g., snow. Currently available systems rely on a simple calculation of differences of time-of-arrival to estimate angles-of-arrival. This approach, however, lacks robustness by not taking full advantage of the array of sensors. This paper shows how the delay-and-sum beamforming technique can be applied to estimate the DOA for both the shockwave and the muzzle blast. The method has the twofold advantage of 1) adding an array gain of 10logN, i.e., an increased SNR of 6 dB for a 4-microphone array, which is equivalent to doubling the detection range assuming free-field propagation; and 2) offering improved robustness in handling single- and multi-shots events as well as reflections by taking advantage of the spatial filtering capability. Moreover, the improved SNR output signal contributes to lowering false alarm and miss-detection rates at the recognition stage.

Return to Contents

8019-33, Session 8

Analysis of multispectral signatures of shot

M. Kastek, R. Dulski, T. Piatkowski, H. Madura, J. Barela, H. Polakowski, Military Univ. of Technology (Poland)

The paper presents some practical aspects of sniper IR signature measurements. Description of particular signatures for sniper shot in typical scenarios has been presented. We take into consideration sniper activities in open area as well as in urban environment. The measurements were made at field test ground. High precision laboratory measurements were also performed. Several infrared cameras were used during measurements to cover all measurement assumptions. Some of the cameras are measurement class devices with high accuracy and speed. The registration was made in NWIR, SWIR and LWIR spectral bands simultaneously. The infrared cameras have possibilities install optical filters for multispectral measurement. An ultra fast visual camera was also used for visible spectra registration. Exemplary sniper IR signatures for typical situation were presented. During the experiments in laboratory and test field was used LWIR imaging spectroradiometer HyperCam. The signatures collected by HyperCam were useful for determination of spectral characteristics of shot.

8019-34, Session 8

Fast uncooled module 32×32 array of polycrystalline PbSe used for muzzle flash detection

M. Kastek, R. Dulski, T. Sosnowski, H. Madura, G. Bieszczad, P. Trzaskawka, Military Univ. of Technology (Poland)

The paper presents some aspects of muzzle flash detection using low resolution polycrystalline PbSe uncooled 32×32 detectors array. This system for muzzle flash detection works in MWIR (3 - 5 microns region) and it is based on VPD (Vapor Phase Deposited) technology. The low density uncooled 32×32 array is suitable for being used in low cost IR imagers sensitive in the MWIR band with frame rates above 1.000 Hz. The FPA detector, read-out electronics and processing electronics (allows the implementation of some algorithms for muzzle flash detection) has been presented. The system has been tested at field test ground. Results of detection range measurement with two types of optical systems (wide and narrow field of view) have been shown. The initial results of testing of some algorithms for muzzle flash detection have been presented too.

8019-35, Session 9

Concept of data processing in multisensor system for perimeter protection

R. Dulski, M. Kastek, P. Trzaskawka, M. Szustakowski, M. Zyczkowski, Military Univ. of Technology (Poland)

The nature of recent 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 day/night cameras, IR uncooled thermal cameras as well as millimeter-wave radars detecting radiation reflected from target. Ranges of detection, recognition and identification for all targets depends on the parameters of the sensors used and the observed scene itself. Apart from the sensors the most important elements that influence the system effectiveness is intelligent data analysis and a proper data fusion algorithm. A multi-sensor protection system allows to achieve significant improvement of detection probability of intruder. The concept of data fusion in multi-sensor system has been introduced. It is based on image fusion algorithm which allows visualizing and tracking intruders under any conditions.

8019-36, Session 9

Localisation of threat substances in urban society - LOTUS: a viable tool for finding illegal bomb factories in cities

H. G. Önnerud, H. Oestmark, S. Wallin, Swedish Defence Research Agency (Sweden)

Today, basic chemicals for the production of explosives are easily accessible. This availability attracts terrorists and criminals to manufacture and use home made explosives since military and commercial explosives are harder to come by. The attacks in the London Underground in 2005 are frightening examples. The explosives used were home-made peroxide based.

The LOTUS project is funded by the European Union Framework Program 7. The LOTUS consortium consists of participants from seven European countries ranging from research organisations, universities to small and medium sized enterprises, industry and end users (authorities). The project budget encompasses about 6 M$.

The objective of the LOTUS project is to develop a new anti-terrorist tool for law enforcement agencies, in the form of an integrated surveillance system for continuous chemical background monitoring using mobile sensors to identify “chemical hotspots” such as bomb factories in urban areas. The idea with LOTUS is to test a system concept for detecting illicit production of explosives and drugs during the production stage. The system is based on sensors mounted in law enforcement vehicles under government control. The findings from the sensors (type and amount of substance, position (GPS) and time are sent, independent of the operator, to an operations centre display unit where data is collected and evaluated for further action.

In the present paper, the results from this still ongoing study will be presented. Dispersion data of threat substances from laboratory production of drugs and homemade explosives shows that the concentration of substances outside the clandestine production is at detectable levels. In addition, the hitherto obtained measurement data using the LOTUS sensors shows that the substances are possible to detect up to a distance of 50 metres from the production facility. Three different sensor types are being evaluated in the project and the concept is the easy addition of new sensors to the system depending on the threat substance that will be detected. The LOTUS system will be described on both a general system level and components sublevel.

8019-37, Session 9

Smart border: ad-hoc wireless sensor networks for border surveillance

J. He, R. A. Norwood, M. Fallahi, N. Peyghambarian, College of Optical Sciences, The Univ. of Arizona (United States)

Wireless sensor networks have been proposed as promising candidates to provide automated monitoring, target tracking, and intrusion detecting for border surveillance. However, the constraints in sensor nodes, such as limited processing power, memory, and energy supply, hinder the wider deployment of sensor nodes as practical solutions and pose the key research challenge.

In this paper, we demonstrate an ad-hoc wireless sensor network system that mitigates these constraints for border surveillance. The network consists of heterogeneously autonomous sensor nodes that distributively cooperate with each other to enable a smart border in remote areas.

In our system, sensor nodes are powered by either lithium batteries or solar panels, controlled by a power management module. The solar panel charges the battery and powers the sensor nodes during sunny, daylight hours and the battery powers the node otherwise. We integrate heterogeneous components into the system to enable multi-functional sensing capabilities, including a multimedia video camera, audio sensor, passive infrared sensor, and vibration sensor. Other sensors, such as temperature, light, and humidity sensors, are also integrated for monitoring the environment. In our network, three types of sensor nodes

running on two different open-source operating systems are wirelessly connected by 802.15.4 protocols. The embedded SD card offers storage space for data aggregation and local processing.

This paper also presents energy-aware and sleeping algorithms for maximizing the operating lifetime of the deployed sensor network. Lessons learned in building the network and important findings from field experiments are shared in the paper.

8019-38, Session 9

Detection of person borne IEDs using multiple cooperative sensors

S. MacIntosh, L. Tang, Reveal Imaging Technologies, Inc. (United States)

Reveal Imaging is currently investigating the use of multiple cooperative sensors for the detection of person borne IEDs, funded in part by the Department of Homeland Security Counter IED Division. The purpose of the effort is to evaluate the performance benefits of adding multiple sensor data streams into an aided threat detection algorithm, and an analysis of which sensor data improves overall detection performance. Results of the study can be used to aid design of next generation personnel screening systems to improve threat detection and reduce false alarms. Testing includes using both modified mannequins and human subjects with simulated suicide bomb devices of various configurations, materials, sizes and metal content. Aided threat recognition algorithms are being developed to test detection performance of individual sensors against combined fused sensors inputs. Reveal is currently investigating a variety of sensors, including active and passive millimeter wave imaging systems, mid-range passive infrared, 3D profiling sensors and acoustic imaging. The paper will include preliminary findings on the performance of the various sensors, their benefits and limitations and initial results of using multiple sensors inputs on an aided threat recognition algorithm for the detection of person borne improvised explosive devices.

8019-39, Session 9

Bayesian paradox in homeland security and homeland defense

T. P. Jannson, T. C. Forrester, W. Wang, Physical Optics Corp. (United States)

In this paper, we discuss a rather surprising result of Bayesian inference analysis that performance of a broad variety of sensors depends not only on a sensor system itself, but also on CONOPS parameters in such a way that even an excellent sensor system itself can perform poorly if absolute probabilities of a threat (target) are lower than false alarm probability. This result, called by us Bayesian paradox, holds not only for binary sensors discussed in authors' previous papers, but also for a more general class of multi-target sensors, discussed in this paper. Examples include: ATR (automatic target recognition), luggage x-ray inspection against explosives, medical diagnostics, car engine diagnostics, judicial decisions, and many others. It is shown that the basic figure of merit is a Bayesian one, called positive predictive value (name originated in x-ray breast mammography), which mostly depends on conditional (direct) probability of false alarm and absolute probability of signal (target) detection. It is also shown that the system/CONOPS performance metrics is composed of three types of probabilities: absolute, direct-conditional and inverse-conditional, the latter one being the Bayesian one. Also, in the case of non-binary multi-target systems, the direct conditional probability matrix includes (wanted) diagonal elements as well as (unwanted) non-diagonal elements. The non-diagonal ones include: false-positives, false-negatives and mixed targets, the latter being new ones, existing only in the case of multi-target sensor systems. It is shown that all these matrix elements, both diagonal and non-diagonal, can be measured and verified experimentally. A number of practical cases are discussed, to be helpful in further understanding and analysis of sensor decision process, in general, and Bayesian reasoning, in particular.

8019-40, Session 9

Pervasive awareness and guidance for military training

H. A. Abeykoon, National Univ. of Singapore (Singapore); S. Ying, Real Space Pte Ltd. (Singapore); K. Karunanayaka, O. N. Newton Fernando, A. D. Cheok, National Univ. of Singapore (Singapore)

There is an increasing emphasis on training for Urban Operation (UO) and in dealing with asymmetric threats such as improvised explosive devices. Soldiers are expected to operate in dense environments such as in heavily populated, urban areas where situational awareness becomes a major concern. In addition, bomb disposal units are also expected to handle and defuse improvised explosive devices that are likely to be of very different designs from those with which they have been trained.

This project conducts Research &D development on Pervasive Awareness and Guidance for Military Training where It combines ubiquitous computing technologies, new sensor technologies, and game engine technologies to build a technical prototype system that is suitable for both indoor and outdoor environment .Using the system mission commanders can have a rapid overview and can give instructions to soldiers through 3D Virtual Reality Environment and soldiers will receive the instruction as augmented objects to the head mounted display.Potential uses include training, mission planning, rehearsal, and operations in battlefield for both soldiers and commanders.

8019-02, Session 10

The all-optical warship: design and integration considerations for a future electro-optical sensor suite

K. A. Scholte, K. P. A. Ten Holter, Koninklijke Marine (Netherlands)

Nowadays electro-optical sensors are commonplace on naval vessels. However, these sensor systems are usually implemented as stand-alone systems or are minimally integrated in shipboard combat management systems. Therefore, it is difficult to include these systems in generic command and control concepts and on board they remain an operator aid at best. To facilitate integration in the future, this paper proposes a model of a fully integrated electro-optical sensor suite in order to not only supplement, but eventually replace certain types of radar-based systems found on board naval vessels. This study focuses on sensor management and data abstraction in particular, and its implications for the command and control process. Further design and integration challenges are discussed, as well as relevant mission profiles and cost aspects.

8019-03, Session 10

Nanostructure based EO/IR sensor development for homeland security applications

A. K. Sood, Magnolia Optical Technologies, Inc. (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); A. F. M. Anwar, Univ. of Connecticut (United States); N. K. Dhar, D. L. Polla, Defense Advanced Research Projects Agency (United States)

Next Generation EO/IR focal plane arrays that have the ability to improve signal to noise and reduced dark current using nanostructured ZnO/MgZnO and CNT based technology. These technologies are being developed for threat detection, Imaging and other Defense Applications. These technologies can also be used for a variety of Homeland Security and threat detection applications.

Our recent work on ZnO nanowires has demonstrated large signal to noise ratio as a wide band gap nanostructure material in the UV band. Similarly, we are developing Carbon Nanotubes (CNT) based bolometers for SWIR, MWIR and LWIR applications.

In this paper, we will discuss the sensor design and model predicting performance of an EO/IR focal plane array that can cover the UV to IR bands of interest. The model can provide a robust means for comparing performance of the EO/IR FPA's and Sensors that can operate in the UV, Visible-NIR (0.4-1.8), SWIR (2.0-2.5), MWIR (3-5), and LWIR bands (8-14). This model can be used as a tool for predicting performance of nanostructure arrays under development. We will also discuss our results on growth and characterization of ZnO nanowires and CNT's for the next generation sensor applications.

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8020-01, Session 1

Miniaturization of a SWIR hyperspectral imager

C. P. Warren, W. R. Pfister, D. M. Even, A. Velasco, J. Naungayan, S. M. Yee, D. S. Breitwieser, NovaSol (United States)

A new approach for the design and fabrication of a miniaturized SWIR Hyperspectral imager is described. Previously, good results were obtained with a VNIR Hyperspectral imager, by use of light propagation within bonded solid blocks of fused silica. These designs use the Offner design form, providing excellent, low distortion imaging. The same idea is applied to the SWIR Hyperspectral imager here, resulting in a microHSI SWIR Hyperspectral sensor, capable of operating in the 850-1700 nm wavelength range. The microHSI spectrometer weighs 910 g from slit input to camera output. This spectrometer can accommodate custom foreoptics to adapt to a wide range of fields-of-view (FOV). The current application calls for a 15 degree FOV, and utilizes an InGaAs image sensor with a spatial format of 640 x 25 micron pixels. This results in a slit length of 16 mm, and a foreoptics focal length of 60 mm, operating at F# = 2.8. The resulting IFOV is 417 microradian for this application, and a spectral dispersion of 4.17 nm/pixel. A prototype SWIR microHSI was fabricated, and the blazed diffraction grating was embedded within the optical blocks, resulting in a high diffraction efficiency. This spectrometer design is capable of accommodating slit lengths of up to 25.6 mm, which opens up a wide variety of applications. The application area of skin detection is discussed; and test results are shown for matched filter skin detections in the SWIR wavelength region.

8020-02, Session 1

Small unmanned aerial system high performance payload

R. J. Morgan, A. A. Abtahi, U. Raghuram, F. E. Strömqvist Vetelino, Aerospace Missions Corp. (United States)

A unique, hyperspectral imaging plane “on-a-chip” developed for deployment as a High Performance Payload (HPP) on a micro or small unmanned aerial vehicle is described. HPP employs nanophotonics technologies to create a focal plane array with very high fill factor fabricated using standard integrated circuit techniques. The spectral response of each pixel in the focal plane array can be independently tuned and controlled over the entire spectral range of the camera. While the current HPP has been designed to operate in the visible, the underlying physical principles of the device are applicable and potentially implementable from the UV through the long-wave infrared.

Performance of a single detector within the HPP hyperspectral imager focal plane array has been extensively modeled using a thin film approach. A detailed design and fabrication trade study concluded that HPP is at least comparable in build risk with the alternatives, including a MEMS-type Fabry-Perot filter array, and performs better or equally well.

The behavior of the HPP focal plane array, including optical interactions between individual pixels, has been investigated using a 3D finite-difference time-domain (FDTD) optical simulation implemented for parallel processing on an 8 computer cluster. The 3D FDTD optical simulation was also used to optimize the design of the HPP’s imaging fore optics, and for its integration with the focal plane array’s nanophotonics structure.

A prototype of the High Performance Payload hyperspectral imager “on-a-chip” has been fabricated. “First light” test results will be compared with the High Performance Payload’s predicted performance.

8020-03, Session 1

Real-world noise in hyperspectral imaging systems

R. L. Wiggins, L. E. Comstock, J. J. Santman, Corning NetOptix (United States)

Corning Specialty Materials Advanced Optics in Keene, NH has an ongoing effort to improve the performance of hyperspectral imaging systems. We have identified real-world noise as a limiting both spectral classification and in calibration transfer between nominally identical instruments. Real-world noise is defined as noise that originates in the observation of an inhomogeneous world with an instrument that is expecting a uniform input. CSM foreoptics typically image into a hyperspectral system at resolutions ten times finer than the detection element. However, spatial scene variations within a detection element and scene-originated illumination distribution changes at any scale are both important sources of real-world noise. Laboratory calibration of hyperspectral imaging systems is careful to minimize real-world noise by providing repeatable, uniform illumination. However, in-flight performance degrades significantly compared to laboratory calibration because of real-world noise. A pushbroom spectrograph system is a good example of an instrumental response function that creates real-world noise. An inhomogeneous scene on the spectrograph entrance slit will cause the measurement to shift in wavelength. An inhomogeneous angular distribution of light in the input aperture changes the resolution of the spectral measurement. CSM is conducting theoretical and experimental analyses of these effects, and is developing innovative methods and apparatus to desensitize the response function of hyperspectral imaging systems to the real world inhomogeneity that contributes noise to the measurement.

8020-04, Session 1

Flight test of an imaging O2(X-b) monocular passive ranging instrument

J. R. Anderson, M. R. Hawks, K. C. Gross, G. P. Perram, Air Force Institute of Technology (United States)

An instrument for monocular passive ranging based on atmospheric oxygen absorption near 762 nm has been designed, built and deployed to track emissive targets, including the plumes from jet engines or rockets. An intensified CCD array is coupled to variable band pass liquid crystal display filter and 3.5 - 8.8 degree field of view optics to observe the target. By recording sequential images at 7 Hz in three 6 nm width bands, the transmittance of the R-branch of the O2 (X-b) (0,0) band is determined. A metric curve for determining range from transmittance is developed using the HITRAN spectral database. A low cost system was designed and ground tested at ranges of 50 -380 m using halogen and incandescent light sources, establishing an average range error of 12%. The system was first deployed for a ground test viewing an F-16 in afterburner at ranges of 0.35 - 4.8 km, establishing a range error of 15% despite the presence of optical turbulence and a structured source spectrum. Finally, the instrument was flight tested in a C-12 imaging an F-16 in afterburner at ranges up to 11 km. The target was manually tracked, and pointing jitter limited image interpretation. A study of range error as a function of signal-to-noise ratio produced superior results to previous methods using Fourier Transform Spectroscopy. However, increased signal relative to background scatter will be required for accurate ranging for these tactical air-to-air scenarios. The promise for improved instrument performance is discussed.

Return to Contents

8020-05, Session 1

A novel SAL detector giving enhanced spatial and temporal resolution

M. S. Robbins, C. Weatherup, e2v Technologies plc (United Kingdom)

A novel charge coupled device (CCD) array enables the combination of imaging and semi-active laser (SAL) target designation to enhance seeker functionality at reduced inventory cost with lower collateral damage risk. The integration of SAL detection with imaging requires a high level of spatial and temporal resolution of the laser pulse detector and its correlation with the field of view of the imaging sensor so that laser spot location and code are presented with the image in real time. This evaluation of a novel SAL CCD detector concept shows that it is possible to achieve a temporal resolution in the region of 5μsec, an order of magnitude better than the basic requirement, and to achieve sensitivity to the laser pulse that allows operation in direct sunlight. The analysis indicates that the SAL CCD meets requirements using standard CCD processes. This paper reviews the detector architecture options and shows how the temporal, spatial and sensitivity requirements can be met.

8020-06, Session 1

Orbit efficiency for persistent wide area ground surveillance

J. J. SantaPietro, MITRE Corp. (United States)

A typical airborne ground surveillance radar is a multimode system with a ground moving target indicator (GMTI) mode for surveillance and tracking of moving ground targets and a synthetic aperture radar (SAR) mode for imaging of terrain features and stationary ground targets. One of the key features of the GMTI mode is the ability to perform wide area surveillance (WAS) of a substantial ground area, ehile providing persistent surveillance of a pre-specified ground area. The accomplishment of this task requires careful optimization of radar parameters and careful planning of the platform orbits so as to minimize the time spent repositioning the radar and turning the aircraft. This paper defines the notion of surveillance orbit efficiency which, for constant speed flight, is simply the percentage of time spent on the straight legs of a race track orbit. It then examines the orbit efficiency for each of three cases depending on the assumed radar azimuth field of view (FOV).

8020-07, Session 2

Modular multispectral imaging system for multiple missions and applications

J. Schoonmaker, Y. Podobna, J. Sofianos, S. Saggese, C. Boucher, D. Oakley, D. Medeiros, Advanced Coherent Technologies LLC (United States)

The Navy recently began investing in the design of mission-specific payloads for the Small Tactical Unmanned Aircraft System (STUAS). STUAS is a Tier II size UAS with a roughly 35 pound mission payload and a gimbaled general purpose electro optical/infrared (EO/IR) system. The EO/IR system is likely composed of a video camera in the visible, a mid-wave infrared (MWIR) and/or a long-wave infrared (LWIR) for night operations, and an infrared marker and laser range finder.

Advanced Coherent Technologies, LLC (ACT), in a series of SBIR efforts, has developed a modular, multi-channel imaging system for deployment on airborne and UAV platforms. ACT's system, called EYE5, demonstrates how an EO/IR system combined with an on-board, real-time processor can be tailored for specific applications to produce real-time actionable data. The EYE5 sensor head and modular real-time processor descriptions are presented in this work. Examples of the system's abilities in various Navy-relevant applications are reviewed.

8020-08, Session 2

Imaging EO/IR optical system for Long Range Oblique Photography

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Imaging optical system for a Long Range Oblique Photography (LOROP) should satisfy the set of requirements, two main of them are outer dimensions defined to place the system in available volume, and resolving power dependent on both optical characteristics and image quality. Taking into account the fact that the focal length of the system should be long enough, satisfying volume requirement becomes nontrivial task. Additionally, in order to fully utilize resolving power, the system should be corrected well, i.e. should have image quality close to diffraction limit, that requires applying specific design techniques, especially in visible region. Here we present the dual-band imaging optical system designed for operation in both regions of 0.6 ~ 0.9 um (EO channel) and 3.7 ~ 4.8 um (IR channel). To simultaneously meet volume and image quality requirements, we built it as Cassegrain-type telescope with lens compensators applied for compensating aberrations of telescope mirrors. The optimization of telescope mirrors and compensators together allowed getting diffraction limited image quality. To provide dual-band functionality, we applied the tilted plane-parallel plate which acts as a beam splitter located in between primary and secondary mirrors. The designed system is near to telecentric in detector space (EO) and telecentric in interim image space (IR) that provides image height constancy while adjusting the focus. The optical system includes Back Scan Mechanism (BSM) to decrease image blurring for integration time.

8020-09, Session 2

Autonomous collection of dynamically cued multisensor imagery

S. A. Anderson, M. D. Jensen, Space Dynamics Lab. (United States); T. J. Walls, D. C. Linne von Berg, M. L. Wilson, U.S. Naval Research Lab. (United States)

The availability of imagery simultaneously collected from sensors of disparate modalities enhances an image analyst's situational awareness and expands the overall detection capability to a larger array of target classes. Dynamic cooperation between sensors is increasingly important for the collection of coincident data from multiple sensors either on the same or on different platforms suitable for UAV deployment. Of particular interest is autonomous collaboration between wide area survey detection, high-resolution inspection, and RF sensors that span large segments of the electromagnetic spectrum. The Naval Research Laboratory (NRL) in conjunction with the Space Dynamics Laboratory (SDL) is building sensors with such networked communications capability and is conducting field tests to demonstrate the feasibility of collaborative sensor data collection and exploitation. Example survey / detection sensors include: NuSAR (NRL Unmanned SAR), a UAV compatible synthetic aperture radar system; microHSI, an NRL developed lightweight hyperspectral imager; and RASAR (Real-time Autonomous SAR), a lightweight podded synthetic aperture radar. From these sensors, detected target cues are automatically sent to the NRL/SDL developed EyePod, a high-resolution, narrow FOV EO/IR sensor, for target inspection. In addition to this cooperative data collection, EyePod's real-time, autonomous target tracking capabilities will be demonstrated. Preliminary results and target analysis will be presented.

8020-10, Session 2

High-speed laser communications in UAV scenarios

W. Griethe, F. F. Heine, M. Gregory, H. Kaempfner, Tesat-Spacecom GmbH & Co. KG (Germany)

Optical data links in space are sufficiently verified in experimental campaigns since 2008 and now routinely operated between NFIRE (MDA) and TerraSAR X (DLR). The links based on homodyne BPSK transmit bidirectional data streams of 5.6 Gbps across nearly 6,000 km with a bit error rate below 10-8.

Hence, for upcoming space infrastructures optical data links are used to networking satellites as for instance the GEO-stationary EDRS (European Data Relay Satellite) and the Sentinel spacecrafts in Low Earth Orbits in order to enable real-time access to Earth observation data. Consequently, Laser Communication Terminals (LCTs) from TESAT will be accommodated on the EDRS data relay system as well as on Sentinel Earth Observation Satellites.

As extremely efficient, reliable and robust for high speed laser communication in space the above-mentioned coherent homodyne BPSK technology has been verified which asserts itself now more and more as a global standard. The results of several years of practical tests and optimization of this promising technology have shown that the coherent homodyne transmission is suitable not only for space applications but also for tropospherical applications. Thus, the paper discusses firstly the future utilization of satellite-based optical data links for High-Altitude Long-Endurance (HALE) Unmanned Aerial Vehicles (UAV). Moreover, the advantages of the optical communication in UAV scenarios and its importance for Network Centric Warfare (NCW) as well as for Intelligence, Surveillance, Reconnaissance (ISR) are emphasized.

Secondly, the design concept of a UAV-borne laser communication terminals is described. Relevant questions regarding data handling, terminal accommodation and routine operations are discussed.

Since a bidirectional optical communication link at 5.6 Gbps has been verified between the low Earth orbit satellite (NFIRE) and and a TESAT optical ground station hosted at the ESA site in Tenerife (Spain), the results are useful for implementing air/ground diversity site group communication. Thirdly, preliminary analysis on tracking and BER performance and the impact of atmospheric disturbances on coherent links will be presented.

8020-12, Session 2

On-flight correction algorithm of alignment errors in an optical system

S. Imaizumi, Mitsubishi Electric Corp. (Japan)

For airborne optical system, displacement of optical elements position on flight caused by environmental condition changes may deteriorate image quality. The correction method of wave-front errors by a deformable mirror is adequate for a telescopic system, but generally it is not adaptable for a wide-angle system. In this paper, we propose a correction method by driven mirror adjustment, which is capable of retrieving image deteriorations of the wide-angle system. The method requires only a wave-front error measurement of single image point to achieve light weight. The wave-front errors can be broken into field-dependent components and field-independent components, and those must be corrected in different ways. In the method, factors called “weight matrix” are introduced in its algorithm to automatic correction according to the field dependency of the aberration. The effect of the image correction is confirmed by Monte-Carlo simulations.

8020-13, Session 3

Optical characterization of artillery blast waves and muzzle flash

B. J. Steward, K. C. Gross, G. P. Perram, Air Force Institute of Technology (United States)

Properties of the blast wave in artillery firings are directly attributable to flow-field conditions at the barrel exit, and properties of the flow can be inferred from remote observation of the blast. Muzzle blast data have been collected on a 152 mm caliber gun howitzer in the near and mid-fields utilizing high-speed visible imagery, and in the far-field utilizing audio-video instrumentation. Several blast wave propagation models have been applied to the data to determine their utility in extracting information on the gun system. Interpretation of model parameters is discussed in context of being physically realistic and for the purpose of classification. Equations for mass flow rate and barrel emptying time are presented to support assessment of model fit parameters. Results show that all models perform similarly well in the mid-field, but classical point blast and drag models are insufficient to predict the propagation of the blast wave into the far-field. Constant energy efflux model parameters represent the most realistic fits to the data in terms of physical interpretability of energy deposition.

8020-14, Session 3

The building block approach to airborne pod structures

J. D. Johansson, Terma A/S (Denmark)

The certification and testing of new airborne structures is a costly undertaking. This paper presents which measures can be taken to limit the cost and certifi-cation required in order to improve the capabilities of the current airborne as-sets, by applying a building block approach to the design and certification of airborne pod structures.

A simple way of improving aircraft capabilities is by adding external pod struc-tures, which has been performed for many applications over many years. However, this paper describes a truly modular approach, in which a typical airborne pod structure may be reconfigured to many various roles, with only limited re-certification requirements.

Using existing or general aerodynamic shapes, the basic outer shape for the external store is defined, which is then combined with a modular substructure which can accommodate a large variety of electronic and/or optical sensors. This also allows the airborne pod structure to perform several intelligence col-lecting operations during the same sortie, thereby limiting the time spent near the danger area.

The re-use of existing substructure modules reduces the cost and leadtime of the design phase allowing for a rapid entry into service. The modular design, relying on proven interface systems between the building blocks, significantly reduces risk involved in new programs.

The certification process is also discussed in order to optimize the use of the pod structure modularity and certification requirements in order to simplify the certification task, by drawing similarity to existing designs.

Finally the paper covers how modularity is implemented in new composite pod designs with stealth capabilities.

8020-15, Session 3

Search Metric Adaptive Resource Tasking (SMART)

W. J. Rudnisky, Raytheon Space & Airborne Systems (United States)

The ability to perform Autonomous Wide Area Surveillance (AWAS) is an ongoing area of interest for the defense community. Current systems dedicated to AWAS collect large amounts of data, making it difficult to

post analyze and impractical to analyze in real-time. As such, a shift in collection strategy that pushes toward more intelligent system's resource utilization is required. Such a solution would adapt in real-time to focus system resources on information rich regions, while also attempting to maximize the observations of key events of interest. The Search Metric Adaptive Resource Tasking (SMART) is an AWAS application that can effectively aid in the collection of information rich data while reducing redundant data collection. SMART implements a novel approach that combines closed loop methods with real time adaptive sensor resource management techniques to re-task sensors in real time to focus collection on information rich regions. Preliminary results show that SMART achieves a measurable performance improvement over current AWAS techniques.

8020-16, Session 3

Boron carbide and silicon carbide reinforced aluminum composites

E. E. Vidal, Brush Wellman, Inc. (United States); J. Silk, Aerospace Metal Composites Ltd. (United Kingdom); A. L. Wood III, Brush Wellman, Inc. (United States)

An improved family of metal matrix composite (MMC) materials are manufactured by a powder metallurgy route to achieve, through solid-state processing, a homogeneous dispersion of a carbide reinforcement phase in an aluminum alloy metal matrix. The gas-atomized aluminum alloy powder is blended with the ultra fine carbide reinforcement by mechanical alloying which imparts a significant amount of cold work to the material through cold welding and cold fracturing mechanisms. The resultant powder is degassed and then consolidated by Hot Isostatic Pressing (HIP) to a near 100% theoretical density billet in which the average aluminum grain size (0.92 +/- 0.01 µm) and a carbide particle size of (3 +/- 2 µm). The MMC parts are fabricated by machining from HIP block, or forging, rolling, and extruded into complex shapes at temperatures between 300°C and 600°C. MMC formulations that use 2000 and 6000 series aluminum are heat treatable using conventional water, and polymer quench methods. This paper summarizes the mechanical and thermal properties of these MMCs, its forms and applications, and compares them to other materials commonly used.

8020-17, Session 4

Feature-based image registration for multispectral imagery

B. T. Cheng, Goodrich Corp. (United States)

The fundamental concept of image registration is geometric correction of a distorted image in accordance to the reference image. A general approach to image registration is to determine a number of matching pixels on the two images, called tie-points, from which a mapping of the pixel coordinates between the two images can be derived, and the "distorted" image can then be "corrected" by interpolation. It is a trivial problem if images involved are frame-based and have the same band-width, in which case a few tie-points throughout the image obtained from cross-correlation are sufficient to produce a first order warping function for image registration. It is also easy to determine the quality of image registration from the difference of the "reference" and the "corrected" images. However, a multi-spectral imagery (MSI) is consisted of multiple channels at different band-widths, each may have a different spectral response to the same material being imaged. For example, the roof of a house may look dark (i.e. low DN) on the NIR (~800nm) but appear to be bright (i.e. high DN) on the MWIR (~3500nm) bands if the image was collected on a hot sunny day. Optical correlation method cannot be used in such case since the two input images (signals) are vastly different. We propose an algorithm for multi-spectral image registration that is based on feature mapping between the two images, rather than their pixel values. The feature considered consists of points, lines, and areas of various shapes, and the feature mapping algorithm adapts certain constraints that are based on the expectation of the variation of these features from the system point of view. The goodness of feature mapping after and before the registration can be an indicator of quality of image registration. Theoretically, it can be made into an iterative process such that a "best" registration can be obtained. Image registration for a multi-spectral line scanning system is different only by the fact that the two images could have local distortions that would require much more sophisticated algorithm in image correction. We will discuss the different interpolation algorithms that can be used in image registration.

8020-18, Session 4

Ocean modeling at multiple resolutions for ISR applications

J. M. Cathcart, B. Kocher, J. R. Teague, S. E. Lane, E. Burdette, Georgia Institute of Technology (United States)

Recent research efforts at Georgia Tech have focused on the development of a multi-resolution ocean clutter model. This research was driven by the need to support both surveillance and search requirements set by several government customers. These requirements indicated a need to support target detection and tracking for both resolved and unresolved scenarios for targets located either above or on an ocean surface. As a result of this changing sensor resolution characteristic for the various acquisition scenarios, a need for accurate ocean surface models at different geometric resolutions arose. Georgia Tech met this need through development of a multi-resolution approach to modeling both the ocean surface and, subsequently, the ocean signature across the optical spectrum. This approach combined empirical overhead data with high resolution ocean surface models to construct a series of varying resolution ocean clutter models. This paper will describe the approach to utilizing and merging the various clutter models as well as the results of using these models in the target detection and tracking analysis. Remaining issues associated with this clutter model development will be identified and potential solutions discussed.

8020-19, Session 4

Experimental analysis of adaptive clutter removal techniques in IR target detection systems

A. Rossi, N. Acito, M. Diani, G. Corsini, Univ. di Pisa (Italy)

In many civilian and military applications, early warning IR systems are employed for the detection of long-range targets embedded in highly structured background clutters, typical of naval and aviation scenarios. In this framework, a well-established detection scheme is composed of two cascaded stages: (i) background clutter estimation and removal, (ii) detection over the residual clutter.

The performance of the whole system is especially determined by the proper choice and setting of the background estimation algorithm (BEA). In this context, a novel procedure to automatically select the most performing BEA has been recently proposed. In such a procedure, a BEA selection criterion (BEA-SC) has been proposed where a target-free image representing the characteristics of the operating scenario is assumed to be available. Simulated targets are implanted in different positions of the target-free image to investigate the performance of the detection system in correspondence of several BEAs and different values of the parameters setting. Moreover, the selection procedure can be periodically updated in order to handle the changes of the background clutter.

In this paper, the robustness of the BEA-SC is investigated in detail. In the BEA-SC the user can specify the characteristics of the target of interest, such as Signal-to-Clutter Ratio (SCR), shape, and dimensions. Thus, fixed the typology of target we are interested to detect, we examine the performance of the detection system when the characteristics of the targets in the scene sensibly differ from the synthetic ones used in the BEA-SC, i.e. when the choice of the BEA is not optimal.

The investigation is developed considering target detection schemes that include BEAs based on different filters. BEA-SC is applied to a sequence of IR images acquired on a typical operating scenario. The comparison of the performance is carried out in terms of experimental receiver operating characteristics (EX-ROC). Finally, the results show that the recently introduced BEA-SC is robust in the detection of targets whose characteristics are in complete agreement with the operational requirements of early warning systems.

8020-21, Session 4

The effect of minimum target size and other factors on the performance envelope of Automated Moving Target Indication Systems for airborne surveillance with EO sensors

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Wide Area Airborne Surveillance requires high-resolution imagery, which in turn drives the requirement for automated, on-board imagery analysis. This study is based on a range of imagery, including in theatre examples, and identifies the critical factors that determine the minimal (critical) edge of the performance envelope for automated detection of moving targets for this task. It analyses the combined effects of minimum target size, target type (dismounts versus vehicles) and ground resolution on detection probability and target persistence.

Other influencing factors, such as platform stability, meta-data availability and platform velocity versus height above ground level and the resultant parallax effects are also examined.

The data source consists of a ground truth database containing full motion imagery sourced from a wide variety of UAS and manned ISR missions, including from operations in both Iraq and Afghanistan. The analysis compares imagery from a diverse range of common unmanned aerial systems and manned ISR platforms, ranging from small, hand-launched UAVs to MALE/HALE UAVs and large, manned surveillance aircraft and identifies the key factors for each class of platform.

The results include a definition of the critical factors and the relationship between them that determine the performance envelope minima for automated Moving Target Indication systems for Airborne Surveillance with EO sensors.

This knowledge is critical to future directions in research and development of automated airborne ISR imagery analysis systems.

8020-22, Session 4

Robust vehicle detection in aerial images based on salient region selection and superpixel classification

S. Sahli, P. Duval, Y. Sheng, Univ. Laval (Canada); D. A. Lavigne, Defence Research and Development Canada (Canada)

For detecting vehicles in large scale aerial images we first used a non-parametric method proposed recently by Rosin to define the regions of interest, where the vehicles appear with dense edges. The saliency map is a sum of distance transforms (DT) of a set of edges maps, which are obtained by a threshold decomposition of the gradient image with a set of thresholds. A binary mask for highlighting the regions of interest is then obtained by a moment-preserving thresholding of the normalized saliency map. Secondly, the regions of interest were over-segmented by the SLIC superpixels proposed recently by Achanta et al. to cluster pixels into the color constancy sub-regions. In the aerial images of 11.2 cm/pixel resolution, the vehicles in general do not exceed 20 x 40 pixels. We introduced a size constraint to guarantee no superpixels exceed the size of a vehicle. The superpixels were then classified to vehicle or non-vehicle by the Support Vector Machine (SVM), in which the Scale Invariant Feature Transform (SIFT) features and the Linear Binary Pattern (LBP) texture features were used. Both features were extracted at two scales with two size patches. The small patches capture local structures and the larger patches include the neighbourhood information. Preliminary results show a significant gain in the detection. The vehicles were detected with a dense concentration of the vehicle-class superpixels. Even dark color cars were successfully detected. A validation process will follow to reduce the presence of isolated false alarms in the background.

8020-23, Session 5

Robust component-based car detection in aerial images with new segmentation techniques

Y. Ouyang, P. Duval, Y. Sheng, Univ. Laval (Canada); D. A. Lavigne, Defence Research and Development Canada (Canada)

Several new techniques were introduced to improve the component-based vehicle detection in the aerial imagery. At 11.2 cm/pixel resolution only the large car parts as car bodies (hood, roof, and trunk), windshields and shadows can be seen. Car bodies appear with various sizes, shapes and colors. Their images are distorted by noise, low color contrast and specular reflection. The windshields appear as dark narrow regions, which can be confused with shadows and dark color car bodies. The shape of shadows varies constantly with the sunlight direction. In spite the difficulties in the detection, combining the car parts according their spatial relationship provides a powerful tool to car detection with detection redundancies. We used the shape-independent tricolour attenuation model to identify the cast shadows based on the spectral power density difference between the segmented regions lighted by direct sunlight and/or diffuse skylight. The simple linear iterative clustering (SLIC) performed a local clustering of pixels in both spatial and rang spaces, resulting in a dense over-segmentation of image, to form superpixels, which were merged into regions by a statistical method based on the independent bounded difference inequality theorem. More powerful merging technique such as the perceptual grouping can be also useful. We then found the car body parts with Support Vector Machine based on the radiometric and geometric features of the segmented regions. We finally searched windshields among the regions in direct vicinities of the detected car bodies. All the precedent algorithms require minimum human intervention, providing a robust detection.

8020-24, Session 5

Vision-based drone flight control and crowd or riot analysis with efficient color histogram-based tracking

T. Müller, M. Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Object tracking is a direct or indirect key issue in many different military applications like visual surveillance, automatic visual closed-loop control of UAVs (unmanned aerial vehicles) and PTZ-cameras, or in the field of crowd evaluations in order to detect or analyse a riot emergence. Of course, a high robustness is the most important feature of the underlying tracker, but this is hindered significantly the more the tracker needs to have low calculation times. In the UAV application introduced in this paper the tracker has to be extraordinarily quick.

In order to optimize the calculation time and the robustness in combination as far as possible, a highly efficient tracking procedure is presented for the above mentioned application fields which relies on well-known color histograms but uses them in a novel manner. This procedure bases on the calculation of a color weighting vector representing the significances of object colors like a kind of an object's color finger print. Several examples from the above mentioned military applications are shown to demonstrate the practical relevance and the performance of the presented tracking approach.

8020-25, Session 5

Layer-based object detection and tracking with graph matching

Q. He, Mississippi Valley State Univ. (United States); A. Camargo, The Univ. of North Dakota (United States)

How to automatically extract useful interesting objects from digital images and track them in consecutive video frames is a critical task for image understanding and has been widely applied in the video surveillance systems for homeland security and data fusion in the remote sensing and airborne imagery. Although automatic object detection and tracking is so important, the current related research is ignorant of contextual information. As a result, the fidelity of populating attributes corresponding to interesting features and objects cannot be satisfied. Here we develop an approach on meaningful object detection and tracking integrating global geometric contextual cues and local invariant moments. Our framework employs a top-down design and consists of two layers: a top and a bottom, capturing the global and local contextual information of the interesting objects in digital images, respectively. On the top layer, a graphical model provides a discrimination tool to describe the global status of the interesting objects. The graphical model is the representation of an image using its geometrical structures - vertices and edges. It captures the significant structural features and internal relationships of interesting objects, and thus provides strong discrimination power between different categories of objects. Unfortunately, the computation of graphical models is not robust to image segmentation and object occlusion. In order to improve the object tracking performance for inaccurate segmentation and occlusion, we incorporate low-level local contextual information. Here we are particularly interested in introducing affine invariant moments to describe the local status of the interesting objects. On the bottom layer, the affine invariant interest points are extracted and treated as vertices of graphical models. The object tracking is based on the topology correspondence (that is, graph isomorphism) between graphical models of objects in consecutive frames. The algorithm is tested on real data including IR data to show its efficiency.

8020-26, Session 5

Software-based robust global motion estimation for real-time video target tracking

C. Yang, H. Mao, Arizona State Univ. (United States); G. P. Abousleman, General Dynamics C4 Systems, Inc. (United States); J. Si, Arizona State Univ. (United States)

In an image tracking system using image subtraction for motion detection, the global (camera) motion is usually estimated to compensate for the camera motion. The accuracy and robustness of the global motion compensation critically affects the performance of the target tracking system. The global motion between video frames can be estimated by matching the features from the image background. However, the features from moving targets contain both camera and target motion and should not be used to calculate the global motion. Sparse optical flow is a classical image matching method. However, the image features selected by optical flow may come from moving targets, and some of the image features matched may not be accurate, which leads to poor video tracking performance. Least Median Square (LMedS) is a popular robust linear regression model and has been applied to real-time video tracking systems implemented in hardware to process up to 7.5 frames/second. In this paper, we use a robust regression method to select features only from the image background for robust global motion estimation, and we develop a real-time (10 frames/second), software-based video tracking system that runs on an ordinary Windows-based general-purpose computer. The software optimization and parameter tuning for real-time execution are discussed in detail. The tracking performance is evaluated with real-world Unmanned Air Vehicle (UAV) video, and we demonstrate the improved global motion estimation in terms of accuracy and robustness.

8020-27, Session 5

Tracking targets through occlusions in outdoor videos

H. Mao, C. Yang, Arizona State Univ. (United States); G. P. Abousleman, General Dynamics C4 Systems, Inc. (United States); J. Si, Arizona State Univ. (United States)

In real-world, outdoor videos, moving targets (e.g., vehicles, people, etc.) may be partially or even fully occluded by other objects such as buildings, trees, and bridges, which make it difficult to continuously track the targets. This work presents a motion-based target tracking framework, which employs novel methods to deal with multiple types of occlusions. For an existing track that is fully occluded, a Kalman filter is applied to predict the target's current position based upon its previous locations. However, the prediction may drift away from the target's true trajectory due to accumulated prediction error, especially when the occlusion lasts a long time. To address this problem, temporally disappearing tracks are checked with an extra data association procedure, which evaluates their potential association to targets just coming out of occlusion. Another issue with motion-based tracking is that the algorithm may mistakenly take the visible part of a partially occluded target as the whole target region. This is problematic because an inaccurate target motion trajectory model will be built, causing the Kalman filter to generate inaccurate position predictions. Accordingly, we present a novel method of estimating the target's position when it is partially occluded. Experimental results with real-world UAV video show that the proposed system successfully improves tracking continuity with various types of occlusion.

8020-28, Session 5

Target location from the estimated instantaneous received frequency

D. J. Nelson, National Security Agency (United States)

We consider the problem of estimating the location of a signal source from the signal received from one or more moving receivers. Our solution requires that the transmitted signal has a stable frequency that may estimated. The stable frequency may be the carrier frequency, baud rate or chip rate of a bauded communication signal, or it may be the carrier frequency of an analog FM speech signal. We consider the example of analog FM modulated speech and demonstrate a process that can estimate and track the instantaneous FM carrier with a tracking error less than a tenth of a Hertz. The process we present is based on a cross-spectral computed as the product of a short time Fourier transform (STFT) and the complex conjugate of the STFT computed from the signal delayed by one sample. Based on the estimated instantaneous frequency, we develop a new system of equations that may be used to accurately locate the source location of the signal. Unlike the conventional cross-ambiguity function (CAF) process, the solution we present does not require simultaneous intercept from two or more receivers. The solution presented is based on low degree polynomial representations of both the instantaneous receiver location and the instantaneous received frequency. Unlike the conventional CAF process, only one receiver is required, and only instantaneous frequency is required. Signal time delay need not be estimated. Signal location is resolved from the instantaneous frequency and the rate of change of instantaneous frequency.

8020-29, Session 6

Task-based video interpretability as a function of target motion, frame rate, and playback speed

D. L. Young, Raytheon Intelligence & Information Systems (United States)

Task-based interpretability is measured for clips with varying frame rate, playback rate, and target motion. Catagorical analysis is used to determine statistical significance between video treatments and population characteristics. Regression analysis is used to find coefficients to predict video interpretability.

8020-30, Session 6

Interactive video compression for remote sensing

R. Maleh, F. A. Boyle, P. B. Deignan, J. W. Yancey, L-3 Communications Integrated Systems (United States)

Modern day remote video cameras enjoy the ability of producing quality video streams at extremely high resolutions. Unfortunately, the benefit of such technology cannot be realized when the channel between the sensor and the operator restricts the bit-rate of incoming data. In order to cram more information into the available bandwidth, video technologies typically employ compression schemes (e.g. H.264/MPEG 4 standard) which exploit spatial and temporal redundancies. We present an alternative method utilizing region of interest (ROI) based compression [1,2]: Each region in the incoming scene is assigned a score measuring importance to the operator. Scores may be determined based on the manual selection of one or more objects which are then automatically tracked by the system; or alternatively, listeners may be pre-assigned to various areas that trigger high scores upon the occurrence of customizable events. A multi-resolution wavelet expansion is then used to optimally transmit important regions at higher resolutions and frame rates than less interesting peripheral background objects subject to bandwidth constraints. We show that our methodology makes it possible to obtain high compression ratios while ensuring no loss in overall situational awareness. If combined with modules from traditional video codecs, compression ratios of 100:1 to 1000:1 can easily be achieved.

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8020-31, Session 6

Efficient compression of sequences of multispectral images

M. G. Milanova, Univ. of Arkansas at Little Rock (United States); R. Kountchev, Technical Univ. of Sofia (Bulgaria); R. Kountcheva, T&K Engineering Co. (Bulgaria)

A new algorithm is presented for efficient compression and archiving of sequences of images, based on the Inverse Pyramid Decomposition. The algorithm is based on joint processing of all images in a group representing the same object and obtained using sensors of changing light length (multispectral images) or after time intervals. The background of the new approach is the use of the Inverse Pyramid Decomposition which performs layered image representation with increasing quality of the approximations obtained in the consecutive decomposition layers. The coarsest approximation of one of the images in the group, selected to be the reference one, is used to calculate the next (better) approximations of the remaining images in the group. As a result, the efficient compression of the processed groups of images is obtained, which is of high importance for their archiving and storage in image databases. The software implementation of the algorithm was developed in Visual C, Windows environment. A special format was developed for the images archiving. The method was adapted for the processing of multi-view images of same object as well. Numerous experiences were performed with satellite and medical images, which proved the method's efficiency.

8020-32, Session 6

Scene-based blind deconvolution in the presence of anisoplanatism

D. C. Dayton, Applied Technology Associates (United States); J. D. Gonglewski, Air Force Research Lab. (United States)

Most non-conventional approaches to image restoration of objects observed over long atmospheric paths require multiple frames of short exposure images taken with low noise focal plane arrays. Multi-frame blind deconvolution is such an approach. In most cases the object is assumed to extend only over a single isoplanatic patch. However, when one is observing scenes over a near horizontal or downward looking slant path the isoplantic patch size is small due to extended atmospheric turbulence over the entire slant path, and the scene usually extends over many isoplanatic patches. In addition base motion jitter in an airborne observing platform introduces a frame-to-frame linear shift that must be compensated for in order for the multi-frame restoration to be successful. In this paper we describe a maximum a-posteriori parameter estimation approach to the simultaneous estimation of the frame-to-frame shifts and non-isoplanatic point spread functions. This approach can be incorporated into an iterative algorithm. We present a brief derivation of the algorithm as well as its application to actual image data collected from airborne and ground based platforms. We also show results for enhanced intelligence gathered from actual airborne imagery.

8020-33, Session 6

Video enhancement effectiveness for target detection

M. C. Simon, A. D. Fischer, P. V. Petrov, 21st Century Systems, Inc. (United States)

Unmanned aerial vehicles (UAVs) capture real-time video data of military targets while keeping the warfighter at a safe distance. This keeps soldiers out of harm's way while they perform intelligence, surveillance and reconnaissance (ISR) and close-air support troops in contact (CAS-TIC) scenarios. Ideally, UAV video would also provide a force multiplier, enabling the military to do more with less. However, to achieve effective force multipliers, numerous UAVs with cameras must be fielded, and multiple videos processed by few operators. Monitoring multiple video streams is a difficult task, especially if the videos do not contain high quality imagery. To address this problem, we have done research on several promising video enhancement algorithms that focus on improving the quality of hazy, noisy, blurry, and low resolution video. In this paper we discuss several algorithms in our video enhancement suite and provide examples of their video enhancement capabilities. The four areas of focus for our algorithms are dehazing, denoising, deblurring, and super-resolution. Additionally, we provide results that show the positive effects which our video enhancement suite has on target detection and tracking algorithms used to assist the operator in identifying and tracking relevant targets. These results indicate that a significant capability to increase the force multiplier effect of UAVs can be developed. The ability to assist the operator by providing enhanced video and target detection is immediately applicable to video-reliant domains, like UAV ISR. This research can additionally form the basis for human factors research into the effects of enhancement algorithms on ISR.

8020-34, Session 7

Automatic registration and mosaicing algorithm for SAR images

M. Samykannu, C. Nigam, P. Vardhani, A. Vengadarajan, Defence Research and Development Organisation (India)

The synthetic aperture radar (SAR) image formation process is beneficially applied by mosaicing of consecutive subpatch images, especially in condition of a highly squinted antenna where most of the SAR imaging algorithms become inefficient mainly due to the large range migration effects. Furthermore, for an airborne squint mode SAR, the mosaic processing also suffers seriously from the geometric distortions and the border discontinuities in the neighboring images caused by insufficient motion compensations. This paper presents a methodology to generate the continuous full image with options like automatic and seamless mosaicing processes based on the Feature detection, matching and ransac imaging algorithm which is developed to correct the geometric distortion and compensate the spatially-variant phase error. In this, the image registration is suggested to do with the modes such as with reference from the database or based on location or manually selecting the inputs points to register. Then also some geometric corrections can be done by automatic mosaicing technique. The feature points are detected by using the SIFT algorithm and the matched points are mosaiced by ransac algorithm.

8020-36, Session 7

Automated UAV-based video exploitation using service oriented architecture framework

S. Se, C. Nadeau, S. Wood, 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, damage assessment and others. Unmanned Aerial Vehicles (UAVs) gather huge amount of video data but it is extremely labour-intensive for operators to analyse hours and hours of received data.

At MDA, we have developed a suite of tools that can process the UAV video data automatically, including mosaicking, change detection and 3D reconstruction, which have been integrated within a standard GIS framework. In addition, the mosaicking and 3D reconstruction tools have also been integrated in a Service Oriented Architecture (SOA) framework.

The Visualization and Exploitation Workstation (VIEW) integrates 2D and 3D visualization, processing, and analysis capabilities developed for UAV video exploitation. Visualization capabilities are supported through a thick-client graphical user interface (GUI), which allows visualization of 2D imagery, video and 3D models. The GUI interacts with the VIEW server, which provides video mosaicking and 3D reconstruction exploitation services through a SOA.

The SOA framework allows multiple users to perform video exploitation by running a GUI client on the operator's machine and invoking the video exploitation functionalities residing on the server. This allows the exploitation services to be upgraded easily and allows the intensive video processing to run on powerful workstations.

MDA provides UAV services to the Canadian and Australian forces in Afghanistan with the Heron, a medium altitude long endurance UAV system. On-going flight operations service provides important intelligence, surveillance and reconnaissance information to commanders and front-line soldiers.

8020-37, Session 7

Techniques for inferring terrain parameters related to ground vehicle mobility using UAV born IFSAR and lidar data

P. J. Durst, G. D. Cantrell, U.S. Army Engineer Research and Development Ctr. (United States)

Predicting ground vehicle performance requires in-depth knowledge, captured as numeric parameters, of the terrain on which the vehicles will be operating. For off road performance, predications are based on rough terrain ride comfort, which is described using a parameter entitled root-mean-square (RMS) surface roughness. Likewise, on-road vehicle performance depends heavily on the slopes of the individual road segments. Traditional methods of computing RMS and road-slope values call for high-resolution (inch-scale) surface elevation data. At this scale, surface elevation data are both difficult and time consuming to collect. Nevertheless, a current need exists to attribute large geographic areas with RMS and road slope values in order to better support vehicle mobility predictions, and high-resolution surface data are neither available nor collectable for many of these regions. On the other hand, meter-scale data can be quickly and easily collected for these areas using unmanned aerial vehicle (UAV) based IFSAR and LIDAR sensors. A statistical technique for inferring RMS values for large areas using a combination of fractal dimension and spectral analysis of five-meter elevation data is presented. Validation of the RMS prediction technique was based on 43 vehicle ride courses with 30-centimeter surface elevation data. Also presented is a model for classifying road slopes for long road sections using five-meter elevation data. The road slope model was validated against one-meter LIDAR surface elevation profiles. These inference algorithms have been successfully implemented for regions of northern Afghanistan, and some initial results are presented.

8020-38, Poster Session

Mean-shift tracking for surveillance applications using thermal infrared and visible band data fusion

C. Beyan, Middle East Technical Univ. (Turkey) and Baskent Univ. (Turkey); A. Temizel, Middle East Technical Univ. (Turkey)

Separate tracking of objects such as people and the luggages they carry is important for video surveillance applications as it would allow making higher level inferences and timely detection of potential threats. However, this is a challenging problem and in the literature, people and objects they carry are tracked as a single object. In this study, we propose using thermal infrared imagery in addition to the visible band imagery for tracking in indoor applications (such as airports, metro or railway stations). We use adaptive background modeling in association with mean-shift tracking for fully automatic tracking. Trackers are refreshed using the background model to handle occlusion and split and to detect newly emerging objects as well as objects that leave the scene. Visible and thermal infrared domain tracking information are fused to allow tracking of people and the objects they carry separately using their heat signatures. By using the trajectories of these objects, interactions between them could be deduced and potential threats such as abandoning of an object by a person could be detected in real-time. Better tracking performance is also achieved compared to using a single modality as thermal reflection and halo effect which adversely affect tracking are eliminated by the complementing visible band data.

The proposed method has been tested on videos containing various scenarios. The experimental results show that the presented method is effective for separate tracking of objects such as people and their belongings and for detecting the interactions in the presence of occlusions.

8020-39, Poster Session

Multi-field-of-view hyperspectral imager

L. E. Comstock, R. L. Wiggins, Corning NetOptix (United States)

There is increasing interest in imaging spectrometers working in the SWIR and LWIR wavelength bands. Commercially available detectors are not only expensive, but have a limited number of pixels, compared with visible band detectors. Typical push broom hyperspectral imaging systems consist of a fore optic imager, a slit, a line spectrometer, and a two dimensional focal plane with a spatial and spectral direction. To improve the spatial field coverage at a particular resolution, multiple systems are incorporated, where the “linear fields of view” of the systems are aligned end to end. This solution is prohibitive for many applications due to the costs of the multiple detectors, coolers, spectrometers, or the space, weight, or power constraints. Corning will present a cost effective solution utilizing existing detectors combined with innovative design and manufacturing techniques.

8020-40, Poster Session

Plenoptic processing methods for distributed camera arrays

F. A. Boyle, J. W. Yancey, R. Maleh, L-3 Communications Integrated Systems (United States)

While the light passing through a volume can be described in 5 dimensions, conventional cameras capture only a portion of the field to create 2D projections of a scene. Plenoptic photography samples the light field around an object in way that spans more of its dimensionality. This enables 3D rendering [1]. While plenoptic methods have been studied for over 100 years [e.g., 2, 3], recent advances in digital photography have enabled the development and demonstration of plenoptic cameras with impressive capabilities [4, 5, 6]. These function by recording sub-aperture images that can be combined to re-focus images or to generate stereoscopic pairs.

The authors are exploring plenoptic methods for fusing images from distributed arrays of cameras, with a view toward applications in which hardware resources are limited (e.g. size, weight, power constraints).

Through computer simulation and experimental studies, the influences of non-idealities such as camera position uncertainty are being considered. Component image rescaling and balancing methods are being explored to compensate. Of interest is the impact on precision passive ranging and super-resolution. In a preliminary experiment, a set of images from a camera array was recorded and merged to form a 3D representation of a scene. Conventional plenoptic refocusing was demonstrated and techniques were explored for balancing the images. In an initial observation, a nonlinear method for combining the images limited the ghosting caused by sub-sampling.

The presentation will include descriptions of simulation and experiment, along with a discussion of limitations and how non-idealities might be compensated to enhance performance.

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8021-01, Session 1

Ground penetration radar using free-electron maser

A. D. McAulay, Lehigh Univ. (United States)

A proposed airborne ground penetration radar is described that detects and identifies small buried objects up to 30cm into the earth with a range resolution of 5 to 10 cm. We discuss the operation and advantages of the free-electron maser over other high power microwave and radio frequency sources such as vircator pulse generators and gyrotrons [1]. The high power source allows deeper penetration into the earth relative to lower powered sources without sacrificing range resolution. Normally the free-electron approach is used to extend operating frequencies into light frequencies or even X-rays, higher than that in other cyclotron devices. However, in this case, the wiggler in the free-electron source is modified to extend the frequency lower to below 5 GHz. In selecting frequency we discuss the trade-off between depth penetration and range resolution. For range resolution we control the bandwidth by using pulse shaping or chirp. The earth model for assessing the penetration depth is described. The tunability of the free-electron maser allows adjustment to cope with earth variability. In order to gain advantage from the higher power in the presence of clutter, we discuss the use of receiving arrays and SAR to form narrower beams. Finally we make an approximate prediction of signal to noise performance achievable with such as system. Distinguishing objects of interest from clutter can be accomplished using techniques used in electromagnetics with thin film layers [1] or in elastic and acoustic waves in geophysics [2],[3].

8021-02, Session 1

A computer simulation of a long-range CWFM radar showing trade-offs of performance as a function of range

R. S. Gordy, S. Zoledziowski, Global Technical Systems (United States)

CWFM is a modulation type that gives a short range radar exceptional performance with low power transmitters. The radar reported here shows the method for using CWFM modulation and obtaining the advantages while operating as a multi range radar having a 200 nautical miles as the highest range. The radar reported here has a 100 Watt transmit transmitter operating CW. It is a X-Band radar operating at a BW (Band Width) of 500 MHz giving it the ability of obtaining a processing gain of 68.7 dB, and enabling the radar to support a SAR processing image with a 1 foot resolution.

A description of the CWFM modulation and the detection method is given as a functional block diagram and the performance of the radar is determined using MathCad (which will be provided in the paper). The advantage of this radar over the short pulsed radar is that a low power signature is presented and a solid state implementation is within the current state-of-the-art. Radar cross sections of 1 square meter, 10 square meters, 200 square meters, and 1,000 square meters are used to calculate the detection range with a Pd= 0.75 and Pfa=10-5. This provides an estimate of the minimum discernible signal.

8021-03, Session 1

Augmented reality using ultra-wideband radar imagery

L. H. Nguyen, F. Koenig, K. D. Sherbondy, U.S. Army Research Lab. (United States)

The U.S. Army Research Laboratory (ARL) has been investigating the utility of ultra-wideband (UWB) synthetic aperture radar (SAR) technology for detecting concealed targets in various applications. Recently, we have designed and built a vehicle-based low-frequency UWB SAR radar for a proof-of-concept demonstration detecting obstacles for autonomous navigation, detecting concealed targets (mines, etc.), and mapping internal building structures to locate enemy activity.

Although the low-frequency UWB radar technology offers valuable information to complement other technologies due to its penetration capability, it is very difficult to comprehend the radar imagery and correlate the detection list from the radar with the objects in the real world.

Using augmented reality (AR) technology, we can superimpose the information from the radar onto the video image of the real world in real time. Using this, Soldiers would view the environment and the superimposed graphics (SAR imagery, detection locations, digital map, etc.) via a standard display or a head-mounted display. The superimposed information would be constantly changed and adjusted for every perspective and movement of the user.

ARL has been collaborating with ITT Industries to implement an AR system that integrates the video data captured from the real world and the information from the UWB radar. ARL conducted an experiment and demonstrated the real-time geo-registration of the two independent data streams. The integration of the AR sub-system into the radar system is underway.

This paper presents the integration of the AR and SAR systems. It shows results that include the real-time embedding of the SAR imagery and other information into the video data stream.

8021-04, Session 1

High-coherence track-while-scan low-cost radar for anti-piracy operations

V. Gouz, V. Lipatov, Kvant Scientific Research Institute (Ukraine); V. Molebny, National Taras Shevchenko Univ. of Kyiv (Ukraine)

Minimizing the piracy risk depends not only on timely detection/identification of piracy-potential objects on sea, but also on effective management of the anti-piracy operation. We report on a low-cost civil-ship radar solving both the detection/identification of the surface threat objects and guiding the patrol forces. After the threat is detected in the circular surface scan mode, the elevation scan mode is switched on to provide the detection of the patrol helicopter and its further guidance in the track-while-scan mode. The radar is built on a solid-state transmitter and uses digitally controlled chirped signals and their coherent FFT based accumulation at the reception with window widths 64, 128, 256 pulses. The clutter is suppressed by digital MTI with adaptive changing of the rejection filter zone depending on the type of the clutter (sea surface, skies, hydrometeors, etc.). The total number of tracked targets is no less than 50. Operation zone is 96 km, azimuth scan 0-360°, target heights - up to 3 km.

8021-06, Session 2

A survey of radar applications in medicine

A. K. Mitra, Air Force Research Lab. (United States)

This paper provides a survey of recent research in the area of potential radar applications in medicine. Discussions on techniques and radar system parameter tradeoffs related to topics such as human vital signs detection are provided. Notional analysis with respect to a number of environmental and electromagnetic propagation models are included as part of this survey including a review of possible approaches to vital signs detection for through- wall environments/materials as well as consideration of aspects of injury-detection via detection of electromagnetic propagation thru layered media (i.e. thru internal tissue boundaries.) A significant portion of this treatment is focused on a notional analysis of recent advances in the controlled interaction of ingestible nano-particles and interaction of nano-particles with RF radiation for applications such as Cancer Research and Cosmetic Surgery. Additional applications such as notional systems parameters for the measurement of additional vital signs such as human blood flow rates are also considered as part of this speculative analysis.

For example, one such notable technique, invented by John Kanzius, looks promising as a future alternative to standard chemo-therapy. Kanzius' experimental system makes provisions for the patient to ingest a special class of nano-particles that form bonds with internal cancer cells within a given patient's body. Then, the patient's body is irradiated with a signal from an external RF Generator which, according to reported results, can have the overall effect of eliminating cancer cells via electromagnetic absorption of radiation by the bonded nano-particles. A parametric speculative analysis of this type of system is provided to enable the potential exploration of additional applications such as alternative RF/Radar liposuction systems for medical cosmetics applications. A discussion and speculative analysis of other future medical applications of RF/Radar systems is also included; such as a notional discussion of movable and/or distributed sensor-node systems for the possible measurement of quantities such as human blood flow at non-contact standoff distances.

8021-07, Session 2

Polarization dynamics and interference analysis for wideband signals

G. Stratis, G. C. Maalouli, D. G. Manzi, R. Ihly, Raytheon Missile Systems (United States)

In this paper, we investigate the impact of polarization dynamics of wideband signals and interference analysis. The key idea is that once a non-monochromatic wave impinges upon buildings and various scatterers, the spectral components of the wave are variable depolarized upon scattering. In this paper we incorporate 3-D buildings and terrain data bases and show polarization dynamics of wideband signals in various environments; in addition we introduce various polarizations within the sub bands in such a way that each sub band is differently and uniquely depolarized once the signal bounces around. We introduce different scattering environments including indoor or outdoor to indoor; we show how polarization dynamics are different in various environments. Finally we introduce interferers and show how interference is reduced.

8021-08, Session 2

Phenomenology of fully polarimetric imaging radars

J. V. Geaga, Consultant (United States)

We have previously reported on the analysis of fully polarimetric single look and multilook SIR-C data. We have reported that the Stokes(Kennaugh) matrices for each pixel have one and only one eigenvector that satisfies the property of a Stokes Vector. We now report of new analysis of fully polarimetric SIR-C data and ISAR data from the Submillimeter-Wave Technology Laboratory at the University of Massachussetts Lowell which shows that the remaining three eigenvectors of the Stokes matrix are quaternions which represent rotations. Furthermore, the three direction vectors of these quaternions form an orthogonal cartesian set of axes. We also discuss relationships between the angles of the Stokes Vector with the Euler parameters initially proposed by Huynen.

8021-10, Session 2

Human polarimetric micro-doppler

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

Modern radars can pick up target motions other than just the principle target Doppler velocity, they pick out the small micro-Doppler variations as well. These can be used to visually identify both the target type as well as the target activity. We model and measure some of the micro-Doppler motions that are amenable to polarimetric measurement.

Understanding the capabilities and limitations of radar systems that utilize micro-Doppler to measure human characteristics is important for improving the effectiveness of these systems at securing areas. In security applications one would like to observe humans unobtrusively and without privacy issues, which makes radar an effective approach. In this paper we focus on the characteristics of radar systems designed for the estimation of human motion for the determination of whether someone is carrying something in their arms.

Radar can be used to measure the direction, distance, and radial velocity of a walking person as a function of time. Detailed radar processing can reveal more characteristics of the walking human. The parts of the human body do not move with constant radial velocity; the small micro-Doppler signatures are time-varying and therefore analysis techniques can be used to obtain more characteristics. Looking for modulations of the radar return from arms, legs, and even body sway are being assessed by researchers. We analyze these techniques and focus on the improved performance that fully polarimetric radar techniques can add. We perform fully polarimetric simulations and measurements of the varying micro-Doppler signatures of humans as a function of elevation angle and azimuthal angle in order to try to optimize this type of system for the detection of arm motion, especially for the determination of whether someone is carrying something in their arms. The arm is often bent at the elbow, providing a surface with a double-bounce potential. This is distinct from the more planar surfaces of the body and allows us to separate the signals from the arm (and knee) motion from the rest of the body. The double-bounce can be measured in polarimetric radar data by measuring the phase difference between HH and VV.

8021-11, Session 2

Visualizing and displaying radar micro-doppler data

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

Displaying radar data has typically been done with a set of dots or blobs rendered over a map with very little information other than a moving target indicator (MTI). However, modern radars can pick up target motions other than just the principle target Doppler velocity, they pick out the small micro-Doppler variations as well. These can be used to visually identify both the target type as well as the target activity. Effectively displaying the micro-Doppler for visualization can be a challenge. Typical approaches utilize spectrograms to display the time-varying micro-Doppler and eliminate the range entirely, or display the spectrogram in an auditory tone. This paper demonstrates incorporating the micro-Doppler onto a typical display by overlaying the spectrogram with a variable hold time and also demonstrates range-Doppler movies for classification.

8021-05, Session 3

A picosecond measuring technique to determine phase instability in a synthetic aperture radar system

R. S. Gordy, D. Markell, M. Burns, A. Anderson, Global Technical Systems (United States)

Synthetic Aperture Radars are phase sensitive and require methods to accurately measure phase stabilities within picoseconds. This paper

reports on a novel system that is capable of measuring phase stability within several picoseconds. The method consists of a digital FM Chirp Modulator, up/down converter, amplifier, digitizer and transversal correlator. The method is dependent on the bandwidth of the modulator and the sample rate of the Analog to Digital Converter. The output of the correlator is dependent on the bandwidth of the modulator, the broader bandwidth, the smaller the increment of time measurement at the output of the correlator. The output of the correlator is an impulse response that has a peak that is related to the sample rate and side lobes that are dependent on the distortion of the system. The correlator makes a comparison between a reference signal and the return signal from the output of the system. The reference is often a sample of the transmit signal without the distortion of the system, so that the output of the correlator represents the response containing the instabilities and distortions contributed by the system.

A functional flow diagram is shown of the system with actual responses of a typical system showing resolutions of 2 to 5 picoseconds. The system was evaluated using a phased array antenna which was adjusted to within a few picoseconds prior to range testing.

8021-09, Session 3

Polarisation transform analysis for detection of shallow buried non-metallic landmines in microwave x-band region

K. C. Tiwari, Military Engineering Services (India)

Alternative approaches and models continue to be investigated and evolved to correctly locate and identify a buried mine with minimum risk. Though microwave remote sensing based detection of shallow buried landmines provides such a risk free alternative, but it is a highly complex and computationally intensive task involving several parameters. The present paper deals with the use of data obtained in multiple polarizations and their transforms approximating smooth roughness conditions in sand for landmine detection. Data in both HH and VV polarizations in microwave X-band frequency (10 GHz, 3cm) was generated using dummy landmines (without explosives) for the present study under laboratory conditions. Various transforms such as image differencing, image ratioing and polarization discriminant ratio (PDR) were studied for its effect on landmine detection. However, it was found that most of the clutter and noise gets suppressed on using a transform obtained by subtracting the difference of data in two polarizations from its sum. The surface roughness conditions was approximated as smooth as available in western parts of India. These conditions make them extremely suitable for application of microwave radar remote sensing for detection of minefields. With the advent of satellites providing data in various polarizations, it has now become relevant to investigate methods which can be used for landmine detection using polarization techniques. The proposed analysis is expected to be extremely useful in future in detection of landmines using multi-polarisation satellite data in microwave X-band in deserts such as those existing in the western borders of India.

8021-12, Session 3

Radar cross section statistics of dismounts at Ku-band

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Knowing the statistical characteristics of a target's radar cross-section (RCS) is crucial to the success of radar target detection algorithms. A wide range of applications currently exist for dismount (i.e. human body) detection and monitoring using ground-moving target indication (GMTI) radar systems. Dismounts are particularly challenging to detect. Their RCS is orders of magnitude lower than traditional GMTI targets, such as vehicles. Their velocity of about 0 to 1.5 m/s is also much slower than vehicular targets. Studies regarding the statistical nature of the RCS of dismounts focus primarily on simulations or very limited empirical data at specific frequencies. This paper seeks to enhance the existing body of work on dismount RCS statistics at Ku-band, which is currently lacking, and has become an important band for such remote sensing applications. We examine the RCS probability distributions of different sized humans in various stances, across aspect and elevation angle, for HH and VV polarizations, and at diverse resolutions, using experimental data collected at Ku-band. Additionally, we examine RCS coherence time for the dismounts. We further fit Swerling target models to the RCS distributions and suggest appropriate detection thresholds for dismounts in this band.

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8021-13, Session 3

Radar cross section statistics of ground vehicles at Ku-band

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Knowing the statistical characteristics of a target's radar cross-section (RCS) is crucial to the success of radar target detection algorithms. Open literature studies regarding the statistical nature of the RCS of ground vehicles focus primarily on simulations, scale model chamber measurements, or limited experimental data analysis of specific vehicles at certain frequencies. This paper seeks to expand the existing body of work on ground vehicle RCS statistics at Ku-band for ground moving target indication applications. We examine the RCS probability distributions of civilian and military vehicles, across aspect and elevation angle, for HH and VV polarizations, and at diverse resolutions, using experimental data collected at Ku-band. We further fit Swerling target models to the distributions and suggest appropriate detection thresholds for ground vehicles in this band.

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8021-14, Session 3

Human activity classification using Hilbert-Huang transform analysis of radar Doppler data

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The automatic identification of human activities has become an area of interest in recent years. Identifying human activities can be put to use in surveillance, health, and military applications to identify intruders, monitor patients, or determine if a person has malicious intentions. Numerous methods of human activity classification have been proposed in the past, including the use of Artificial Neural Networks and Support Vector Machines (SVM). Most research in this area thus far has utilized the Short-Time Fourier Transform as a method of obtaining the feature vectors necessary for classification. In this paper, we propose the use of the Empirical Mode Decomposition (EMD) algorithm as an alternative method of obtaining feature vectors from human micro-Doppler signals and utilize an SVM for classification. Since the micro-Doppler signature is unique to a specific activity, the EMD outputs can be utilized as feature vectors. Utilizing the EMD algorithm in conjunction with an SVM, binary

classification of human activities have shown to yield accurate results. Because SVMs were created to solve the binary classification problem, additional steps must be taken in order to extend the problem to identify multiple classes. In this paper, two methods for multi-class classification will be demonstrated and compared. The first method is the one-against-all approach and the second is a decision tree based approach. In both cases, a high degree of accuracy is achieved.

Submitted to the Special Session on Noise Radar.

8021-15, Session 3

Multifrequency Doppler characteristics of human activities using biomechanical models

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Human detection and recognition is a topic of great interest in modern radar systems, such as those involving through-wall detection and perimeter monitoring. A subsequent step that most of these systems eventually engage in is to classify the human (or the object of interest) activity. Modeling random human movement is essential to these systems to gain an understanding of the reflected Doppler signals to aid in activity classification leading to intent recognition. Distinct human-induced Doppler is caused by various types, such as swinging of arms, rotation of torso, and sudden limb movements, in addition to breathing and heartbeat. The Doppler frequencies thus induced not only depend on the velocity of movement but also on the radar operating wavelength, since small movements less than a fraction of the wavelength may not be manifested in the Doppler signature. All of these specific movements will induce various Doppler shifts, which can be analyzed by several well-known time-frequency approaches, including the recently-developed empirical mode decomposition (EMD) analysis. Previous work has addressed the modeling of a stationary human with a swinging arm, but very little work has expanded from this into other types of activities which can signal the presence of a human, possibly concealed. However, in addition to human activity, there can be clutter fluctuations caused by rotating fan blades in an indoor environment or swaying branches and fluttering leaves in an outdoor scenario. Such clutter fluctuations may confuse the processor and cause misclassifications. This work is of importance for radars systems operating at long distances, especially when the object of interest has a low radar cross section (RCS). Low RCS objects reflect very weak signals back toward the system therefore making it harder to detect. Cancellation of these clutter signals will increase the signal-to-clutter ratio (SCR) dramatically, in turn making the signal much cleaner and easier to process for its specific purposes. A final model will be used to detect the human movement with various types of clutter variations added to the received Doppler signal. Doppler signatures will be compared for S-band frequencies and W-band frequencies.

Submitted to the Special Session on Noise Radar.

8021-16, Session 4

Comparison of three radars for through-wall sensing

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Through-the-wall imaging and target discrimination using Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR) imagery and non-imaging techniques has many important military and civilian applications such as search and rescue after earthquake, patrol of empty houses in high crime activity areas, etc. This application is challenging for the following reasons. First, images formed may be blurry and fuzzy due to limited target resolution. Second, the target features may be weak and confusing due to the strong wall interference or ground clutter.

In this research, we investigated the following issues in through-the-wall sensing: 1) accurate localization and tracking of various stationary and moving targets; 2) investigation of bi-static and multi-static configurations; 3) extraction of motion characteristics of moving and stationary objects from micro-Doppler features; 4) realistic visualization of moving objects.

This paper summarizes our results on target localization, tracking and feature extraction. Other results will be reported in other papers. Three radar systems were used for this purpose: 1) Impulse radar (12 ps source and 50 GHz sampling rate); 2) Swept frequency radar (1-13.5 GHz); 3) Continuous-wave (CW) radar at 882 MHz. Experimental results showed that none of the radars is perfect for all situations. In practical applications, it is necessary to synergistically combine them for more effective results.

8021-17, Session 4

A fast data acquisition and processing scheme for through-the-wall radar imaging

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Through-the-wall radar imaging (TWRI) is an emerging research area of increasing interest as the objective of detection and localization of obscured targets is shared by many defense and civilian applications [1, 2]. The demand for a high degree of situational awareness to be provided by TWRI systems requires high-resolution imaging capabilities, which, in turn, necessitate the use of wideband signals and large array apertures. Such systems generate huge amounts of data, which presents substantialchallenges in both data collection and processing for TWRI applications.

We present fast data acquisition and processing schemes for TWRI. We use novel concepts of microwave tomography to establish a non-redundant measurement configuration (in terms of spatial points and frequencies), which provides clear advantages in terms of measurement time and algorithm complexity. The processing speed and computational cost associated with 3D imaging is significantly improved via a sliced approach based on 2D reconstructions [2]. Performance validation of the proposed strategy will be presented using experimental data collected in a semi-controlled laboratory environment.

[1] M. Amin and K. Sarabandi, Guest Eds., Special Issue on "Remote Sensing of the Building Interior", IEEE Trans. Geoscience Remote Sens., vol. 47, no. 5, pp. 1270-1420, May 2009.

[2] Soldovieri, F.; Ahmad, F.; Solimene, R.; , "Validation of Microwave Tomographic Inverse Scattering Approach via Through-the-Wall Experiments in Semicontrolled Conditions," Geoscience and Remote Sensing Letters, IEEE, vol. 8, no. 1, pp.123-127, Jan. 2011.

8021-18, Session 4

Target localization with a single-antenna monostatic radar via multipath exploitation

P. Setlur, G. E. Smith, F. Ahmad, M. G. Amin, Villanova Univ. (United States)

Target localization is typically achieved by using wideband signals and multiple sensors. The radar signal bandwidth provides the range resolution whereas the radar aperture yields angular or cross-range resolution. In this paper, we show that by using a single-antenna monostatic radar, a target can be localized in downrange and cross-range. This is achieved by utilizing resolvable multipath returns. Considering the multipath generated from the specular reflection off a wall of a building or a room with known geometry, it is shown that the target multipath in a monostatic scheme is also equivalent to a virtual bistatic radar geometry. The bistatic time-of-flight leads to an elliptical locus that passes through the target coordinates. This allows a noncoherent approach to be devised, which localizes the target using

both the bistatic elliptical locus resulting from the multipath and the monostatic circular locus corresponding to the direct target return.

We consider the general setting of a single target present, and surrounded by multiple walls. We focus on sense-through-the-wall (STTW) applications, but note that the localization approach is also applicable to urban canyons, thereby indicating its generalized utility. The proposed scheme first associates each multipath return with the corresponding wall it originated from, and then determines the target location using multilateration. Our analysis shows that the association of the multipath returns with the correct reflecting surfaces is critical for determining the loci, and that without it target localization cannot be performed. We use an iterative search procedure to perform the association. The multilateration process is formulated as a nonlinear least squares technique in order to account for the non-line-of-sight propagation through walls and the change in propagation speed. Supporting simulations and experimental results are provided to validate the proposed technique.

8021-19, Session 4

Real-time subsurface imaging algorithm for intra-wall characterization

W. Zhang, A. Hoorfar, C. Thajudeen, Villanova Univ. (United States)

For through-the-wall imaging (TWI), an accurate characterization of the wall is important for the enhancement of imaging of the target behind the wall. The ability to determine fidelity information of the wall, such as material composition, interior structure of the wall, presence of void, and/or use of reinforcement, is beneficial for both military and civilian applications. In this paper we cast the wall interior structure imaging as a subsurface imaging problem. The region between the front and back wall is imaged using subsurface tomography algorithm. A fast and efficient tomographic linear inverse scattering algorithm for the imaging of inhomogeneous objects embedded in the subsurface medium is presented. The imaging algorithm is based on first order Born approximation and exploiting halfspace Green's function. The exploding source model is employed and then the Green's function is expanded in the spectrum domain to formulate a novel real time subsurface imaging algorithm. The linearization of the inversion scheme and employment of FFT/IFFT in the imaging formula make the subsurface imaging algorithm suitable in several applications concerning the diagnostics of large probed domain and allow real-time processing. Numerical results will be presented to show the effectiveness and efficiency of the proposed subsurface imaging algorithm for real time wall interior structure characterization.

8021-20, Session 4

UWB through complex scattering mechanisms

R. D. White, B. J. Anderton, E. Williams, J. Hess, S. Manson, G. Stratis, Raytheon Missile Systems (United States); C. Penney, Remcom, Inc. (United States)

In this paper, we investigate various UWB signals going through various scattering mechanisms. We use the finite-difference time-domain (FDTD) method in our computations since, by its nature, FDTD can model an ultrawideband source and can separate the various scattering mechanisms by exploiting causality. The key idea is that, once a non-monochromatic wave is incident upon a scattering object, the various spectral components will be differently depolarized upon scattering depending upon the shape and material composition of the scatterer. In the case studied here, all of the impinging spectral components are co-polarized (whereas arbitrary polarization distributions are permitted more generally). Fundamentally, we are exploring the concept of depolarization of the various spectral components through the various scattering mechanisms. We first begin our analysis with simple cases and then we pursue further with more complex type of scatterers. Using the time space unique capabilities of the FDTD method we are able to see how the spectral components depolarize through the various stages when signals penetrate through complex wall structures.

8021-21, Session 4

Wave propagation through complex wall structures

B. J. Anderton, R. D. White, E. Williams, J. Hess, S. Manson, G. Stratis, Raytheon Missile Systems (United States)

Analytical expressions for Fresnel reflection and transmission coefficients have been extensively used in ray tracing simulation. Although these tools accurately predict the field for simple homogeneous wall structures, it is difficult, if not impossible, to extend such an analysis to find reflection and transmission coefficients for walls composed of dielectric and imperfectly conducting materials or complex inhomogeneous structures. In principle, Fresnel theory is considered a high frequency method, but in practical problems (such as walls with metallic re-bars and similar applications), transmission does not monotonically decrease with incidence angle, and Fresnel theory does not apply. In this paper we use the FDTD method to extend the theoretical Fresnel formulation to certain types of problems where Fresnel theory does not apply. We find that the presence of rebar affects transmission characteristics much more significantly than permittivity or wall depth. We initially verify the FDTD method with simple theoretical applications and then we go further in more complicated cases; we furthermore extend our analysis in polarization effects that occurs from such inhomogeneities.

8021-22, Session 5

Novel antennas based upon extraordinary transmission metamaterial lenses

M. Sorolla Ayza, M. Navarro-Cia, M. Beruete, F. Falcone, Univ. Pública de Navarra (Spain)

We present directivity enhancement by using a short focal length plano-concave lens engineered by stacked subwavelength hole arrays in such a way that an effective negative index of refraction is obtained. An additional unexpected property of this design is that it opens the possibility to achieve an index close to zero, $n \rightarrow 0$, arisen from eps- and mu-near-zero extreme values. Our original design works with evanescent modes in comparison with the well known classical metallic lenses operating with propagating modes. In our case, this leads to a negative index of refraction, whereas metallic lenses exhibit a positive but less than one index of refraction. It is demonstrated by means of a simple design based on dispersion diagram and ray tracing an easy and correct method for rather accurate results. Also, an optimization of the hole diameter or longitudinal lattice constant to achieve not only $n = -1$, but also free space matching is possible simultaneously. A power enhancement up to 24 dB with cross-polarization below -30 dB with regards to co-polar, when the lens is applied as antenna radiation beamforming has been measured. For the case of index close to zero, $n \rightarrow 0$, the power enhancement is 27 dB whereas the cross-polarization remains -17 dB with regards to co-polar.

New improvements are under analysis in order to determine if this technology could be competitive with current state of the art of waveguide lenses and Fresnel zone plate lenses. Actually, we have shown that in terms of HPWB and FSLL this technology already exceeds eggcrate topologies and, technical aspects aside, LHET-lenses are lighter than eggcrate configurations due to their plate-air gap assembly.

8021-23, Session 5

Transformation optics compressed Rotman lens implemented with complementary metamaterials

J. D. Hunt, Duke Univ. (United States); N. Kundtz, Intellectual Ventures (United States); B. B. Sun, Duke Univ. (United States); A. Genc, A. F. Starr, SensorMetrix (United States); D. R. Smith, Duke Univ. (United States)

Rotman lenses are utilized in microwave and radar technology to form directed beams over a wide angular region. At its core, the Rotman lens consists of a parallel plate waveguide that serves as a quasi-optical element, adjusting the phases from a set of input feeds to produce a planar wave front form the exit feeds. The geometry of the lens coupled with the wavelength associated with the operating frequency constrain the minimum size of the device, and hence its overall profile. Here we apply the emerging technique of Transformation Optics (TO) to compress the standard Rotman lens by 27 percent along the optical axis while maintaining the beam steering range, gain, and side lobe amplitudes over a broad frequency range. The transformation medium is implemented through the patterning of the waveguide surfaces with complementary metamaterial elements, that can be understood in the present context as providing effective values of permittivity and permeability that can be independently engineered throughout the lens. The particular transformation applied requires an anisotropic magnetic response, achieved through the use of complementary electric dipole metamaterials. These metamaterials are advantageous for many transmission line applications as they exhibit magnetic response over a broad bandwidth.

8021-24, Session 5

Scalable smart antenna architectures using metamaterials

A. K. Mitra, C. Hu, Air Force Research Lab. (United States); C. Johnson, Louisiana Tech Univ. (United States)

This paper provides an introductory discussion and sample preliminary results on a new metamaterial-based smart antenna concept. This new antenna concept is based on controlling closed-loop interactions between printed slot microstrip patterns and a variety of lattice substrate structures. These type of interactions are controlled via the integration of controllable active devices within a set of microstrip antenna geometries that are under consideration. The resulting antenna technology enables the real-time configuration of antenna systems that transmit multiple programmable tones across large percentage bandwidths. The control philosophy is based on specifying a desired spectrum within the system memory and then iteratively sequencing through a series of programmable modes on the antenna-integrated substrate devices to achieve convergence to the desired spectrum. A significant portion of the focus of this investigation is on an analysis of geometrical scalability of the resulting design configurations. This investigation is conducted as part of ongoing Student Internship Programs at AFRL.

8021-25, Session 5

Considerations for dielectric breakdown of metamaterials

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Electromagnetic Metamaterials (MTMs) typically consist of a homogeneous host material containing compact inclusions. While, MTMs have the potential to enable significant improvement on performance of radar antennas, one key consideration for MTM implementation in radar systems is the possibility of dielectric breakdown from high electric fields arising from the high-power radar transmitter or environmental effects.

Our approach is to calculate the detailed electric field distribution within the MTM and compare the peak values of the field to the field that would exist in a homogeneous material. Embedded conductive structures, such as those comprising MTMs, cause electric field enhancement near the metallic inclusion lowering the electric strength.

Using the mean-field theory, we replace each inclusion by an equivalent multipole. The effect of inclusions is taken into account by an effective field resulting from the electric dipole term of each inclusion. We determine the detailed field in the vicinity of the inclusion by summing the effective field and the local field due to the inclusion. We incorporate frequency dependence by developing an equivalent electrical circuit for the inclusions that allows us to scale the electric field at the tips of the inclusions that have been determined by the quasi-static approach. We find that the presence of inclusions reduces the electric strength of the MTM in comparison to the electric strength of the pure host material. For a dilute MTM, the reduction depends mainly on the geometry of the inclusion with weak dependence on the concentration of the inclusions.

8021-26, Session 5

Metamaterial-driven lens optics for new beam forming patterns

A. I. Zaghloul, S. J. Weiss, U.S. Army Research Lab. (United States)

No abstract available

8021-27, Session 6

Super-resolution technologies for all-weather sense and avoidance (SAA) radar

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The all-weather sense and avoidance (SAA) and due-regard radar systems have strict requirements on size, weight and power (SWaP) and target localization accuracies. Also, the multi-mission capabilities with both weather and hard targets are critical to the survivability of unmanned aerial vehicles (UAV) in the next generation national airspace. The aperture limitations of the aircraft sensor installation, however, have prevented large antennas/arrays to be used. The tradeoffs among frequencies, resolutions and detection range/accuracies have not been fully addressed. An innovative concept of overcoming the aperture limitation by using a special type of super-resolution technology is introduced. The technique is based on a combination of thinned antenna array, an extension to the traditional Multiple Signal Classification (MUSIC) technique, and applying a two-dimensional sidelobe mitigation processing. To overcome the degradation of MUSIC-type of approach due to coherent radar signals, the special waveform coding techniques are used. Simulated and measured results of super-resolution techniques are discussed and evaluated, and the capability of separating multiple targets within aperture-constrained beamwidth is demonstrated. Moreover, the potential capabilities of on-board monitoring of weather hazards are also analyzed, with a particular example of simultaneous hail/aircraft detection in the same field of view. The implementation considerations of the super-resolution techniques are addressed with respect to frequency selections, antenna array layout, waveform design, target detection capability and real-time implementation with Rapid-IO fabric based, distributed DSP platforms.

8021-28, Session 6

Using SAR back-projection for precise interferometric scene height measurement

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Using interferometry with synthetic aperture radar (SAR) for measuring the topographic heights in an image scene, when each channel of SAR data has been processed using the backprojection algorithm, requires development of a new height estimation algorithm. Backprojection is a precise, though inefficient, image formation algorithm which allows processing of SAR data from non-linear flight paths and systems with wide-beamwidth antennas. The advantages of backprojection, combined with parallel processing make backprojection an attractive alternative to frequency-domain SAR processing, particularly for small SAR systems used on small unmanned aircraft, where the aircraft motion is more variable than larger platforms. For interferometry, each channel forms an image of the same area using a digital elevation map (DEM), which is often of much coarser resolution than the SAR data. The phase difference between SAR channels in the complex images is due to errors in the DEM. An iterative process is proposed, where the DEM is updated based on the geometry of the interferometric antennas and the target scene, then the SAR data is re-processed. The cycle continues until the phase differences are minimized. The resulting DEM then contains a precise height for each pixel in the SAR images. This paper presents the theoretical development of the backprojection interferometry algorithm, and actual results using data from the NuSAR X-band radar system. The results are compared to measured ground truth of the altitude of flat areas and the heights of trees.

8021-29, Session 6

SAR vibrometry using a pseudo-subspace approach based on the discrete fractional Fourier transform

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In synthetic-aperture radar (SAR), ground-target vibrations introduce a phase modulation in the returned signals, a phenomenon often referred to as the micro-Doppler effect. Earlier work has shown that the problem of estimating common ground-target vibrations can be transformed into a problem of successively estimating chirp parameters of the returned signal in properly sized subapertures. Recently, a method based on the Discrete Fractional Fourier Transform (DFRFT) was proposed, in conjunction with the subaperture framework, to estimate vibration frequencies of ground targets in the absence of noise. However, the task of peak identification in the angle-frequency plane associated with the DFRFT becomes formidable in the presence of noise. In this paper we employ a pseudo-subspace algorithm to extend the applicability of the DFRFT-based method to signals that corrupted by white noise. The algorithm first calculates the inverse discrete Fourier transform of row and column projections of the magnitude of the DFRFT of the SAR returned signal to obtain two vectors that contain information on the center frequency and chirp rate. Next, a pseudo-subspace approach is applied to the covariance matrices of the two vectors to yield a pseudo spectrum for each matrix. The center frequency and the chirp rate are then extracted from the pseudo spectra. Simulations are undertaken to investigate the capability of the proposed algorithm in estimating harmonic vibrations using SAR platforms. The performance of the proposed algorithm is statistically analyzed and compared to the Cramer-Rao lower bound. Effects of subaperture size and covariance-matrix forms are also investigated.

8021-30, Session 6

Generation of FM signals with quasi-chirp behavior using three-dimensional chaotic flows

C. S. Pappu, B. C. Flores, B. Verdin, The Univ. of Texas at El Paso (United States)

In previous work we constructed wideband FM signals with high range resolution applications using the non-linear Lorenz system, which has a set of three state variables and three control parameters [1]. The FM signals were generated using any one of the state variables as the instantaneous frequency by varying the values of the parameters in the chaotic regime. We now determine the spectral characteristics of the Lorenz FM signal and compare the spectral characteristics to those of a similar signal based on the Lang-Kobayashi flow [2]. We show that for either chaotic flow, the local linearity of the attractor yields an FM signal with a distinct chirp behavior. Irrespective of the statistical independence of the instantaneous frequency, we show that the chaotic FM signal follows Woodward's theorem in the sense that the spectrum of the FM signal follows the shape of the probability density function of the state variable. The chirp rate of the FM signal can be controlled through a time-scale parameter that compresses or expands the chaotic flow. As the chaotic flow evolves so does the spectrum of the corresponding FM signal which experiences changes in center frequency, bandwidth, and power spectral density. We show that segments of the signal with a high chirp rate can be significantly compressed to achieve high range and Doppler resolution. The ability to change the center frequency and the shape of the spectrum could be interpreted as added frequency agility.

8021-31, Session 6

PADF RF localization criteria for multimodel scattering environments

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This paper provides a summary of recent results on a novel multi-platform RF emitter localization technique denoted as Position-Adaptive RF Direction Finding (PADF). This basic PADF formulation is based on the investigation of iterative path-loss based (i.e. path loss exponent) metrics estimates that are measured across multiple platforms in order to robotically/intelligently positionally adapt (i.e. self-adjust) the location of each distributed/cooperative platform. Recent results at the AFRL indicate that this position-adaptive approach shows potential for accurate emitter localization in challenging embedded multipath environments such as urban environments. As part of a general introductory discussion on PADF techniques, this paper provides a summary of our recent results on PADF and includes a discussion on the underlying and enabling concepts that provide potential enhancements in RF localization accuracy in challenging environments. Also, an outline of recent results that incorporate sample approaches to real-time multi-platform data pruning is included as part of a discussion on potential approaches to refining a basic PADF technique in order to integrate and perform distributed self-sensitivity and self-consistency analysis as part of a PADF technique with distributed robotic/intelligent features. The focus of this paper is on the experimental performance analysis of hardware-simulated PADF environments that generate multiple simultaneous mode-adaptive scattering trends. Specifically, we cite approaches to addressing PADF localization performance challenges in these multi-modal complex laboratory simulated environments via providing a detailed analysis of our multi-model experiment design together with a detailed analysis of the resulting hardware-simulated PADF data. We conclude by providing an introductory conceptual discussion on the potential for initiating joint Position-Adaptive Passive Radar (PAPR) and PADF multi-function RF research during the Summer of 2011.

8021-32, Session 6

A method for selecting radar waveforms based upon post-selection criteria

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In previous work, we have shown that measurement using a radar can be viewed as taking the expected value of an operator. The operator typically represents some aspect of the characteristics of the object being tracked (such as Doppler, distance, shape, polarization, etc.). The expectation is taken with respect an optimal matched filter design process based on the waveform broadcast by the radar and a receiver which is optimized to a specific characteristic of the object being tracked. With digital technology, it is possible to produce designer waveforms to broadcast or to mix with the return signal. Consequently it is possible to maximize the expectation of the operator by judiciously choosing (post-selecting) the received signal. We describe a method for post-selecting the return signal to detect different “target operators” based on perturbation theory based on the Rayleigh-Reitz method and illustrate it with different operators and waveforms.

8021-33, Session 7

Clutter locus equation for more general array orientation

D. L. Bickel, Sandia National Labs. (United States)

This paper presents a more generalized 3-D interpretation of the standard clutter locus presented in text’s such as Klemm.

8021-34, Session 7

Multisignal radar techniques using smartphone technologies

A. K. Mitra, Air Force Research Lab. (United States); C. Hu, The Ohio State Univ. (United States); K. Maxwell, Univ. of Dayton (United States)

This paper provides a discussion on radar techniques using smartphone technologies. Both active and passive techniques are considered. The first portion of the paper is dedicated to illustrating concepts for the development and design of radar systems via the implementation of distributed RF front-ends associated with typical state-of-the-art smartphone applications. An analysis of a number of techniques for the potential development of this type of system are considered including techniques based on signal correlation between multiple spatially distributed receivers that may require less a priori knowledge of the transmission signal in relation to other popular techniques. Another major focus of this discussion is the processing and exploitation of GSM signals at multiple frequencies via the analysis of techniques such a frequency interferometrics. (These techniques can be generalized for the potential follow-on development of smartphone radar applications that employ a combination of GSM and similar categories of smartphone signals in combination with WiFi/WiMax along with typical onboard navigation signals such as GPS.) The second portion of this paper is a presentation and analysis of a preliminary set of experimental results obtained via measurements at the AFRL RF Systems Integration Lab at IDCAST (Institute for Development and Commercialization of Advanced Sensor Technologies). These results are obtained via interfacing three distributed commercial Multi-Signal RF GSM Front-Ends to a laptop computer for convenient laboratory processing and analysis. These experiments are conducted as part of ongoing Student Internship Programs at AFRL.

8021-35, Session 7

Determination of instantaneous frequency using MCMC bayesian model selection

A. Mehmood, U.S. Army Research Lab. (United States); P. M. Goggans, The Univ. of Mississippi (United States); J. M. Sabatier, U.S. Army Research Lab. (United States)

In this paper, we apply Bayesian probability theory to the problem of estimating instantaneous frequency (IF) of non-stationary signals. First, the signals emanating from moving targets are represented by suitable localized models. These models are constructed on the basis of number of frequency components of the returned scatters from moving targets. Then, the posterior probabilities of these models are computed and compared to determine which model best describes the data under observation. Once the preferred model is chosen, then its parameters are estimated. We present a method that performs parameter estimation and model selection simultaneously, and extends to the IF estimation of multi-component non-stationary signals. The calculations are implemented using Markov chain Monte Carlo (MCMC) in conjunction with thermodynamic integration with simulated annealing to draw samples from the joint posterior probability for the model and the parameters. Monte Carlo integration is then used to approximate the marginal posterior probabilities for all the parameters, including the number of frequency components in the selected model.

The technique presented in this paper can be employed in a wide range of applications such as biomedical, radar, sonar, seismic, natural mechanical oscillation in bridges and buildings, automobiles, aviation, and human body movements. We demonstrate the performance of this method using simulated and experimental results and compare it with existing IF estimation techniques.

8021-36, Session 7

Quick signal detection and dynamic resource allocation scheme for ultra-wideband radar

X. Kong, M. Ahmed, HRL Labs., LLC (United States)

In many environments, the spectrum is not very sparse, especially over a long period. However, it is “instantly sparse”, i.e. many signals are short lived and only a small portion of a large frequency band is occupied in any instant. Existing radars usually sweep through the frequency band to detect signals within the band. During the sweeping process, the radar signal needs to reside at each frequency point for a certain amount of time. Hence, to cover a large bandwidth, either a long sweeping time is required, missing many short pulse signals, or many receivers covering different subbands have to work in parallel. With the aid of the compressive sensing technique, a new scheme for monitoring a large bandwidth with only one receiver is processed. In essence, it is an adaptive sampling procedure. Assume the input signal is a mixture of several signals with unknown center frequencies and non-overlapping frequency bands. The receiver modulates the input signal with a pseudorandom sequence and takes samples below the Nyquist rate. Unlike existing compressive sensing techniques that use complex iterative optimization algorithms to detect and reconstruct the signal, the samples go through a one-step transformation. From the transformation result, the frequency band of the largest signal can be determined. As traditional radars, a separate receiver is allocated to further measure this detected signal. This signal is then filtered out from the input signal and a new set of samples are taken. In this way, all signals can be detected one by one quickly.

Return to Contents

8021-38, Session 7

Adaptive detection of range-spread targets by the generalized detector

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we address an adaptive detection of range-spread targets or targets embedded in Gaussian noise with unknown covariance matrix by the generalized detector based on the generalized approach to signal processing in noise. We assume that cells or secondary data that are free of signal components are available. Those secondary data are supposed to process either the same covariance matrix or the same structure of the covariance matrix of the cells under test. In this context, we design the generalized detectors according to the generalized approach to signal processing and use a two-step design procedure. The criteria lead to receivers ensuring the constant false alarm rate (CFAR) property with respect to unknown quantities. A thorough performance assessment of the proposed detection strategies, together with the evaluation of their processing cost, highlights that the two-step design procedure of decision-making rule in accordance with the generalized approach to signal processing in noise is to be preferred with respect to the plain one. In fact, the proposed design procedure leads to generalized detectors that achieve significant improvement in detection performance under several situations of practical interest. For estimation purposes, we resort to a set of secondary data. In addition to the classical homogeneous scenario, we consider the case wherein the power value of primary and secondary data vectors is not the same. More precisely, both groups of data separately satisfy the homogeneity condition, but the two covariance matrices coincide only up to a scaling factor. The design of adaptive detection algorithms based on the generalized approach to signal processing in noise in case of mismatch is a problem of primary concern for radar applications. In fact, although most of the space-time adaptive processing detection schemes have been designed employing the assumption that interference returns were independent and identically distributed Gaussian vectors, experimental campaigns have demonstrated that such an assumption is not always verified. Analysis of several space-time adaptive processing algorithms, mostly conducted assuming homogeneity of the secondary data, has shown that inhomogeneities magnify the loss between the adaptive implementation and optimum conditions. We demonstrate that two-step design procedure based on the generalized approach to signal processing in noise ensures minimal loss.

8021-58, Poster Session

ECCM performance analysis of chaotic coded orthogonal frequency division multiplexing (COFDM) SAR

X. Feng, X. Xu, BeiHang Univ. (China)

Conventional linear frequency modulation (LFM) synthetic aperture radar (SAR) is incapable of countering repeat deception jamming. In this paper, a new SAR signal based on chaotic coded orthogonal frequency division (COFDM) is studied. The fact that chaotic codes are sensitive to the initial values allows generating a large number of different chaotic sequences to form SAR transmitting waveforms, where all the signal sequences are orthogonal to each other, enabling COFDM-SAR countering not only active noise but also repeat deception jamming. The procedures for COFDM waveform generation and SAR anti-jamming processing are discussed. Comparative studies of the electronic counter-countermeasure performance (ECCM) between COFDM-SAR and conventional linear frequency modulation (LFM) SAR are made. Simulation results are presented to demonstrate the superior performance of COFDM-SAR in countering repeat deception as well as active noise jamming.

The paper consists of the following sections:1. Introduction; 2. COFDM-SAR Signal Model; 3. Jamming Signal Models; 4. COFDM-SAR Imaging Algorithm; 5. Simulation Results; References.

“Submitted to Special Session on Noise Radar.”

8021-59, Poster Session

Noise radar with broadband microwave ring correlator

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Noise radars are the radars which use random or pseudo-random signals for target illumination and coherent detection techniques for receiving noise signals. A real narrowband noise signal representation in the form of an analytical signal in the Hilbert space is presented in the paper. This analytical signal is illustrated in a variable complex plane as a mark with defined amplitude, phase, pulsation and instantaneous frequency. A block diagram of a broadband product detector in a quadrature system is presented. Correlation receiver is a typical element entering into the noise radar. A principle of quadrature correlation detection of noise signals using an analog broadband microwave correlator is presented in the paper. Measurement results for the correlation function of noise signals are shown and application of such solution in the noise radar for precise determination of distance changes and velocity of these changes is also presented. The idea of direct correlation detection of the noise signal transmitted and received by the noise radar is presented in this article Results for short range noise radar operation both for static and moving objects are presented. New phase microwave discriminator configuration for synchronic double balanced ring correlator is proposed. In the paper the idea of microwave quadrature correlation of noise radar using analog correlation technique, especialy for detection of human activities, is presented. Various parts of the human body have movements when a person is performing different physical activities. There is a need to remotely detect human activities for through the wall detection technics.The microwave quadrature correlator, which is used to extract the human-induced Doppler frequency shift from the received signal, facilitates the identification of various human activities for anti-terrorism applications. Experimental results using 2.6 - 3.6 GHz noise like waveform for the signal from a breathing human is presented. Conclusions and future plans for the use of presented detection technique in broad-band noise radars close the paper.

8021-60, Poster Session

Interference suppression in noise radar systems

S. Djukanovic, Univ. of Montenegro (Montenegro); T. Thayaparan, Defence Research and Development Canada (Canada); M. Dakovic, L. Stankovic, Univ. of Montenegro (Montenegro)

Although noise radars possess the interference suppression ability, a strong interference can severely deteriorate their performance. Interference suppression methods can be divided into non-parametric and parametric.

Of non-parametric methods, the most important are time-frequency (TF) based methods which have proved very effective when radar return is corrupted by broadband interferences with narrowband instantaneous bandwidths. These methods include the short-time Fourier transform (STFT) and the local polynomial Fourier transform (LPFT) as tools for representing and suppressing the interference in the TF plane. The STFT is the simplest and most intuitive TF representation with fast implementation using the FFT routines. The STFT-based interference suppression is obtained by removing corrupted TF bins using a binary mask. The drawback to the STFT is low resolution due to the uncertainty principle. If the underlying interference is highly non-stationary, a great portion of the radar return’s energy can be removed along with the interference. The appropriate choice of the analysis window can alleviate this drawback to a certain degree. The LPFT offers a solution to the resolution problem by incorporating a set of phase parameters with which we can cancel the interference’s non-stationarity within the analysis window. The drawback to the LPFT is, however, the increased computational complexity.

Very attractive computationally efficient parametric approach is the high-order ambiguity function (HAF), which assumes that the interference is a

polynomial-phase signal (PPS), supported by the Weierstrass's theorem. The HAF suffers from the identifiability problem when multicomponent PPSs are considered. The product high-order ambiguity function (PHAF) resolves this problem.

Submitted to Special Session on Noise Radar

8021-61, Poster Session

Detection and identification of concealed weapons using matrix pencil

R. S. Adve, Univ. of Toronto (Canada); T. Thayaparan, Defence Research and Development Canada (Canada)

The detection and identification of concealed weapons is an extremely hard problem due to the weak signature of the target buried within the much stronger signal from the human body. This paper furthers the automatic detection and identification of concealed weapons by proposing the use of an effective approach to obtain the resonant frequencies in a measurement. The technique, based on Matrix Pencil, a scheme for model based parameter estimation also provides amplitude information, hence providing a level of confidence in the results. Of specific interest is the fact that Matrix Pencil is based on a singular value decomposition, making the scheme robust against noise.

"Submitted to Special Session on Noise Radar."

8021-62, Poster Session

Through-the-wall detection of human activity

T. Johansson, J. Rahm, J. Gustavsson, S. L. Nilsson, A. Sume, A. Orbom, Swedish Defence Research Agency (Sweden)

An approach towards real-time radar through-the-wall (TTW) sensing is presented. The aim is to detect and classify human motions behind walls. In the future we want to utilize multi-path information to support an operator with information on the activity in a closed room, e.g., in a hostage situation.

To meet this objective, radar TTW measurements have been performed on moving person(s) inside a closed room and an MTI-based signal processing algorithm, using coherent subtraction between different frequency sweeps, has been developed.

The radar was equipped with ridge horn antennas which were directed towards an outer door. For each measurement the radar frequency was swept between 5 and 10 GHz 1893 times, with a sweep sampling rate of ~94 Hz. Free-space reference data were collected in an open area.

A crucial algorithm parameter is the time distance between two subtracting sweeps, or the sweep difference. Fast and slow motions are captured by using separate sweep differences. By using Inverse Fast Fourier Transform after the subtraction it is possible to make down-range plots and by applying a simple detection threshold, the detections can be shown in a range vs. time plot.

Applying the algorithm to the TTW data, we find that human motions behind a door can be detected with the background well suppressed. Some specific motions can be recognized. Even a person who is standing still without breathing is fairly easy to detect. The results are promising with low false alarm rates and fast signal processing rates, enabling real-time operation capability.

8021-63, Poster Session

Some comments on GMTI false alarm rate

A. W. Doerry, Sandia National Labs. (United States)

A typical Ground Moving Target Indicator (GMTI) radar specification includes the parameters Probability of Detection (PD) - typically on the order of 0.85, and False Alarm Rate (FAR) - typically on the order of 0.1 Hz. The PD is normally associated with a particular target 'size', such as Radar Cross Section (RCS) with perhaps some statistical description (e.g. Swerling number). However, the concept of FAR is embodied at a fundamental level in the detection process, which traditionally employs a Constant-FAR (CFAR) detector to set thresholds for initial decisions on whether a target is present or not. While useful, such a metric for radar specification and system comparison is not without some serious shortcomings. In particular, when comparing FAR across various radar systems, some degree of normalization needs to occur to account for perhaps swath width and scan rates. This in turn suggests some useful testing strategies.

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8021-64, Poster Session

Optimal antenna beamwidth for stripmap SAR

A. W. Doerry, Sandia National Labs. (United States)

The classical rule-of-thumb for Synthetic Aperture Radar (SAR) is that a uniformly illuminated antenna aperture may allow continuous stripmap imaging to a resolution of half its azimuth dimension. This is applied to classical line-by-line processing as well as mosaicked image patches, that is, a stripmap formed from mosaicked spotlight images; often the more efficient technique often used in real-time systems. However, as with all rules-of-thumb, a close inspection reveals some flaws. In particular, with mosaicked patches there is significant Signal to Noise ratio (SNR) degradation at the edges of the patches due to antenna beam roll-off. We present in this paper a calculation for the optimum antenna beamwidth as a function of resolution that maximizes SNR at patch edges. This leads to a wider desired beamwidth than the classical calculation.

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8021-65, Poster Session

Synthetic aperture radar for disaster monitoring

R. Dunkel, R. Saddler, General Atomics Aeronautical Systems, Inc. (United States); A. W. Doerry, Sandia National Labs. (United States)

Synthetic Aperture Radar (SAR) is well known to afford imaging in darkness and through clouds, smoke, and other obscurants. As such, it is particularly useful for mapping and monitoring a variety of natural and man-made disasters. A portfolio of SAR image examples have been collected using General Atomics Aeronautical Systems, Inc.'s (GA-ASI's) Lynx® family of Ku-Band SAR systems, flown on test-bed aircraft. Images are provided that include scenes of flooding, ice jams in North Dakota, agricultural field fires in southern California, and ocean oil seeps off the coast of Santa Barbara, California.

GA-ASI, an affiliate of privately held General Atomics, is a leading manufacturer of unmanned aircraft systems (UAS), tactical reconnaissance radars, and surveillance systems, including the Predator® UAS-series and Lynx SAR/GMTI.

8021-66, Poster Session

Design and implementation of a digital impulse generator for a 24GHz UWB radar

S. Kim, J. Lee, Daegu Gyeongbuk Institute of Science &

Technology (Korea, Republic of)

In this paper, we design and implement a digital impulse generator using a DCM block and an OSERDES block for a 24GHz UWB impulse-Doppler radar. The Federal Communications Commission (FCC) has confirmed the spectrum from 22 to 29GHz for UWB radar with a limit power of -41.3dBm/MHz. UWB signal possesses an absolute bandwidth larger than 500MHz or a relative bandwidth up to 20%. The vehicle radar is the key technology with the inherent advantage detected the distance and the velocity regardless of weather. Radar has a role to measure the distance and the velocity of long-distance vehicle. But, the radar with 1m resolution is difficult to satisfy the detection performance in the blind spot zone because the blind spot zone needs high resolution. So, UWB impulse-Doppler radar with 30cm resolution is suitable for the blind spot zone. The designed impulse generator has a 2ns pulse width and 100us PRI. We perform simulations through Xilinx ISE; experiments use a spectrum analyzer and a digital oscilloscope. For UWB radar, we use an AD9779 DAC module with a 1Gsps maximum sampling rate. For equipment, we use a TDS5104B oscilloscope of Tektronix with 3dB bandwidth at 1GHz for the analysis of the time domain and an E4448A spectrum analyzer of Agilent with a 50GHz spectrum for the analysis of the frequency domain. The results of the digital impulse measurement show a 2ns pulse width in the time domain, a 500MHz bandwidth, and a 10KHz spectrum peak in the frequency domain.

8021-67, Poster Session

Dc-offset effect cancelation method using mean-padding FFT for automotive UWB radar sensor

Y. Ju, S. Kim, J. Lee, Daegu Gyeongbuk Institute of Science & Technology (Korea, Republic of)

To improve road safety and realize intelligent transportation, Ultra-Wideband (UWB) radars sensor in the 24 GHz domain are currently under development for many automotive applications. Automotive UWB radar sensor must be small, require low power and inexpensive. By employing a direct conversion receiver, automotive UWB radar sensor is able to meet size and cost reduction requirements. We developed Automotive UWB radar sensor for automotive applications. The developed receiver of the automotive radar sensor is direct conversion architecture. Direct conversion architecture poses a dc-offset problem. In automotive UWB radar, Doppler frequency is used to extract velocity. The Doppler frequency of a vehicle can be detected using zero-padding Fast Fourier Transform (FFT). However, a zero-padding FFT error is occurs due to dc-offset problem in automotive UWB radar sensor using a direct conversion receiver. Therefore, dc-offset problem corrupts velocity ambiguity. In this paper we proposed a mean-padding method to reduce zero-padding FFT error due to dc-offset in automotive UWB radar using direct conversion receiver, and verify our proposed method with computer simulation and experiment using developed automotive UWB radar sensor. We present the simulation results and experiment result to compare velocity measurement probability of the zero-padding FFT and the mean-padding FFT. The proposed algorithm simulated using Matlab and experimented using designed the automotive UWB radar sensor in a real road environment. The propose method improved velocity measurement probability.

8021-68, Poster Session

Integrated radar-camera security system: experimental results

M. Zyczkowski, N. Palka, T. Trzcinski, R. Dulski, M. Kastek, P. Trzaskawka, Military Univ. of Technology (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 day/night cameras, IR uncooled thermal cameras as well as millimeter-wave radars detecting radiation reflected from target. 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 our research into a such system.

8021-69, Poster Session

Resolution analysis of bistatic SAR image

Z. Qiao, G. Garza, J. Lopez, The Univ. of Texas-Pan American (United States)

In our paper, we analyze the resolution of the Bistatic Synthetic Aperture Radar (BISAR) imaging for stationary objects. In particular, we analyze the resolution of the image reconstructed by the method of a filtered backprojection inversion, which is derived from a scalar wave equation model. In all cases, we assume that the radar system transmits a chirp signal. Our results are for two scenarios: a parallel trajectory for both the transmitter and receiver, and a circular trajectory where the receiver and transmitter are at opposite ends of the diameter of their circular path. We present numerical results and simulations for both cases.

8021-70, Poster Session

Side-looking image formation with a maneuvering vehicle-mounted antenna array

K. I. Ranney, L. H. Nguyen, C. Tran, R. Innocenti, U.S. Army Research Lab. (United States)

Researchers at the U.S. Army Research Laboratory (ARL) designed and fabricated the synchronous impulse reconstruction (SIRE) radar system in an effort to address fundamental questions about the utilization of low frequency, ultrawideband (UWB) radar. The SIRE system includes a receive array comprising 16 receive channels, and it is capable of operating in either a forward-looking or a side-looking mode. When operated in side-looking mode, it is capable of producing high-resolution synthetic aperture radar (SAR) data, thereby enhancing image contrast between targets of interest and background clutter. The SAR imaging algorithms, however, initially operated under the assumption that the vehicle followed a nearly linear trajectory throughout the data collection. Under this assumption, the introduction of vehicle path nonlinearities distorted the processed SAR imagery. In an effort to mitigate these effects, we first incorporated segmentation routines to eliminate highly non-linear portions of the path. We then enhanced the image formation algorithm, enabling it to more effectively process data collected from a non-linear vehicle trajectory.

We describe the incorporated segmentation approaches and compare the imagery created before and after their incorporation. Next, we describe the modified image formation algorithm and present examples of output imagery produced by it. Finally, we compare imagery produced using the initial segmentation algorithm to imagery produced using the modified image-formation algorithm, highlighting the effects of segmentation parameter variation on the final SAR image.

8021-71, Poster Session

Wideband fiber optic vector modulator using 8-tap all-optical Hilbert transform

R. Tucker, S. C. Granieri, A. Siahmakoun, Rose-Hulman Institute of Technology (United States)

A wideband photonic RF vector modulator with novel architecture is presented and demonstrated with capability of continuous amplitude modulation and 0o-360o phase shifting. In-phase and quadrature-phase components of the output signal are used to produce 360o continuous phase shifting and optical attenuation is used to control the signal amplitude. The photonic vector modulator architecture is constructed with a 15 dBm laser diode operating at 1551 nm, 2 electro-optic modulators, optical switches, a fiber-optic transversal filter, and attenuators. An 8-tap fiber-optic filter implementing fiber Bragg gratings, circulators, optical delay-lines, and attenuators to simulate a discrete Hilbert transform is demonstrated. This transversal filter produces the necessary 90o phase shift for broadband RF signals to reach quadrature-phase. However, our experimental results show that a π-phase is attainable for RF inputs. Our optical discrete Hilbert transformer architecture is theoretically limited to process RF signals to the upper bound of 40 GHz. The all-optical discrete Hilbert transformer is implemented in the vector modulator architecture and the system is capable of producing continuous 360o phase-shift and amplitude modulation through the frequency range of 1-6 GHz.

8021-72, Poster Session

Coherent radar optimization using frequency-domain correlation function

V. Gouz, Kvant Scientific Research Institute (Ukraine)

The cross-talk of pulse repetition and clutter spectra creates the problem of clutter suppression in coherent radars. Internal non-stability of different origin, for example, thermal drift of parameters, noise from internal sources, power supply pulsations in transmitter and receiver channels add the uncertainty when processing the received signals. We propose a technique for identification of the origins of this internal non-stability based on the analysis of the frequency-domain correlation function. We make the attenuated signal from transmitter to enter the receiver channel without circulating in the atmosphere, simulate internal non-stability of different origin and different parameters, calculate the frequency domain correlation functions, and analyze the influence of these non-stability simulations on the final result of signal processing. This analysis enables minimization of the internal non-stability in the transmitter and receiver channels. The technique was experimentally tested and further used for adjustment of Navy radars of S and X frequency range.

8021-73, Poster Session

Far-field scattering of random electromagnetic fields from particulate media

Z. Tong, O. Korotkova, Univ. of Miami (United States)

The basic quantity of the unified theory of coherence and polarization of stochastic, statistically stationary, electromagnetic fields is the so-called electric cross-spectral density matrix. In this paper, we derive the expressions of the degree of coherence and the degree of cross-polarization, via the cross-spectral density matrix of the transverse scattered far-field.

We will use a recently introduced concept of a pair-structure matrix to show how these two quantities of the far field, scattered from a collection of particles of different scattering potentials, are distributed. We will consider the cases of a single-type particle and also collections consisting of several types of particles. The effect of correlation between the particle clusters belonging to different types will be explored in depth.

For the two-point quantities one has to adjust the definition of the quantity considered, in order to retain the 2×2 matrix form of the cross-spectral density matrix, in the polar-spherical coordinate system. This problem arises due to the fact that the fields at two different points, in order to be correlated, must be expressed in their own distinct spherical coordinates, which leads to ambiguity for physical meaning of statistical quantities. In this paper, we will derive the adjusted expressions for the degree of coherence and for the degree of cross-polarization in the polar-spherical coordinate system.

Our analysis is of utmost importance to development of sensing techniques for systems operating in random particulate media.

8021-74, Poster Session

Stereo matching: performance study of two global area-based algorithms

S. Arunagiri, V. J. Jordan, P. Teller, The Univ. of Texas at El Paso (United States); J. C. Deroba, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); D. R. Shires, S. J. Park, L. Nguyen, U.S. Army Research Lab. (United States)

Radargrammetric techniques such as clinometry, stereoscopy, interferometry, and polarimetry are used for Digital Elevation Model (DEM) generation from Synthetic Aperture Radar (SAR) images. The choice of technique depends on the SAR configuration, the means used for image acquisition, and the relief type. The most popular radargrammetric techniques are interferometry for regions of high coherence and stereoscopy for regions such as steep forested mountain slopes. Stereo matching, which is finding the disparity map or correspondence points between two images acquired from different sensor positions, is a core process in stereoscopy. Additionally, automatic stereo processing that involves stereo matching is an important process in other 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, stereo matching has traditionally been, and continues to be, one of the most heavily investigated topics in computer vision. Stereo matching algorithms generally perform (subsets of) the following four steps: cost computation; cost (support) aggregation; disparity computation/optimization; and disparity refinement. Based on the method used for cost computation, the algorithms are classified into feature-, phase-, and area-based algorithms; and based on how they perform disparity computation/optimization, they are classified as local or global. We present a comparative performance study of two integer-based stereo matching codes that use global area-based algorithms; one uses a simulated annealing algorithm and the other uses a graph cut algorithm. The performance comparison is done in terms of execution time, power consumption, and the quality of the generated output. The results of this study provide insights into the suitability and relative merits of these two codes/algorithms for execution on field-deployable and on-board computer systems with size, weight, and power (SWaP) constraints.

8021-75, Poster Session

On the use of the Shark antenna for radar detection techniques

L. Desrumaux, L'IUT du Limousin (France); V. Bertrand-Vincent, CISTEME (France); J. Andrieu, M. Lalande, L'IUT du Limousin (France); B. Jecko, XLIM Institut de Recherche (France)

The Shark antenna is an original miniature UWB antenna designed especially for transient applications and dedicated to be used in a 2D array with a N generators / N antennas configuration, in the frequency band [800MHz - 8GHz].

This paper proposes a study concerning the optimization of the transient radiated field of a Shark antenna array. Indeed, thanks to a scaling method on the dimensions of the elementary antenna, two arrays, having a same surface area but a different number of antennas, have been compared with regards to their transient performances and particularly their capacity of steering. Each antenna of the array is fed with an ultra short pulse generated with an optical system . This kind of feeding allows the limitation of the jitter between the sources (around 2ps with an optoelectronic system while the best value is 20ps with an electronic system) and permits to control the generated waveform.

Moreover, from the analyze of the transient performances of the elementary architecture “generator + antenna”, both in simulation and in experimentation (with the addition of coaxial cables), the performances of the global system have been evaluated. In this way, with the objective of radiating a power density of 1W/cm² at a distance of 1km (to increase the range of the system), the necessary number of antennas in the array,

the surface area of the array, and the transient front to back ratio of the global system, have been evaluated as function of the level of each feeding pulse.

8021-76, Poster Session

Attenuation of front-end reflections in an impulse radar using high-speed switching

G. J. Mazzaro, M. A. Ressler, G. D. Smith, U.S. Army Research Lab. (United States)

One of the challenges encountered when developing an impulse radar is impedance mismatch of radio-frequency (RF) front-end components. In a practical radar system, matching impedances of RF components to a reference impedance is possible within only a finite bandwidth. For frequencies outside of this bandwidth, at every point along the signal path where the impedance encounters a discontinuity, a reflection of the radar pulse occurs. These reflections, if not removed from the transmit path of the radar, can cause undesired replicas of the desired radar pulse to be emitted from the front-end, reflected by the environment, and received by the radar. When the undesired reflections are processed as part of the radar image, target echoes appear behind actual targets which generate false alarms.

The proposed solution for eliminating these echoes is to redirect and dissipate pulse reflections within the transmit circuit. The solution requires placing a high-speed solid-state switch after the pulse generator and before the transmit antenna. After the desired radar pulse is transmitted, the switch connects the antenna to a matched load. In this way, the radar pulse is reflected from the antenna, but the reflection is dissipated before it can be transmitted.

Using an impulse waveform, several RF switches are evaluated to achieve minimal loss, minimal distortion, and maximum reflected-pulse attenuation simultaneously. Low-loss cabling and timing signals required to implement the circuit are described. Successful reflection attenuation is demonstrated using the Army Research Laboratory's Synchronous Impulse Reconstruction (SIRE) radar.

8021-77, Poster Session

Scannerless gain-modulated three-dimensional laser imaging radar

C. Jin, Y. Zhao, X. Sun, L. Wu, Y. Zhang, Harbin Institute of Technology (China)

Scannerless laser imaging radar will be the trend of laser imaging radar in future because it has several advantages of high frame rate, wide field of view, small size and high reliability owing to giving up mechanical scanner. A scannerless gain-modulated three-dimensional laser imaging radar is developed: Our system consists of a pulsed laser which is capable of generating 100mJ pulses with a pulse width of 10ns and a center wavelength of 532 nm, and a receiver which is a digital CCD sensor coupled to a GEN II intensifier with a 10nm bandwidth optical filter. The homogenized light beam passes through a diverging lens to flood illuminate the targets. The return light is collected by a Nikon camera lens and amplified by the image intensifier which is electronically driven and can be set to exponentially modulated gain or constant gain. The CCD sensor can record a 12 bit gray-level image with a resolution of 780×582 pixels at a 50 Hz frame rate. For a range image of the target can be extracted by processing an intensity image with exponentially modulated gain and an intensity image with constant gain, the range image is acquired at a 25 Hz frame rate. During our outdoor experiment, the range image of the targets at 500m is acquired with 2m range accuracy and the range image of the targets at 1000m is acquired with 5m range accuracy in daytime.

8021-78, Poster Session

Exploiting spatial diversity in MIMO radars with collocated antennas

G. C. Maalouli, D. Rosser, G. Stratis, Raytheon Missile Systems (United States)

MIMO systems have revolutionized wireless communications resulting in unprecedented channel capacity. This breakthrough led researchers in radar as well as wireless communications communities to investigate the applicability of MIMO systems to radar. Preliminary research is showing that the full benefits of MIMO technology is realized when antenna spacing results in a decorrelated target scattering matrix. This requires antenna placement such that each receiver is observing an independent view of the target. Research is also showing that suboptimal improvements can be attained when the scattering matrix is partially correlated. This situation arises when antennas are collocated. In this work, we investigate the feasibility of MIMO Radar technology when antenna placement is quite restricted, such as in phased-array antennas. We extend the theoretical results for the correlation coefficients derived for statistical MIMO radar. We apply these results to assess the degree of decorrelation that can be achieved with Phase-Array antennas. We quantify our results as a function of antenna element spacing, frequency band and target RCS. In addition, we quantify the degree of decorrelation that is attained by antennas that are typical in a tactical missile environment. Our results show that even when the antennas are relatively small, it is possible to achieve a significant degree of decorrelation for a certain class of targets and certain frequency bands.

8021-39, Session 8

Radar signature acquisition using indigenously designed noise radar system

A. Freundorfer, Queen's Univ. (Canada); J. Siddiqui, Y. Antar, Royal Military College of Canada (Canada); T. Thayaparan, Defence Research and Development Canada (Canada)

An indigenously designed noise radar system was used to measure the radar signature of various targets. This radar system was capable of covering a noise bandwidth of near DC to 50 GHz. With its existing capabilities, this novel design offers more flexibility, making it well suited for experimental collection of radar signatures and in the study of radar cross-section of ultra wide-band signals.

Using this noise radar system, the radar signatures measurements were conducted for selective targets over the whole noise band of 400MHz-3000MHz. The primary limitations for this system was the lower frequency limit of the antennae and the upper frequency limit of the multiplier at the receiver. These limitations could be mitigated by using a new multiplier and amplifiers and by designing the antenna with a broader bandwidth.

An ultra wide-band antipodal tapered slot antenna [1] with a bandwidth of 400MHz - 9.8GHz was designed and used for the application. The antennae gain measurement was conducted and verified using a unique noise gain measurement system [2].

Measured radar signatures of different targets like spheres and carpenter squares with dielectric bodies were conducted and verified with simulations.

[1] J.Y. Siddiqui, Y.M.M. Antar, A.P. Freundorfer , S.M. Mikki and T. Thayaparan, "Ultra Wideband Antipodal Tapered Slot Antenna," Proc. ANTEM/AMEREM 2010 , July 05-08, 2010, Ottawa, Canada, p.147

[2] A.P. Freundorfer , J.Y. Siddiqui, Y.M.M. Antar and T. Thayaparan, "A Study in Antennae Characterization System Using Noise," Proc. ANTEM/ AMEREM 2010 , July 05-08, 2010, Ottawa, Canada, p.154

8021-40, Session 8

High-resolution noise radar using slow ADC

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Power spectral density (PSD) width of radar signal defines range resolution of any radar: the wider the spectrum the better the resolution. Obviously, the higher the range resolution (the wider PSD) the higher might be sampling rate of the ADC used for signal sampling in Noise Radar receiver. The faster ADC to be used the smaller number of bits is available and, hence, the lower dynamic range has Noise Radar. Actually this is the main bottleneck of high resolution Noise Radars. This problem might be solved to make Noise Radar competitive to conventional radars. Nowadays, there are known several approaches which enable increasing of Noise Radar dynamic range and at the same time provide its high range resolution.

In the paper we present first results of our consideration and design of high resolution Noise Radar which use slow ADCs. We suggested and studied so called stepped delay Noise Radar which uses two channels Arbitrary Waveform Generator for generation of both probing and reference signals digitally and realization of their cross-correlation at the carrier frequency in an analog correlator. The results of cross-correlation are sampled at the output of the analog correlator for different delays which forms range profile of the radar. The latter operation requires rather slow ADC having normally 24 bits at least for amplitude resolution which gives about 130 dB of dynamic range. We present also comparative analysis of the suggested approach with the known stepped frequency method implemented earlier by authors for noise radar.

8021-41, Session 8

Direct digitization of ultra-wideband (UWB) noise signals using frequency band folding

R. Vela, The Pennsylvania State Univ. (United States); G. Woodington, M. R. Deluca, Raytheon Co. (United States); R. M. Narayanan, The Pennsylvania State Univ. (United States)

For the development of a target identification and recognition UWB Radar, frequency spectrum responses for given targets are of importance. As technology's digitization rate of analog sources increases, direct acquisition of wider bandwidths is becoming possible. Through conversion to the frequency domain, wider bandwidth spectral responses for targets can be produced. However, to directly digitize higher frequency with ultrawide bandwidths directly (i.e., $\geq$ 4 GHz), the technology is somewhat limited. This paper will present a technique which utilizes both hardware and software to produce a lower bandwidth signal (e.g., 1 GHz), which contains larger spectral bandwidth information (e.g., 8 GHz). The technique utilizes a double band folding method implemented in hardware to overlap larger bandwidths into lower frequency bandwidths. The generated lower bandwidth will have a unique spectral response containing the superimposed amplitudes of the larger bandwidth transmitted signal. This folded spectrum can be used in certain specific applications for target identification. Simulated and experimental results will be presented to evaluate the advantages and disadvantages of such an approach.

8021-42, Session 8

Cross-correlation analysis of noise radar signals propagating through lossy dispersive media

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Correlation detection is used in noise radar for target detection and ranging. Correlation is achieved via coherent signal processing, which, theoretically, gives the best improvement in the signal-to-noise ratio. Over the years, much research and progress has been made on the use of noise radar systems as a means for effective through-wall detection. The ability to detect an object behind obscurement is a challenging yet feasible task. Information about a particular target's range and/or speed are often acquired by comparing and analyzing the transmit and received waveforms. As previously stated, one of the widely used techniques employed to measure the degree of similarity between the two signals is correlation, or in this particular instance, cross-correlation. In a noise radar, the received waveform which is delayed due to the round-trip time to the target, is cross-correlated with a time-delayed replica of the transmit signal. However, transmission and reflection impairments will affect the propagating signals and thereby degrade the correlation, and subsequently reduce the probability of detecting the target. Sources of such distortion to the signal arise from hardware design, which includes, but not limited to, the radar components and overall configuration, the antenna and polarization of choice, the environment, non-ideal scatters from the target as well as the media through which the signal propagates. Examples of media which can cause correlation degradation include reinforced concrete and cinder block walls. Depending on the orientation of the rebars in the reinforced concrete, the transmit signal may encounter polarization effects. Furthermore, due to the dispersive properties of wall materials such as concrete, the waveform suffers from higher loss at higher frequencies. In the case of cinder blocks, depending upon the dimensions of the internal cavity, oscillations causing deep nulls may occur in the signal spectrum. Thus, it is essential that we try to understand the effects that such phenomena and degradations can have on the signals that will be used in the correlation. The scrutiny of these problems and possible remedies to address these issues are instrumental in improving not only the performance of but also the accuracy (i.e. maximizing the probability of detection and minimizing the probability of false alarms) of a noise radar system. This paper presents part of the noise radar system design, simulation study, experimental data, and an analysis of the results ascertained.

Submitted to the Special Session on Noise Radar.

8021-43, Session 8

Super-resolution techniques for velocity estimation using UWB random noise radar signals

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The Doppler spread pertaining to the ultrawideband (UWB) radar signals from moving target is directly proportional to the bandwidth of the transmitted signal and the target velocity. Using typical FFT-based methods, the estimation of true velocities pertaining to two targets moving with relatively close velocities within a radar range bin is problematic. In this paper, we extend the Multiple Signal Classification (MUSIC) algorithm to resolve targets moving velocities closer to each other within a given range bin for UWB random noise radar waveforms. Simulated and experimental results are compared for various target velocities using both narrowband (200MHz) and wideband (1GHz) noise radar signals, clearly establishing the unbiased and unambiguous velocity estimations using the MUSIC algorithm."Submitted to Special Session on Noise Radar."

8021-44, Session 9

Generation of noise-like radar waveforms

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An iterative method is described to generate pseudo-random, wide band waveforms for noise radar. The method is aimed to satisfy the conflicting requirements of: (a) good exploitation of the power transmitter by signals with a large (as close as possible to the unit, i.e. the case of the standard phase/frequency coding) peak-to-average power ratio; (b) low power spectral density in bands where other services are present, e.g. navigation or communication; (c) acceptable ambiguity function.

The process to design the waveforms uses an iterative method working in time/frequency domain. It includes the generation of a Gaussian pseudorandom sequences (noise waveforms I, Q). To attenuate the unwanted frequency bands, the noise waveforms are properly filtered then a non-linear processing is applied to optimize the performance of the power transmitter. By evaluation of both the auto-correlation function and the power spectral density, if the sequences do not satisfy the requirements in term of PSL (Peak Sidelobe Level) and the Integrated Sidelobe Level (ISL) as well as of the desired stop bands, the waveforms are again processed and analyzed in time/frequency. The iterative algorithm continues until the requirements are satisfied.

The results have shown that this technique is adapted in order to fit the radar waveform into the allowed frequency channels and also to satisfy the constraints on both the PSL and ISL. Finally the proposed method will be compared with those reported in the literature.

8021-45, Session 9

A technique for the generation of customizable ultra-wideband pseudo-noise waveforms

R. Vela, The Pennsylvania State Univ. (United States); D. Erisman, X-COM Systems (United States); R. M. Narayanan, The Pennsylvania State Univ. (United States)

Noise excitation sources in Radar systems have become increasingly useful in applications requiring wideband spectral responses and covertness. However in applications requiring spectral controllability, traditional analog noise sources prove troublesome and require additional hardware such as set or digital filtration whose own spectral characteristics must also be accounted for. In an effort to reduce these issues and increase the applications of noise waveforms, a technique for generating a fully controllable pseudo-noise waveform will be presented. This technique exploits the phase noise phenomenology associated with single tone waveforms to create a multi-tone waveform whose ΔF is small enough to allow the overlapping of spectral powers. By randomizing the phase angles and setting the appropriate amplitudes to the individual tones, the result is a waveform whose temporal pattern resembles noise and frequency response is broadband . This paper will present this technique's ability through generation of an Ultra-Wideband (UWB) signal whose bandwidth is 2.5 GHz ranging from 2 to 4.5 GHz. Simulated and experimental results will be presented to validate this techniques ability to produce fully customizable broadband waveforms which adhere to UWB characterizations.

8021-46, Session 9

Brillouin precursor waveforms pertaining to UWB noise radar signals propagating through dispersive media

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The electromagnetic (EM) waves propagating through causal, linear, and lossy dispersive media (soil, foliage, plasma, water, biological tissue, etc.), experience frequency-dependent attenuation and phase distortion. This has assumed significant importance for systems operating with ultrawideband (UWB) spectrum. This paper analyzes the dynamical evolution of transmitted signals used by UWB noise radar sensors for dispersive media. The effects on the signal propagation due to the evolution of the Brillouin precursor through dispersive media are discussed."Submitted to Special Session on Noise Radar."

8021-47, Session 9

Mitigation of RF spectrum co-channel interference through the application of noise radar technology

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Today's tactical Army ISR assets are employed in aggressive environments leading to an accumulation of co-use scenarios. In order to mitigate co-channel interference (CCI) between RF ISR systems, operational timelines are actively managed to reduce co-use of spectrum. The recent proliferation of deployable assets has certainly challenged spectrum managers trying to coordinate this dynamic environment. Military assets are forced to conform to receding international spectrum allocations and increasing regulations set forth by the spectrum managers. These constraints reduce tactical capability.

This paper provides an analysis derived from an in-house modeling and simulation effort where results are focused on offering one possible solution to addressing CCI within the RF ISR community. The experimental signal basis is presented, and includes the co-use signal under consideration. Simulation results are extracted from the output of a digital signal processor that has been implemented in software. A comparative analysis presenting the inherent advantages offered by noise radar technology (NRT) as opposed to a conventional radar waveform is illustrated through the range-FFT and the 2D-FFT (range-Doppler map). Probability of detection curves are calculated as a function of relative signal-to-noise (SNR) and illustrate the notional performance expectations for the case when NRT is used. It will be shown that artifacts resulting from CCI are mitigated for the case when NRT is considered. ** Submitted to Special Session on Noise Radar.

8021-48, Session 9

A technique for the extraction of ultra-wideband (UWB) signals concealed in frequency band folded responses

R. Vela, R. M. Narayanan, The Pennsylvania State Univ. (United States); D. Erisman, X-COM Systems (United States)

Ultra-Wideband (UWB) excitation sources in Radar systems has allowed for enhancement in capabilities such as target spectral response, clutter suppression and range resolution. While generation of generic UWB signals has become trivial, direct acquisition, or digitization, of these bandwidths ($\geq$ 4 GHz) is not. To account for this, many UWB Radar systems implement a single or multi-stage band folding technique in the receiver hardware chain which allows for the direct digitization of the UWB waveform at a smaller bandwidth (e.g., 4 GHz into 1 GHz). While lower bandwidth allows for larger than narrowband capabilities, it reduces desired features such as range resolution (e.g., 3.75 cm to 15 cm). In an effort to address this problem, and allow for utilization of full bandwidth of an UWB waveform, this paper will present a signal processing technique which utilizes hardware band folding to wrap a spectrally unique UWB multi-tone waveform into a lower frequency, lower bandwidth signal allowing for both direct digitization and conservation of UWB features. The waveform exploits the phase noise phenomenology associated with single tone waveforms to create a multi-tone waveform whose ΔF is small enough to allow the overlapping of spectral powers resulting in an UWB signal. The signal processing technique utilizes this multi-tone waveform to generate an UWB signal composed of sections whose separate spectral peaks fold into the inner ΔF regions of the previous band. Through reassignment of these peaks, and addition of the original phase noise to the individual frequencies, intended UWB capabilities can be restored.

8021-49, Session 10

SAR imagery using chaotic carrier frequency agility pulses

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Synthetic aperture radar (SAR) systems are getting more and more applications in both civilian and military remote sensing. With the increasing deployment of electronic countermeasures (ECM) on modern battlefields, SAR encounters more and more ECM. The ECM jamming signals cause the SAR system to receive and process erroneous information which results in severe degradations in the output SAR images and/or formation of phony images of nonexistent targets. As a consequence, development of the electronic counter-countermeasures (ECCM) capability becomes one of the key problems in SAR system.

This paper is concerned with developing radar signaling strategies and algorithms that enhance the ability of synthetic aperture radar to image targets under conditions of electronic jamming. The concept of SAR using chaotic carrier frequency agility pulses (CCFAP-SAR) is first proposed. Then the imaging procedure for CCFAP-SAR is discussed in detail. The ECCM performance of CCFAP-SAR for both noise depressive jamming and deceptive jamming is analyzed. The impact of the carrier frequency agility range on the image quality of CCFAP-SAR is also studied. Simulation results demonstrate that, with adequate agility range of the carrier frequency, the proposed CCFAP-SAR performs as well as conventional radar with frequency-stepping waveform (FSW) in image quality and slightly better in anti-noise depressive jamming; while performs very well in anti-deceptive jamming which cannot be rejected by FSW-SAR.

The paper consists of the following sections: 1. Introduction; 2. CCFAP-SAR Signal Model; 3. Image Processing Procedure; 4. ECCM Performance Analysis; 5. Simulation Results; References.

“Submitted to Special Session on Noise Radar.”

8021-50, Session 10

The constructive role of noise in tracing of targets behind wall using SAR

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The ability to identify and localize targets within buildings using exterior sensors offers advantages to the military and law enforcement communities. Recent experiments have shown that RF sensors are an appropriate technology to perform non-invasive detection and estimation through walls. However, wall parameter ambiguities, multipath reflections, clutter, attenuation and measurement noise pose significant challenges to developing robust imaging techniques with synthetic aperture radar (SAR).

In the present work we demonstrate the potential to mitigate these challenges using an adaptive, model-based approach to iterative maximum likelihood estimation. The ray-tracing method is used to simulate the observed data and to model the signals. We examine the effects of measurement and parametric noise on the standard processed SAR image. Measurement noise is randomly generated from a zero-mean Gaussian distribution and added to the received spatial and spectral samples. The parametric noise is manifested during the observation using a multiplicative alteration of the material constants depending on the position. Our results indicate the onset of a parametric resonance effect, whereas the properly tuned parametric noise enhances the performance of the ray-tracing algorithm. Details of the results are given in the full paper.

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8021-51, Session 10

Target discrimination technique utilizing noise waveforms

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Noise waveforms generated using low cost diodes are a simple way for radars to transmit a wideband (> 4 GHz) multi-bit pseudorandom code for use in a cross correlation receiver. This type of waveform also has the advantage of being difficult to intercept and is less prone to interfere with adjacent systems. Radar designed to operate over this wide frequency range can take advantage of unique target Radar Cross Section (RCS) ripple versus frequency for objects of different materials and sizes. Specifically the periodicity and amplitude of the ripple is dependant dependent on the shape and size of a target. Since background clutter does not display this variation, RCS variation determines whether a known target is present in a return. This paper will present the radar hardware and signal processing techniques used to maximize a target’s unique spectral response against a cluttered background. The system operates CW over a 4-8 GHz bandwidth requiring the need to address issues regarding range resolution and far out undesired returns. Lessons learned from field observations and mitigation techniques incorporated in the system are included. This paper also deals with the signal processing technique used for detection, then discrimination. Detection thresholds are set and triggered by a simple correlation peak level. Discrimination involves inspection of the spectral return. A comparison performed in real time to a stored library value determines the presence of known objects. Measured data provided demonstrates the ability of the radar to discriminate multiple targets against multiple backgrounds.

8021-52, Session 10

Design and implementation of random noise radar with spectral-domain correlation for moving target detection

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Random noise radar is known to be able to extract the target range and velocity information by using correlation and Doppler processing. As the number of range bins monitored simultaneously, it is highly needed to adopt digital correlator. A research has been made for the design and implementation of delay-domain digital correlator, where the required resource of digital logics may be an issue. Therefore, an alternative processing algorithm based on a spectral-domain correlation was studied in this paper.

Reference and Rx signals after AD conversion and FFT processing are multiplied. Inverse FFT on the multiplied data yields the sub-correlation results. Considering the maximum estimated Doppler frequency, the successive sub-correlation data can be averaged for enhancing the sensitivity. Now accurate target range and velocity information can be extracted by an additional FFT processing. In this design procedure, specific considerations have to be made such as correlation length, averaging number, and number of sub-correlation data for Doppler FFT processing.

The proposed algorithm was verified by Simulink (Mathworks) simulation, and its logic was implemented with Xilinx FPGA (Vertex5-SX95T) in the Simulink environment with System Generator block sets (Xilinx). An X-band random noise radar with the developed spectral-domain FPGA correlator was designed and implemented for validation check. Lab and field tests have been undertaken to detect moving targets, and the good results showed the validity of the proposed algorithm and the operation of implemented FPGA logic.

“Submitted to Special Session on Noise Radar.”

Return to Contents

8021-53, Session 10

Passive radar imaging of moving targets using distributed apertures

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In recent years, passive radar imaging using transmitters of opportunity has emerged as an active area of research. This research effort is motivated by the increasing number of broadcasting stations, mobile phone base stations, communication and navigation satellites, particular in urban areas, as well as relatively low cost and rapid deployment of receivers. A number of passive moving target detection and imaging approaches have been developed in the literature [1-18]. We present a new passive image formation method for moving targets to determine the distribution of targets in position and velocity spaces using a sparse array of receivers and non-cooperative transmitters.

We develop a new passive measurement model that relates the Doppler as well as the delay information measured at a receiver location to the delay and Doppler information measured at other receiver locations due to a hypothetical moving target in position and velocity spaces. We use the new passive measurement model to address the moving target imaging problem as a position- and velocity-resolved binary hypothesis testing, which has its root in the Generalized Likelihood Ratio Test (GLRT) [19, 20]. The GLRT-based approach provides a particularly suitable framework for the sparse aperture arrays due to limited data available. The test-statistic produced by the hypothesis testing can be viewed as a superposition of filtered, delayed and scaled (or dilated) correlations of measurements at different receivers. We use the position- and velocity-resolved test-statistics to form an image in position and velocity spaces. We analyze the resolution of the reconstructed images under different imaging scenarios including different number of receive elements (receivers) and different types of transmitted waveforms. We present numerical simulations to verify the analysis and to demonstrate the performance of our passive moving target imaging algorithms.

Our passive imaging method has the following advantages: (1) Unlike the existing methods that focuses on the detection of the radial velocity of moving targets [1-16] using specific waveforms available in real world or target radiation, our approach determines the two- or three-dimensional velocity vector as well as two- or three-dimensional position vector of the moving target. (2) As compared to the existing passive radar detection methods, our approach does not require transmitters or receivers with high directivity. (3) Our approach is applicable to both cooperative and non-cooperative transmitters of opportunity.

While our treatment focuses primarily on radar imaging, our method is directly applicable to passive imaging of moving objects in seismic, acoustic and microwave imaging. Additionally, our approach can be extended to imaging of moving targets in multiple-scattering environments.

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8021-54, Session 11

Microwave chaotic oscillator: a device based on three-wave interactions of spin waves in magnetic thin films

M. Wu, A. Hagerstrom, R. Eykholt, B. Kalinikos, Colorado State Univ. (United States)

Nonlinear spin waves in magnetic systems are of both fundamental and technological interest. This presentation reports the excitation of chaotic spin waves in magnetic thin films through three-wave nonlinear processes. The experiments made use of a magnetic yttrium iron garnet (YIG) thin film strip and two microstrip line transducers placed over the YIG strip to excite and detect spin waves. The output signal from the detection transducer was fed back to the excitation transducer through an adjustable microwave attenuator and a linear microwave amplifier. The signal from such a feedback ring was sampled through a directional coupler, with feeds to a spectrum analyzer for frequency analysis and a fast oscilloscope for temporal signal measurements. Experiments were carried out in two regimes. In the first regime, a magnetic field was applied in the plane of the YIG film strip and parallel to the length of the strip, and the excitation of chaotic spin waves was realized through three-wave interactions between backward volume spin waves. In the second regime, a magnetic field was applied in the plane of the YIG strip and perpendicular to the length of the strip. In this case, the chaotic excitation was realized through three-wave interactions between

surface and backward volume spin waves. The development of chaotic dynamics with increasing ring gain was studied. The chaotic nature of the measured signals was confirmed by irregular waveforms, broad spectra, finite correlation dimensions, and decaying auto-correlation profiles. The features of the measured chaotic signals for radar applications were also explored.

8021-55, Session 11

Concept for low-cost chaos radar using coherent reception

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We describe a new approach to random-signal radar based on the recent discovery of analytically solvable chaotic oscillators. These surprising nonlinear systems generate random, aperiodic waveforms that offer an exact analytic representation, allowing the implementation of simple matched filters and coherent reception. Notably, this approach enables nearly optimal detection of noise-like waveforms without need for expensive variable delay lines to store wideband waveforms for correlation. Mathematically, the waveform is expressed as a linear convolution of a bit sequence with a fixed basis function. We realize a simple matched filter for the waveform using a linear filter whose impulse response function is the time reverse of the basis function. Importantly, linear filters matched to finite bit sequences can be defined, enabling pulse compression and spread spectrum radar. We present an example oscillator, its matched filter, and simulation results demonstrating the pulse compression radar concept. Preliminary experimental results using low-frequency electronic circuits are also reported.

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8021-56, Session 11

Nonlinear dynamics method for target identification

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It is known that chaotic signals are very sensitive to filtering. A radar or sonar target may be described as a series of weighted delayed copies of a transmitted signal, essentially an FIR filter. Filtering of a chaotic signal creates a fine structure in phase space, and in this work, I show how comparing the fine structures generated by different filters may be used to identify the filters. This identification method can work with relatively low resolution signals for which the target is only a few wavelengths in size. I demonstrate this identification method with numerical simulations and some simple experiments at 900 MHz.

8021-57, Session 11

Quantum radar versus noise radar

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Recently idea of Quantum Radar (QR) has been suggested and has drawn attention of radar engineers. Exploiting of unique properties of the entangled states of multi-photon (or multi-frequency) electromagnetic field is the basic idea of QR. There is a big hope that these properties will enable to go beyond diffraction limit in range and angular resolutions when using multi-particle radar signals. The second schemes for QR design consist in application of a two-particle state of radar signal, and using one of them as a sounding signal, while the second one as the reference. Information on a target is to be extracted via cross-correlation between the received signal and the reference. In this case, there is one more source of target information may be used, namely: entanglement of photons in polarization states, which give a method to make conclusion on a target via detection of photon polarization changes in the reference channel due to polarization changes in the sounding signal.

The second scheme of QR is formally similar to the scheme of Noise Radar where stationary wideband random signal is used as the sounding one while its copy serves as the reference. In the paper we present some results of comparative analysis of QR and Noise Radar. Common and distinguishing features of these radars have been investigated in details. A possibility of application of nonstationary noise waveforms having correlation between different spectral components (kind of entanglement) is considered in comparison with Noise Radar, as well.

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8022-01, Session 1

Millimeter-wave interferometric radiometry for the detection and geolocation of low-power signals

D. Dowgiallo, E. Twarog, W. Peters, S. Rauen, J. Helmboldt, P. Gaiser, U.S. Naval Research Lab. (United States)

Millimeter wave detection and imaging is becoming increasingly important with the proliferation of hostile mobile millimeter wave threats from both weapons systems and communication links. Improved force protection, surveillance, and targeting will rely increasingly on the interception, detection, geo-sorting, and identification of these sources, such as point-to point communication systems, missile seekers, precision guided munitions, and fire control radar systems. Present electronic warfare systems are not able to detect these threats when they are inactive, but the physical aspects of these systems will still have a signature in passive imagery.

This paper describes the Naval Research Laboratory's demonstration broadband passive millimeter-wave (mmW) interferometric imaging system and provides initial results. In addition to limited active signal detection, our Ka-band system has a goal of detecting the passive signature of non-transmitting systems along with a capability for meter-precision geolocation. Weak signals can be detected by kurtosis-signal processing techniques and spatial isolation to distinguish small radio frequency perturbations from background radiation.

8022-02, Session 1

Progress toward a video-rate, passive millimeter-wave imager for brownout mitigation

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Currently, brownout is the single largest contributor to military rotary-wing losses. Millimeter-wave radiation penetrates these dust clouds effectively, and thus millimeter-wave imaging could provide pilots with a valuable frame of reference during hover, takeoff, and landing operations. Herein, we detail efforts towards a passive, video-rate imager for use as a brownout mitigation tool. The imager presented herein uses a distributed-aperture, optically-enabled architecture that provides real-time, video-rate imagery with a minimal size and weight. Specifically, we will detail phenomenology measurements of brownout environments, show developments in enabling component technologies, and present results from a 30-element aperiodic array that has recently been fabricated.

8022-03, Session 1

Towards high-sensitivity and high-resolution submillimeter-wave video imaging

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Against a background of newly emerged security threats the well-established idea of utilizing submillimeter-wave radiation for personal security screening applications has recently evolved into a promising technology. Possible application scenarios demand sensitive, fast, flexible and high-quality imaging techniques. At present, best results are obtained by passive imaging using cryogenic microbolometers as radiation detectors.

Building upon the concept of a passive submillimeter-wave stand-off video camera introduced previously, we present the evolution of this concept in a practical application-ready imaging device. This has been achieved using a variety of measures such as optimizing the detector parameters, improving the scanning mechanism, increasing the sampling speed, and enhancing the camera software. The image generation algorithm has been improved and an automatic sensor calibration technique has been implemented taking advantage of redundancy in the sensor data.

The concept is based on a Cassegrain-type mirror optics, an opto-mechanical scanner providing spiraliform scanning traces, and an array of 20 superconducting transition-edge sensors (TES) operated at a temperature of 450 mK. The TES are cooled by a closed-cycle cooling system and read out by superconducting quantum interference devices (SQUIDs). The frequency band of operation centers around 350 GHz. The camera can operate at an object distance of 7 to 10 m. At 8 m distance it covers a field of view of 110 cm diameter and achieves a spatial resolution of 1.7 cm and a system NETD of 150 mK at 1 Hz frame rate. The maximum frame rate is 10 frames per second.

8022-04, Session 1

Improved reconstruction and sensing techniques for personnel screening in three-dimensional cylindrical millimeter-wave portal scanning

J. L. Fernandes, Pacific Northwest National Lab. (United States); C. M. Rappaport, Northeastern Univ. (United States); D. M. Sheen, Pacific Northwest National Lab. (United States)

The cylindrical millimeter-wave imaging technique, developed at Pacific Northwest National Laboratory (PNNL) and commercialized by L-3 Communications/Safeview in the ProVision system, is currently being deployed in airports and other high-security locations to meet person-borne weapon and explosive detection requirements. While this system is efficient and effective in its current form, there are a number of areas in which the detection performance may be improved through using different reconstruction algorithms and sensing configurations. PNNL and Northeastern University have teamed together to investigate higher-order imaging artifacts produced by the current cylindrical millimeter-wave imaging technique, using full-wave forward modeling and laboratory experimentation. Based on imaging results and scattered-field visualizations using the full-wave forward model, a new imaging system is proposed. The new system combines a multistatic sensor configuration with the generalized synthetic aperture focusing technique (GSAFT). Initial results show an improved ability to image in areas of the body where target shading, specular reflections, and higher-order reflections occur.

8022-05, Session 1

High-resolution passive video-rate imaging at 350 GHz

D. T. Becker, J. A. Beall, H. Cho, W. D. Duncan, National Institute of Standards and Technology (United States); C. M. Gentry, The Univ. of Oklahoma (United States); G. C. Hilton, K. D. Irwin, P. Lowell, M. D. Niemack, C. D. Reintsema, F. Schima,

R. E. Schwall, K. W. Yoon, National Institute of Standards and Technology (United States); P. A. Ade, C. E. Tucker, Cardiff Univ. (United Kingdom)

Millimeter wavelength radiation holds promise for identification of security threats at a distance, such as identifying suicide bomb belts. The sensitivity provided by superconducting Transition-Edge-Sensor (TES) bolometers makes them ideal for high sensitivity passive imaging of thermal signals at millimeter and submillimeter wavelengths. We are developing a 350 GHz cryogenic passive video imaging system. This demonstration system uses 800 photon-noise-limited superconducting TES bolometers. It will image a 1 m x 1 m area at a standoff distance of 16 m to a resolution of approximately 1 cm at video frame rates (20 frames per second). We will present results of recent optical testing of this system.

8022-06, Session 1

Design and performance of a passive video-rate THz system demonstrator

A. R. Luukanen, M. Aikio, M. Grönholm, M. M. Leivo, A. Mäyrä, A. Rautiainen, H. Toivanen, VTT Technical Research Ctr. of Finland (Finland)

In this paper we present the design and performance of a passive video-rate THz camera intended for stand-off and walk-by concealed weapons and explosives detection. The system builds on previously reported work with substantial improvements in both performance and system operability. The system utilizes a linear array of superconducting antenna-coupled microbolometers, operated in a compact cryogen-free cryocooler. Our present efforts have focussed on improving the performance, stability, set-up time and cost of production of all of the aspects of the camera. The system is designed to acquire near video frame rate (~10 Hz) passive THz imagery of objects at 5 meters from the system, with a field-of-view of 2 m x 1 m, a spatial resolution of 1 cm and a per-frame Noise Equivalent Temperature Difference (NETD) below 0.5 K. The system will be readily integrated to other security systems as it provides encrypted stream of THz imagery over conventional LAN interface that also allows for the remote operation of the system.

8022-07, Session 1

A new approach for fast security scanning with millimetre-waves: SARGATE

S. A. Lang, M. Hägelen, S. Hantscher, Fraunhofer FHR (Germany)

Measuring many people within a short time is still a great challenge to scanners in security related areas, e.g. airports or stations. A new approach for fast and high resolution scanning is presented, based on the so called “circular synthetic aperture radar” (CSAR), applied to a walkway.

To overcome most of the limitations given by a linear aperture and fulfilling the requirements for appropriate measuring in a crowd-flow, a new approach is presented: SARGATE. The first part of this acronym is SAR, which stands for synthetic aperture radar. Second is GATE, which indeed means a gate-like scanner-system, where all people have to pass through, while standing on a moving walkway or moving by themselves.

During the person is passing through, an inner ring of the SARGATE is rotating. This ring carries mounted radar modules, which are acting each in interferometric measurement geometry. Due to the circular movement, each of the receiving antennas creates a circular synthetic aperture itself. By reconstructing the complex valued SAR-images for each receiver channel, the ability to perform InSAR-Analysis of a tested person is given.

This tomography-like measurement in reflection-mode leads to a new way for detecting threats concealed by persons clothing. Weapons, e.g. guns made of metal, can be resolved with a high accuracy, resulting in a high image quality with recognizable threats for security screening. The screened persons do not have to stand still, thus, a measurement in a crowd-flow is possible.

Investigations about the signal theory will be shown as well as first simulation results of different scattering scene-reconstructions.

8022-08, Session 1

Multisensor millimeter-wave system for hidden objects detection by non-collaborative screening

R. Zouaoui, T. Lamarque, C. Romain, Thales Research & Technology (France); C. Checkroun, SART (France); A. Khy, Telecom ParisTech (France)

In the current security airport context, there is a great demand for systems able to detect objects concealed under clothes. In addition to having very good detection performances, these detectors need to operate by requiring minimally collaboration of the passenger and to be respectful of health and privacy.

In this work, we present the development of a multi-sensor system for hidden objects detection using passive and active millimeter-wave (mmW) technologies. This study concerns both the optimization of a commercial passive mmW imager and the development of an innovative active mmW detector.

The envisaged use-case is an ‘on-the-move’ people screening. A first wide-field inspection is done by the passive imager while the person is walking. If a suspicious area is detected, the active imager is switched-on and focused on this area in order to obtain more accurate data (shape of the object, nature of the material ...).

The optimization of the passive detector aims at increasing its depth of field. It relies on the use of a phase mask which is transparent but generates a phase shift over a limited area of the beam. This approach has already been validated in the visible and IR range. We present its extension to the mmW range (94 GHz).

The second part of this paper is dedicated to the presentation of the active detector. It is based on synthetic aperture radar (SAR) and on previous work on automotive adaptive cruise control radar (ACC) at 77 GHz. It gives a detailed image of the object for identification of the threat, and not of the body getting around any privacy issues.

8022-09, Session 1

300 GHz imaging with 8 meter stands-off distance and one-dimensional synthetic image reconstruction

A. Keil, T. Loeffler, H. Quast, SynView GmbH (Germany); V. Krozer, Johann Wolfgang Goethe-Univ. Frankfurt am Main (Germany); J. Dall, A. Kusk, V. Zhurbenko, Technical Univ. of Denmark (Denmark); P. J. I. de Maagt, European Space Research and Technology Ctr. (Netherlands)

We report an active stands-off imaging system operating at 230 - 320 GHz. Imaging is achieved by combining a line array consisting of 8 sources and 16 detectors with a scanning cylindrical mirror system. The stands-off distance is 8 Meter and the effective aperture of the system is 0.5 x 0.5 Meter. Range and intensity information of the object are obtained by an active FMCW (frequency modulated continuous wave) radar operation principle. Data acquisition time for one line is as short as 1 ms. Synthetic image reconstruction is achieved in real-time by an embedded GPU (Graphical Processing Unit).

The contribution will introduce the system concept. In addition we will show first experimental data, of real-time measured line scans of various metallic objects. The date will indicate the spatial resolution of about 2 cm and the range resolution of about 2 mm. Currently the dynamic range is limited to 10-20 dB. We will discuss further developments which are planned in order to increase the dynamic range and to achieve full 3D real-time imaging.

8022-10, Session 1

3D rendering of passive millimeter-wave scenes using modified open source software

M. Murakowski, J. P. Wilson, J. Murakowski, G. Schneider, Univ. of Delaware (United States); C. A. Schuetz, Phase Sensitive Innovations, Inc. (United States); D. W. Prather, Univ. of Delaware (United States)

As millimeter-wave imaging technology becomes more prevalent, several applications are emerging for which this technology may be useful. However, effectively predicting the nuances of millimeter-wave phenomenology on the usefulness for a given application remains a challenge. To this end, an accurate millimeter-wave scene simulator would have tremendous value in predicting imager requirements for a given application. Herein, we present a passive millimeter-wave scene simulator built on the open-source 3D modeling software Blender. In this talk we describe the changes made to the Blender rendering engine to make it suitable for this purpose, including physically accurate reflections at each material interface, volumetric absorption and scattering, and tracking of both s and p polarizations. In addition, we have incorporated a mmW material database and world model that emulates the effects of cold sky profiles for varying weather conditions and frequencies of operation. The images produced by this model have been validated against calibrated experimental imagery captured by a passive scanning millimeter-wave imager for maritime, desert, and standoff detection applications.

8022-11, Session 2

Phenomenology studies using a scanning fully polarimetric passive W-band millimeter-wave imager

B. E. Bernacki, J. F. Kelly, D. M. Sheen, D. L. McMakin, J. R. Tedeschi, T. E. Hall, B. K. Hatchell, P. L. J. Valdez, Pacific Northwest National Lab. (United States)

We present experimental results obtained from a scanning passive W-band fully polarimetric imager. Passive millimeter wave imaging offers persistent day/nighttime imaging and the ability to penetrate dust, clouds and other obscurants, as well as thin layers of clothing and even dry soil. The selection of the W-band atmospheric window at 94 GHz offers a compromise as there is sufficient angular resolution for imaging applications using modestly-sized reflectors appropriate for mobile as well as fixed location applications. The imager is based upon an F/2 off-axis parabolic reflector that exhibits -34 dB of cross polarization suppression. The heterodyne radiometer produces a 6 GHz IF with 2-4 GHz of bandwidth resulting in an NEDT of < 250 mK. Polarimetric imaging helps reveal the presence of man-made objects, including polar solvents, due to their typically anisotropic nature and the interaction of these objects with incident millimeter wave radiation. The phenomenology studies were undertaken to determine the richest polarimetric signals to use for exploitation. In addition to a conventional approach to polarimetric image analysis in which the Stokes I, Q, U, and V images were formed and displayed, we present an alternative method for polarimetric image exploitation based upon multivariate image analysis (MIA). MIA uses principal component analysis (PCA) and 2D scatter or score plots to identify various pixel classes in the image compared with the more conventional scene-based image analysis approaches. Multivariate image decomposition provides a window into the complementary interplay between spatial and statistical correlations contained in the data.

8022-12, Session 2

Impact of polarization and frequency diversity on a terahertz radar's imaging performance

K. B. Cooper, Jet Propulsion Lab. (United States); N. Llombart, Univ. Complutense de Madrid (Spain); R. J. Dengler, B. C. Thomas, P. H. Siegel, Jet Propulsion Lab. (United States)

An all-quasioptical two-beam multiplexing technique has been implemented on the Jet Propulsion Laboratory's 680 GHz, 25 m standoff imaging radar. Normally the two beams scan distinct non-overlapping regions of a target in order to reduce its frame time by half, to ~1 second. But reconfigured to simultaneously focus the two beams onto a single point, coherent polarimetric radar images can be obtained instead. Radar polarimetry at conventional carrier frequencies is well known as a technique to improve the image quality of certain ground targets by enhancing the contrast of some physical characteristics of terrestrial landscapes. However, results from our experiments indicate that terahertz radar polarimetry of persons does not offer a significant improvement for the detection of concealed objects. Additional phenomenological studies were made by swapping a small number of RF components and operating the radar at half of its normal frequency and bandwidth. As expected, we find that there is a clear tradeoff between image resolution and through-clothing penetration at 340 GHz compared to 680 GHz.

8022-13, Session 2

Validation of a small-sample, bi-directional scattering measurement system from 200-500 GHz

D. R. Novotny, J. Gordon, E. J. Heilweil, E. N. Grossman, R. Direen, National Institute of Standards and Technology (United States); B. Stillwell, Univ. of Colorado at Boulder (United States)

We present initial results of a full bi-directional scattering measurement system in the 200-500 GHz range. The goal is to produce a dense-spectrum, bidirectional reflectance distribution function (BRDF) or full bi-static Radar cross Section (RCS) of sample materials and small objects that can be propagated into detection models and used as standard materials to compare performance of various detection and imaging systems. Our multi-axis system is designed to scan the majority of the full 4 pi scattering surface to get a nearly complete measurement of the full scattering nature of the targets. Built upon a frequency domain network analyzer system, it will be calibrated against known and calculable RCS standard target reflectors to determine system quality and maximal loss targets to determine dynamic range.

As we hope that the system will eventually produce archival quality data, efforts will be focused on system accuracy and repeatability. Final, processed data will be compared against a time-domain pulsed system to help determine the data uncertainties of each measurement method

8022-14, Session 2

Pulsed terahertz bi-directional reflection distribution function (BRDF) measurements of materials and obscurants

E. J. Heilweil, A. Lo, D. R. Novotny, E. N. Grossman, National Institute of Standards and Technology (United States)

Very little information exists about the reflection properties of materials in the terahertz spectral region. Since pulsed or active imaging approaches depend critically on the contours, periodicity, and polarization interactions with reflective or obscurant objects, a program to investigate these detailed BRDF properties has been undertaken at NIST. Comparisons between active and passive imaging and extension to lower frequencies using the same samples is underway and will

eventually become the basis for advancing BRDF models. In this talk, a BRDF apparatus design capable of interfacing with an active picosecond pulsed imager (using a large aperture GaAs emitter and electro-optic ZnTe upconverter with CCD detection) is presented. Pulsed measurements for a variety of materials as a function of in-plane incident and reflected angles and frequency will be presented and compared to frequency domain measurements using the same samples.

8022-15, Session 2

Calibration, reconstruction, and rendering of cylindrical millimeter-wave image data

D. M. Sheen, T. E. Hall, Pacific Northwest National Lab. (United States)

Cylindrical millimeter-wave imaging systems and technology have been under development at the Pacific Northwest National Laboratory for many years. This technology has been commercialized, and systems are currently being deployed widely across the United States and internationally. These systems are effective at screening for concealed items of all types, however, new sensor designs, image reconstruction techniques, and image rendering algorithms, could potentially improve performance. At PNNL, a number of specific techniques have been developed recently to improve cylindrical imaging methods including wideband techniques, combining data from full 360 degree scans, polarimetric imaging techniques, calibration methods, and 3-D data visualization techniques. Many of these techniques exploit the three-dimensionality of the cylindrical imaging technique by optimizing the depth resolution of the system and using this information to enhance detection. Other techniques, such as polarimetric methods, exploit scattering physics of the millimeter-wave interaction with concealed targets on the body. In this paper, calibration, reconstruction, and three-dimensional rendering techniques will be described that optimize the depth information in these images and the display of the images to the operator.

8022-16, Session 3

Compressive sampling in passive millimeter-wave imaging

N. Gopalsami, T. W. Elmer, S. Liao, R. R. Ahern, A. Heifetz, A. C. Raptis, Argonne National Lab. (United States); M. Luessi, D. Babacan, A. Katsaggelos, Northwestern Univ. (United States)

We have developed a single-pixel passive millimeter wave imaging system at 150 GHz in which an image is produced by raster scanning the lens with respect to the feed horn. Imaging time with such a system runs into several minutes because of the point-by-point scanning and some integration time needed for good signal-to-noise ratio. By exploiting the sparsity of the image data in a certain transform space, one can reduce the image acquisition time by a factor of 10 or more by a recently developed technique called compressive sensing (CS). The effectiveness of CS has been shown in single-pixel optical imaging wherein digital micro mirrors are used to randomly modulate the spatial light at the image plane. The CS implementation at millimeter wavelength, however, is not straightforward due to the longer wavelength and possible reduction in transmission efficiency when sub-wavelength pixels are used for aperture modulation. We present in this paper a Hadamard mask-based millimeter wave image acquisition and a real-time image reconstruction method which sequentially samples the aperture space until an acceptable image is formed in terms of its subjective and objective quality. The tradeoff between imaging speed and resolution will be discussed.

8022-17, Session 3

Two-dimensional, real-time, sub-millimeter-wave imaging using a spatially selective mask

O. Furxhi, E. Jacobs, The Univ. of Memphis (United States)

In the absence of detector arrays, a single pixel coupled with a spatially selective mask has been shown to be a practical solution to imaging problems in the terahertz and sub-millimeter wave domain. In this paper we demonstrate real-time two dimensional imaging for sub-millimeter waves that is based on a spatially selective image plane mask. The imager consists of a heterodyne source and receiver pair, image forming optics, a spatially selective mask, data acquisition hardware, and image reconstruction software. The optics form an image onto the spatially selective mask and linear measurements of the image are made. The mask must be designed to insure maximum transmission, measurement linearity, and measurement to measurement independence and our supporting analysis of these factors is presented. Once enough linearly independent measurements are made, the image is reconstructed by solving a system of linear equations that is generated from the mask patterns and the corresponding measurements. We show that for image sizes envisioned for many current applications, this image reconstruction technique is computationally efficient and can be implemented in real time. We present images collected using this system, discuss the results, and discuss other applications for some components of the imager.

8022-18, Session 3

Compressive sensing for a sub-millimeter-wave single pixel imager

I. Noor, O. Furxhi, E. Jacobs, The Univ. of Memphis (United States)

In this paper we demonstrate the use of compressive sensing to form a full size image with an image plane random mask and a single pixel sub-millimeter wave receiver. This type of imaging device is a practical solution in domains where focal plane arrays do not exist. The imager consists of a heterodyne source and receiver pair, image forming optics, a spatially selective mask, and data acquisition and post-processing hardware and software. The spatially selective mask modulates the signal measured by the receiver which is then sampled by an analog to digital converter and is post-processed to reconstruct the image. The spatially selective mask can produce image samples at full video rates. The post-processing used for this research consists of a sparseness inducing transformation on the measurements and application of compressive sensing reconstruction algorithms. We show several images acquired and reconstructed using this system. While the data acquisition of this system is real time, the processing currently must be done offline. We comment on the processing requirements that will be necessary to implement compressive image reconstruction in real time.

8022-19, Session 3

A multicamera positioning system for steering of a THz stand-off scanner

M. Axelsson, M. Karlsson, S. Rudner, Swedish Defence Research Agency (Sweden)

Stand-off THz imaging to detect concealed treats is a coming technique for security applications. A THz sensor can provide high resolution 3D imagery of a scene. However, efficient scene scanning and management of the sensor is a challenging task due to the limited field of view of the sensor and physical scanning limitations. A scene scanning subsystem can be added to obtain a complete solution to track and position subjects in the scene and steer the THz sensor to the next point of interest. A scene scanning system can also be utilized for tracking interesting body parts and estimation of the scan completeness of each subject.

We present a scene scanning technique using a multi camera system with 3D positioning capabilities. The 3D positioning is demonstrated on real data acquired from seven HD video cameras. We use a visual hull method where each camera view can provide support for the presence of interesting objects in each part of the scene based on an adaptive Gaussian background model. The presented technique limits the requirements on the scanning speed of the THz sensor and facilitates an efficient scene scanning solution.

8022-20, Session 3

Rapid holographic beamsteering reflectarrays for millimeter-wave and sub-millimeter-wave imaging radars

A. R. Luukanen, VTT Technical Research Ctr. of Finland (Finland); J. Ala-Laurinaho, Aalto Univ. School of Science and Technology (Finland); D. Gomes-Martins, J. Häkli, P. Koivisto, P. Pursula, J. Säily, VTT Technical Research Ctr. of Finland (Finland); A. A. Tamminen, Aalto Univ. School of Science and Technology (Finland); R. Tuovinen, M. Sipilä, VTT Technical Research Ctr. of Finland (Finland)

Recent developments in millimetre to submillimetre-wave imaging radars with excellent ranging resolution provide an attractive route towards stand-off imaging of concealed explosives at ranges up to several tens of meters. Present systems typically rely on only one transceiver, coupled with an optomechanical scanning system for image formation. This limits the image acquisition speed to several seconds/frame. Frame rate can in principle be increased with increasing the channel count but this adds substantially to the system complexity and cost, while only providing a modest speed increase. In this paper we present preliminary designs for rapid electronic beam steering system that could provide a way towards real-time millimetre-wave to submillimetre-wave imaging radars.

8022-21, Session 3

A 220 GHz reflection-type phased array concept study

A. Hedden, C. R. Dietlein, T. Ivanov, D. A. Wikner, U.S. Army Research Lab. (United States)

The goal of this project is enabling light-weight, durable, and portable systems capable of performing standoff detection of person borne-IEDs through the development of millimeter-wave reflection-type phased arrays. Systems operating at mm-wavelengths (MMW) are a favorable compromise between signal penetration of clothing, attenuation, resolution, aperture size, and component availability. However, gains achieved with modest apertures are often offset by the small fields of view dictated by optical systems. Mechanical scanning mechanisms are a typical solution, but they are unsuitable for all applications. Electronic beam steering eliminates the need for complex mechanical scanners and can be implemented at RF frequencies with phased arrays. We present the results of a concept study of a 220 GHz reflection-type phased array that would extend these capabilities to MMW. This work focuses on establishing requirements for effective imaging of the target region including resolution, total beam steering, and number of image pixels achievable. These constraints are considered for a system concept that uses a reflection-type phased array to perform beam scanning of a confocal reflector system. We examine the effects of array architecture on beam characteristics as it is electronically scanned, including directivity, and gaussicity. Resulting benchmark requirements including minimum phase shift increment and response time for the phase shifter elements are determined and compared with the capabilities of several potential phase shifter technologies, including MEMS-based variable capacitor phase shifters developed at ARL and low-loss MMW varactor diodes.

8022-22, Session 3

W-band direct detection radiometers using metamorphic HEMT technology

I. Kallfass, A. Huelsmann, A. Tessmann, A. Leuther, E. Weissbrodt, M. Schlechtweg, O. Ambacher, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

A W-band direct detection radiometer cascading a single-pole four-throw switch with integrated 50 Ohm load as a reference noise source, a 60 dB low-noise amplifier chain, and a broadband Schottky-diode detector is demonstrated. All components are designed and fabricated in 100 nm metamorphic high electron mobility transistor (mHEMT) technology and use waveguide packaging. By using 2 channels of the switch module the Dicke-principle is implemented to drastically reduce the inherent amplifier noise. The multi-throw switch insertion loss is less than 3.5 dB on the chip level and 4.4 dB on the module level. The entire W-band direct detection radiometer chain is also integrated on a single chip and packaged into a waveguide module, which was successfully tested and is now ready for system integration. Fig. 1 shows the discrete W-band radiometer chain as well as the single module substituting all discrete components. The module chain was applied to collect the passive thermal millimeter-wave radiation of an outdoor scene from a Cassegrain antenna with 600 mm aperture, which was moved in azimuth and elevation by angle increments of 0.1° to collect image gray scale pixels as shown in Fig. 2.

8022-23, Session 3

New semiconductor and packaging technologies for small receivers for W-band imaging

J. W. McNicol, P. Rice, MMIC Solutions Ltd. (United Kingdom)

94GHz remains the most suitable band for high resolution near-real-time imaging in defence and security applications. The optical benefits of high frequencies are countered by reduced penetration and by very high component costs. Low cost semiconductor processes with low noise and high gain in the W-band are now becoming commercially available.

Gallium Arsenide GaAs semiconductors have lacked high gain in the W-band, so their use in imaging has required multiple amplifier stages resulting in higher cost. Indium Phosphide semiconductors conventionally offer higher gain at 94GHz, but are not widely available at low cost and are very fragile in manufacturing. New metamorphic HEMT GaAs processes with gate lengths under 100nm are now available with higher gain and at low cost.

This paper reviews the considerations in selecting processes to design amplifiers for W-band imaging, and describes the design and measurement of an amplifier device with high gain per stage ~6dB per stage, and excellent noise figure <3dB at 94GH. It also outlines the design and measurement of a W-band direct detection receiver based on this new semiconductor device, suitable for integration into very small form-factor modules to support into tightly packed 1D and 2D arrays for high resolution imaging.

8022-24, Poster Session

The ethics of body scanners: requirements and future challenges from an ethical point of view

B. Rampp, A. Königseder, H. Schäfer, R. Ammicht-Quinn, Eberhard Karls Univ. Tübingen (Germany)

After being developed for quite some time now, body scanners based on terahertz and millimeter-wave technologies are finally being implemented at airports all around the world. With this implementation under real life

circumstances, social challenges of the acceptance and acceptability of body scanners might become pressing. This is why we want to present the results of an ethical research project on the development and implementation of body scanners. It is shown what requirements concerning the system, its developers, and its users have to be met for the scanners to be acceptable from an ethical point of view. These requirements involve, inter alia, questions of privacy, health, data protection, and security processes.

We will then focus on a special ethical challenge to body scanners: the case of people with body structures that differ from the assumptions of normality, on which body scanners' anonymization processes are based on. These people (e.g. persons with hidden disabilities, diapers, transsexuals, etc.) are affected in a special way by the use of body scanners, because their deviation from the standard (i.e., for instance, their disability) is being exposed by body scanners, even if the produced pictures are anonymized. Having this in mind, we address the question how the possible discrimination against and exclusion of people with differing body structures by the use of body scanners can be prevented.

8022-25, Poster Session

Active THz imaging system to measure water content evolution in leaves

J. C. Iriarte, D. Etayo, I. Palacios, I. Maestrojuan, I. Liberal, A. Rebollo, J. Teniente, I. Ederra, R. Gonzalo, Univ. Pública de Navarra (Spain)

THz waves are sensitive to water content in objects. Therefore quite a lot of systems can benefit from this sensitivity to measure water content or water content evolution. For instance, agriculture sector could minimize irrigation costs and at the same time optimize crops production, by knowing the humidity or the plant. Works have been done showing water content measurements in plants. The work presented in this paper shows the water content evolution of leaves in the range from 0.14 THz to 0.22 THz. Different images of the same leaf have been taken with 48 hours of difference to measure the evolution of water content in the leaf. Transmission and reflection parameters have been measured obtaining frequency and time domain information. The evolution of a leaf in a 48 hours time period measured in transmission has been compared with the visible images before the measurements and after 48 hours. In the visible region the leaf is still green after 48 hours of cutting. Therefore, no appreciable change can be seen in the visible image. However, in the THz image more than 5dB variation can be seen due to the loss of water in the leaf.

As a conclusion, it can be said that imaging in active THz technology can be used to measure the evolution of water content in leafs while no change is appreciable in the visible region. Agriculture quality control systems could benefit from this technology.

8022-26, Poster Session

Investigation of fully-polarimetric signatures from targets with some relevance to security applications

M. Peichl, S. Dill, D. Rudolf, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The actual and continuous threat by international terrorism and the increasing number of terroristic attacks raise the danger to the public and create a new and more complex dimension of threat. This evolution must and can only be combat by the application of new counter-measures like advanced imaging technologies for wide-area surveillance and the detection of concealed dangerous objects, in order to protect the human population and sensitive and important infrastructures.
The observation of a variety of security critical premises, borders, and maritime coastal areas for instance attracts the increasing attention of companies, institutions, and authorities. Hence there is a strong demand on wide-field-of-view imaging for intruder detection under all adverse ambient conditions. Furthermore the imaging of persons for security purposes is of increasing interest particularly for airline and other transportation services or public events with large crowds. Therefore personnel inspection with respect to weapons and explosives becomes an important mean.

Passive microwave remote sensing allows a daytime independent non-destructive observation and examination of the objects of interest under nearly all weather conditions without artificial exposure of persons and observation areas, hence fully avoiding health risks. The penetration capability of microwaves provides the detection of objects through atmospheric obstacles like bad weather, fog or dust, vapour and smoke, as well as through thin non-metallic materials and clothing. For the latter the detection of hidden objects like weapons, explosives, and contraband is possible by monitoring dielectric anomalies. Furthermore the acquisition of polarimetric object characteristics can increase the detection capability by gathering complementary object information. Based on the physical principles of microwave radiometry, images have a quasi-optical appearance simplifying the image interpretation for the operator. In addition, the sensor operation is inherently passive and covert.

The recent development and construction of a fully-polarimetric receiver at W band allows the acquisition of a new dimension of information compared to former imaging capabilities. As presented on the 2010 SPIE Europe conference interesting features can be detected using polarimetric signatures. The new receiver can be part of various imaging systems used at DLR over the years. This paper will show some imaging results recorded recently from different scenes. Interesting phenomena will be introduced and discussed with respect to their relevance for security applications.

Return to Contents

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8023-01, Session 1

Toward realizing high-power semiconductor terahertz laser sources at room temperature

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 GaAs/AlGaAs based THz Quantum Cascade Laser (QCLs), with maximum operating temperatures close to 200 K (without magnetic field). However, higher temperature operation is severely limited by a small LO-phonon energy (~ 36 meV) in this material system. With a much larger LO-phonon energy of ~ 90 meV, III-Nitrides are 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. Alternatively, recent demonstration of InP based mid-infrared QCLs with extremely high peak power of 120 W at room temperature opens up the possibility of producing high power THz emission with difference frequency generation (DFB) through two mid-infrared wavelengths.

This talk will present the latest improvements in material and device engineering, GaN-based or InP-based optoelectronic devices which hold the prospect for compact THz laser sources operating at room temperature.

8023-02, Session 1

Large area THz emitters

G. H. Döhler, Max Planck Institute for the Science of Light (Germany) and Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); S. Preu, Univ. of California, Santa Barbara (United States); S. Malzer, Max Planck Institute for the Science of Light (Germany); L. E. García Muñoz, B. Andres Garcia, Univ. Carlos III de Madrid (Spain)

Conventionally, optically driven semiconductor THz sources emit electromagnetic radiation via an antenna, fed by a THz current, originating from absorption of laser pulses or of two CW laser beams differing by a THz beat frequency (“photomixing”). Small (lateral) device dimensions in the range of < 10 µm are required to minimize the RC roll-off. This implies that all laser power has to be focused onto a very small area. Hence, the maximum achievable THz power is limited by screening effects (in the case of pulse) and by the highest tolerable thermal load (in the case of CW excitation).

Recently, record THz intensities have been reported for pulse excitation in “large area emitters” (LAEs). Here, the THz emission results directly from the coherent acceleration and deceleration of carriers generated within an illuminated area of dimensions comparable with THz wavelengths, subjected to a uniform (in-plane) electric field. The large area allows for about 2 to 3 orders of magnitude higher total laser power, before screening or thermal breakdown become a problem. Moreover, the coherent emission implies a high directionality of the radiation, when the dimensions of the LAE exceed the THz wavelength. This allows for efficient outcoupling of the THz beam of the semiconductor substrate without the need of silicon lenses.

In this talk we outline the basics of LAEs, in particular regarding emission pattern and conversion efficiency. A simplifying analytical model and realistic numerical simulations will be presented. The results quantitatively explain the recently reported record THz power. Implications for CW LAEs are discussed.

8023-03, Session 2

Terahertz light amplification by stimulated emission of radiation from optically pumped graphene

T. Otsuji, S. A. Boubanga Tombet, A. Satou, Tohoku Univ. (Japan); V. Ryzhii, Univ. of Aizu (Japan)

[Invited] Graphene is a one-atom-thick planar sheet of carbon atoms that are densely packed in a honeycomb crystal lattice. The gapless and linear energy spectra of electrons and holes lead to nontrivial features such as negative dynamic conductivity in the terahertz (THz) spectral range, which may lead to the development of a new type of THz laser. This paper reviews recent advances in terahertz light amplification by stimulated emission of radiation from optically pumped graphene. Possibility of terahertz negative dynamic conductivity is first described. We experimentally observe fast relaxation and relatively slow recombination dynamics of photogenerated electrons/holes in an exfoliated graphene on SiO_2/Si substrate under pumping with a 1550-nm, 80-fs pulsed fiber laser beam and probing with the corresponding terahertz beam generated by optical rectification in a nonlinear electro optical sensor. The time-resolved electric-field intensity originating from the coherent terahertz photon emission is electro-optically sampled in an total-reflection geometry. The comparison of terahertz electric fields intensities measured on SiO_2/Si substrate and that one from graphene clearly indicate that graphene sheet act like an amplifying medium. The Emission spectra agrees relatively well the pumping photon spectrum and its dependency on the pumping power shows a threshold like behavior, testifying the occurrence of the negative conductivity in the THz spectral range and the population inversion. The threshold pumping intensity is in a good agreement with simulations.

8023-04, Session 2

Modeling electron transport coherence in one- and two-well terahertz step well quantum cascade structures with diagonal optical transitions

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A density matrix and tight binding model along with a Monte Carlo approach are used to model electron transport in one and two-well terahertz (THz) step well quantum cascade structures. Two structures were analyzed, a multi-step one-well structure and a principally two-well structure. Both of these structures use a diagonal optical transition for improved upper to lower lasing state lifetime ratio and feature a step well injector to provide near unity injection efficiency due to the spatial separation of the wavefunctions. Fast intrawell electron longitudinal optical (LO)-phonon scattering is used to depopulate the lower lasing state which does not require the use of resonant tunneling. Density matrix Monte Carlo simulations are used to analyze these structures in order to investigate these properties. In these simulations LO-phonon, electron-electron, impurity, and interface roughness scattering are included and treated semiclassically, while also contributing to dephasing scattering. A phenomenological dephasing time is also included to investigate the influence of dephasing on the electron transport within these structures. Subband populations, electron temperatures, optical gain, and current density are extracted from the simulations. The analysis indicates that it is necessary to include incoherent transport dephasing in order to provide realistic estimates of the transport process because the transport is primarily dominated by transitions between weakly coupled states. In addition, this analysis shows these simplified step well structures are capable of yielding high optical gain ~ 80 cm 1 while at the same time expected to have relatively low threshold current densities |e|j ~ 380 A/cm2.

8023-05, Session 2

Combining backwards wave oscillator and solid state frequency multipliers to extend spectral coverage of electronic sources to 2.2 THz

W. C. Hurlbut, V. G. Kozlov, Microtech Instruments, Inc. (United States)

Millimeter wave sources in the 100-300 GHz spectral range have been used by the global research community for 2-3 decades. Generating up to 100 mW of power coupling these devices to solid state multipliers and optimizing output coupling efficiency has demonstrated that much more power can be extracted from a BWO by improving the output impedance matching. By impedance matching the multipliers and BWOs one can improve conversion efficiency from the 10 % at low frequencies or the .01-1% at higher frequencies by a factor of two on average. In some cases the matching comes close to 100% conversion efficiency at a few specific frequencies. The hybrid systems also generate fairly smooth coverage across the tuning range as multipier peak efficiency occurs at the BWO drop off point. All of this indicating that the poor impedance matching between free space and the BWO internal cavity results in their typically spiky power spectra. With the additional continued development of nonlinear solid state diodes in frequency multipliers we have developed several different product lines of millimeter wave BWO/multiplier hybrid sources covering from .1 THz to 1.5 THz, .18 to 2.2 THz and .2 to 1.1 THz. We have demonstrated that sub-millimeter wave BWO's can also be extended by tripling the 500-710 GHz QS1-710 BWO to the 1.6 to 2.1 THz range doubling the available power to as much as 20 uW from the power level in the QS1-260-2100 MMW BWO/hybrid. Combined with improvements in Golay cell detectors this enables more powerful spectroscopic and imaging instruments.

8023-06, Session 2

Terahertz detection by field effect transistors (FETs) for THz imaging

W. M. Knap, Univ. Montpellier 2 (France)

Nonlinear properties of the plasma/electron gas in the nanometer transistors channel can be used for the rectification and detection of THz radiation[1]. The resonant excitation of plasma waves by sub-THz and THz radiation was demonstrated for short gate transistors at cryogenic temperatures. At room temperature plasma oscillations are usually over-damped, but the FETs can still operate as efficient broadband/nonresonant detectors in the THz range.. In this work we review the most important results concerning the physics and applications of FETs as Terahertz detectors [1]. We present two experiments showing that the physical mechanisms of THZ detection by FETs is effectively related to twodimensional plasma: i) dependence of THz detection by Silicon-CMOS as a function of the gate length and ii) influence of high magnetic fields on the Terahertz detection in InGaAs - HEMTs. We also show first results on THz imaging by Si-CMOS at frequencies above 1THz.

[1] W. Knap, M. Dyakonov, D. Coquillat, F. Teppe, N. Dyakonova, J. Łusakowski, K. Karpierz, G. Valusis, D. Seliuta, I. Kasalynas, A. El Fatimy, T. Otsuji, "Field Effect Transistors for Terahertz Detection: Physics and First Imaging Applications", J. Infrared Milli Terahz Waves 30, 1319 (2009).

8023-07, Session 2

The effects of individual subband electron temperatures in terahertz quantum cascade laser predictions

P. Slingerland, C. S. Baird, R. H. Giles, Univ. of Massachusetts Lowell (United States)

Quantum cascade lasers (QCL's) are a lightweight and portable alternative to traditional laser systems which can emit in the terahertz frequency range. Despite their promising performance, QCL's are not yet optimized for many applications partly due to their poor performance above 200 K. However, with improved understanding of the carrier dynamics, more accurate computational models can be created and better performing QCL's can be built. One widely used model is the self-consistent carrier transport model. An essential element of this model is an average electron temperature which is used to improve the accuracy of calculated scattering rates and populations. However, an average electron temperature assumes there is little variation between the subband temperatures. This assumption has been investigated with respect to how well it represents the carrier dynamics and the effect of using a separate temperature for each subband on the scattering rates and populations has been studied.

8023-08, Session 2

Active layer design of GaN-based quantum cascade lasers

H. C. Chou, A. F. M. Anwar, Univ. of Connecticut (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States)

Quantum Cascade Lasers (QCL) operating at THz frequencies have been demonstrated using GaAs/AlGaAs and InGaAs/InAlAs heterstructures. SiGe/Si heterostructures, being non-polar, also offers an attractive alternative. SiGe/Si with the dominant phonon mode of 64meV offers a larger THz frequency window than its GaAs or InGaAs counterpart with a LO-polar optical phonon energy of 36meV. The rather low LO-phonon energy of 36meV which is comparable to the room temperature thermal energy of 26meV restricts the use of GaAs-material system to low temperatures. With the LO-phonon energy comparable to thermal energy restricts depopulation of the lower lasing state due to thermal excitation of electrons from the ground state to the lasing state. GaN, on the other hand, with LO-phonon energy of 90 meV offers an attractive alternative making possible the realization of QCL operating at room temperatures. In this talk we will present the active layer design of GaN-based QCL by taking into account the electric field induced due to polarization field and applied potential. We will report the transition times between lasing states and their dependence upon active layer design.

8023-09, Session 3

A real-time terahertz imaging system consisting of terahertz quantum cascade laser and uncooled microbolometer array detector

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Communications Technology (Japan); N. Oda, M. Sano, S. Kurashina, M. Miyoshi, K. Sonoda, H. Yoneyama, T. Sasaki, NEC Guidance and Electro-Optics Division (Japan)

[Invited] Terahertz imaging has attracted much attention in recent years, because the technique can be applied to many application fields such as nondestructive analysis and imaging method through opaque materials. A terahertz real-time imaging technique (Terahertz Camera) considered increasingly important in the future has been developed. The terahertz camera consists of a light source (Terahertz quantum cascade laser) and an un-cooled micro-bolometer array, which can easily get real-time image. As an application of the terahertz camera, a stand-off imaging system that could be useful in a fire disaster relief and a label-free bio-materials detection system have developed and demonstrated.

For a real-time terahertz video acquisition, high-intensity illumination must be needed, if un-cooled detector is used. Because a spectral radiance of 300K-black-body in the terahertz range is about 2 or 3 orders of magnitude smaller than those in the mid-IR range. In the mid-IR range, 300K black body emits enough power to detect by using an un-cooled micro-bolometer array. So, it is not necessary to use external light sources in the mid-IR range.

For the purpose of external light sources in the terahertz range, a liquid-nitrogen-cooled compact terahertz quantum cascade laser system has been developed. The system emits a few micro watts as an averaged output power and operates for few hours. The emission power is enough for the improved un-cooled micro-bolometer array. The sensitivity of the un-cooled micro-bolometer has been improved by changing a sheet-resistance of an absorption layer,anti-reflection coating of a window of a device-package, etc.

8023-10, Session 3

Defect engineering of photovoltaic substrates using THz imaging

R. Leitner, T. Arnold, M. De Biasio, Carinthian Tech Research AG (Austria)

Defect engineering of photovoltaic substrates is currently done using photo- or electroluminescence and thermography. Defects as cracks and local shorts can be detected by locally increased luminescence or temperature, but dotation errors, changes in dotation concentration and contaminations are difficult to monitor. It has been shown that terahertz radiation can be used to image electrical defects (opened and shorted transistors) in semiconductors [Yamashita 2008, Kawase 2004]. We demonstrate the feasibility of a contact-free defect imaging using time-domain terahertz measurements on photovoltaic substrates in the range of 0.1 to 2.4 THz. The used terahertz time-domain spectrometer comprises a 100fs fiber laser operating at a wavelength of 780nm and 110mW. A photoconductive ZnTe antenna was used as terahertz emitter together with a ZnTe detector crystal and a mechanical delay stage. The terahertz radiation was focused respectively collected using parabolic gold mirrors. Images were produced using a (200x200) mm^2 XY scanning stage. The results of the terahertz measurements are compared to the results of state-of-the-art inspection approaches using photo- and electroluminescence and also thermography. The comparison shows that additionally to the other methods also defects caused by local dotation errors and contaminations of the substrate can be detected using the proposed terahertz imaging. In the future two topics will be investigated further: (i) we plan to extend the measurements beyond 2.4 THz by flooding the measurement chamber with dry-nitrogen and (ii) analyse the properties of the p-n junction using the proposed THz imaging spectroscopy.

8023-11, Session 3

Video-rate uncooled microbolometer-based THz imaging camera

M. Bolduc, L. Marchese, M. Terroux, B. Tremblay, H. Oulachgar, M. Doucet, L. Le Noc, C. Alain, H. Jerominek, A. Bergeron, INO (Canada)

A modified uncooled microbolometer-based 160X120 pixel array THz camera with nominal pitch of 52 micron equipped with a semi-custom fast THz objective has been developed at INO [1]. Several techniques have been studied to extend the INO VOx-based infrared microbolometer technology into the THz region [2]. Metallic absorber films deposited at a specific thickness onto the detector array permitted to maximize broad range THz absorption. The detector array is sealed with a HRFZ-Si window having an optimized anti-reflective coating of Parylene. The THz objective consists of two HRFZ-Si aspheric lenses again with Parylene coating on both sides of each lens. In order to account for a displacement of the nominal image plane, a compensation mechanism is used to focus the image of an object at distances ranging from 30 cm to infinity. The unique and compact resulting THz imaging camera provides high sensitivity with good image quality. Real-time transmission and reflectance THz imaging at video rates up to 60 frame/s were performed with a low-power 3 THz QCL laser [3-4]. The noise-equivalent-power (NEP) was also measured. Various hidden objects were imaged, proving feasibility of real-time THz imaging in defense and security screening applications while offering a promising solution for stand-alone imaging systems

[1] T. Pope et al., Proc. SPIE 7311 (2009) 73110L.

[2] H. Oulachgar et al., J. Infrared. Millimeter Waves (In press).

[3] L. Marchese et al., Proc. SPIE 7671 (2010) 76710Z.

[4] M. Bolduc et al., J. Infrared. Millimeter Waves (In press).

8023-12, Session 3

Concealed object detection with multichannel passive millimeter-wave imaging and multivariate Gaussian mixture modeling

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

Passive MMW imaging can create interpretable imagery on the objects concealed under clothing. In this paper, we address the multi-level expectation maximization (EM) method to detect concealed objects captured by multi-channel passive millimeter wave (MMW) imaging.

A multi-channel passive MMW imaging system operates at the 3 mm regime with horizontal and vertical linear polarization. Image registration and segmentation are performed to detect concealed objects under clothing. The registration is preceded to align different channel images by means of geometric feature extraction and a matching process. We utilize the multi-level EM method to separate the concealed objects from the other area in the image. In the experiments, the performance is evaluated by the average probability of error. It will be shown that consecutive EM processes produces better outputs than the conventional EM method by means of the multi-channel passive MMW imaging and multi clustering with Gaussian mixture modeling.

8023-13, Session 3

Active THz imaging and explosive detection with uncooled antenna-coupled microbolometer arrays

F. Simoens, J. Meilhan, S. Pocas, V. Goudon, G. Lasfargues, J. Lalanne-Dera, F. Guellec, B. Dupont, T. Maillou, Commissariat à l'Énergie Atomique (France); O. Cathabard, S. Barbieri, Univ. Paris 7-Denis Diderot (France)

Spectral signatures of solid materials in the THz range can provide spectroscopic information for chemical identification. Previously we have demonstrated the absorption coefficient extraction by scanned imaging of QCL THz beams attenuated through explosive samples. The detection was achieved by a unique pixel addressed within an uncooled antenna-coupled microbolometer 160x120 array specifically designed for the 1-5 THz range. This detector technology developed at CEA-LETI relies on amorphous silicon bolometer know-how and aims at opening the way to real-time video rate, with potential low cost.

We report complementary tests of imaging in reflection configuration and the first tests of a second prototype where 320x240 bolometers are monolithically processed above a CMOS read-out circuit.

8023-14, Session 3

Development of an 80 x 64 pixel, broadband, real-time THz imager.

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The widespread adoption of THz based applications has been hindered by the lack of a real-time, broad-band, cost-effective THz camera with sufficient sensitivities to enable applications in markets as diverse as security, non-destructive evaluation, and biomedical applications. In order to fill this technological gap, large format 2D focal plane arrays (FPAs) with highly sensitive detection elements must be developed that can easily integrate directly to CMOS circuits. Traycer Systems has filled this technological gap with the development of an 80 x 64 pixel array of InGaAs heterostructure backward diodes (HBDs) monolithically integrated to broadband (500 GHz - 900 GHz) antennas. The excellent diode output voltage response allows for the direct coupling of the FPA to CMOS electronics without the need for low noise amplifiers which make the construction of 2D arrays difficult, add electronic noise to the signal, and must be designed around a single frequency. A technique has been developed to directly flip-chip Traycer's FPA to a voltage-mode readout integrated circuit (ROIC) provided by New Imaging Technologies to readout data at video rates (30 Hz). This merger of the Traycer's high sensitivity THz FPA with New Imaging Technologies ROIC allows for broadband, real-time THz image acquisition necessary for large scale THz application development. Noise power and responsivity measurements will be presented.

8023-15, Session 3

Broadband sub-millimeter-wave amplifer module with 38dB gain and 8.3dB noise figure

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Broadband sub-millimeter wave technology has received significant attention for potential applications in security, medical, and military imaging. Despite theoretical advantages of reduced size, weight, and power compared to current millimeter-wave systems, sub-millimeter-wave systems are hampered by a fundamental lack of amplification with sufficient gain and noise figure properties. We report on the development of a sub-millimeter wave amplifier module as part of a broadband pixel operating from 300-350 GHz, biased off of a single 2V power supply. Over this frequency range, > 38 dB gain and < 8.3 dB noise figure are obtained and represent the current state-of-art performance capabilities. The prototype pixel chain consists of two WR3 waveguide amplifier blocks, and a horn antenna and diode detector (developed by Virginia Diodes Inc. (VDI)). The low noise amplifier Sub-Millimeter-wave Monolithic Integrated Circuit (S-MMIC) were originally development under the DARPA SWIFT and THz Electronics programs and are based on sub 50 nm Indium Arsenide Composite Channel (IACC) transistor technology with a projected maximum oscillation frequency fmax > 1.0 THz. This development and demonstration may open future sub-millimeter-wave and THz applications such as solutions to brown-out problems, ultra-high bandwidth satcomm crosslinks, and future planetary exploration missions to life.

8023-16, Session 3

Sensitive water concentration mapping in thin fresh tissues using tunable THz-wave parametric oscillator

Y. Wang, M. Tang, T. Notake, K. Nawata, H. Ito, H. Minamide, RIKEN (Japan)

Water is known to play an important role in the function of biochemistry reactions and biological system. Pathological and histology changes of biotissues are closely consistent with the water concentration changes. Therefore, it is clear that the possibility of determining the water concentration of biotissue would be of great help in addressing many biological, medical and diagnosis research questions. THz-wave is very sensitive to water, which makes it a viable tool for water concentration measurement. However, owing to the severe attenuation of terahertz radiation in samples with high water content, it creates huge challenges for fresh tissue measurement. In previous reports, dehydrated tissue or low temperature cooled tissue were used, which require specific sample process and can't obtain water information.

In this study, a novel sample preparation approach is performed to effectively preserve tissue freshness at room temperature. Sensitive water concentration measurements in thin animal tissue samples have been done using tunable monochromatic THz-wave parametric source. Through repeated transmittance spectroscopy and imaging measurement, it is found that transmittances of thin fresh tissue almost keep constant in 70minutes with a standard deviation of less than 1%. Stable water two-dimensional mapping for biotissue is demonstrated experimentally during a relative long time. These results suggest the method of water volume concentration and distribution measurement using THz-wave has good stability with proper sample preparation, which has great potential in the fields of medical and biological diagnosis.

8023-17, Session 4

Frequency-agile terahertz-wave sources and applications to sensitive diagnosis of semiconductor wafers

H. Minamide, H. Ito, RIKEN (Japan)

[Invited]Applications using terahertz (THz) waves have been proposed and developed based on their excellent features: good transparency for non-polar materials, lack of induced ionization, and fingerprint spectra of phonon or collective vibration in the THz-wave region. Particularly, the THz-wave region from sub-THz to 3 THz has been emphasized because it is a conspicuous region highlighting THz-wave characteristics.

However, fingerprint spectra of various materials extend into a wider THz-wave region, with modes differing from those in the infrared optical region: phonon, plasma vibration, and other collective vibrations. Using nonlinear optical wavelength conversion, we have been developing ultra-widely tunable THz-wave sources to exploit the wide THz-wave frequency range. We propose THz-wave generation using organic nonlinear optical crystals such as 4-dimethylamino-N-methyl-4-stilbazolium tosylate (DAST) and N-benzyl-2-methyl-4-nitroaniline (BNA). The THz-wave difference frequency generation using these crystals covers the ultra-widely tunable range of 0.1-40 THz with frequency agility. The frequency can be switched randomly within about 1 ms.

These progressive THz-wave sources are applicable for various fundamental science, industrial inspection, security sensing and imaging tasks. Collaborating with Furukawa Co. Ltd., we used a frequency-agile THz-wave source for industrial applications and produced a sensitive, non-destructive method for examining carrier-density and electrical properties of semiconductors. It provides at least one order higher accuracy in carrier-density measurements than conventional

methods such as Hall-effect measurements do; the mapping of property distributions using THz waves provides effective estimation for additional processes. This method presents novel possibilities for use in the semiconductor industry.

8023-18, Session 4

Optimized THz emission from intrinsic Josephson junctions

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A brief survey of the electromagnetic spectrum shows that nearly every wavelength from dc to x-rays routinely benefits today's society with one exception: the THz or sub-millimeter band. We propose to develop a new THz source technology using a novel application of superconductive Josephson junctions that directly addresses many of the critical barriers for utilization of the THz spectrum. Recent experimental and theoretical studies have shown definitively that Josephson junctions, micron-scale structures made of high temperature superconductors, can be made to directly generate and strongly interact with THz signals. As solid-state devices, they offer distinct advantages over every other competing technology: compactness, high-efficiency, tunability, scalability to high power (as sources), and low power consumption. A Josephson junction is essentially two superconductors separated by a very thin insulating layer. A DC voltage applied across a properly designed junction causes it to oscillate and emit (or interact) with electromagnetic radiation, with frequency proportional to applied voltage. If many junctions can be co-located within a radiation wavelength, it is possible to synchronize oscillations and generate mW-levels of power. Outcoupling of usable power critically depends upon junction geometry and its interface to substrate and to neighboring metallic pads. We present a feasible geometry and approach using BSCCO material which 1.) optimizes radiation power, 2.) enables frequency tunability by avoiding the use of cavity resonance effects, 3.) allows for removal of waste heat, and 4.) provides for a shunt capacitance that tends to stabilize junction synchronization. We will report on initial and on-going experiments.

8023-19, Session 4

Intracavity terahertz generation from gallium arsenide in a fiber laser pumped type 0 doubly resonant optical parametric oscillator

W. C. Hurlbut, V. G. Kozlov, Microtech Instruments, Inc. (United States); K. L. Vodopyanov, Stanford Univ. (United States); P. F. Tekavec, Microtech Instruments, Inc. (United States)

By inserting a periodically-inverted GaAs structure into a high-finesse near degenerate ring-cavity type-0 PPLN (31.78 m period) OPO pumped by a fiber laser we demonstrate tunable narrowband THz-wave generation between 1 and 3 THz. The GaAs samples were made using optically-contacted GaAs wafers held in place by Van Der Waals force. Optimum THz generation was found using PPLN at 151 C. A thin YAG etalon (60 m) is used to set the peak spacing at THz intervals inside the cavity which produced 5 signal and idler line pairs with the THz spacing by dithering a mirror 1 micron. Temporal comparison of the optical spectrum with the THz power generation during slow dithering (<.1 Hz) showed the optimum production was from 2 simultaneous line pairs. We produced circulating power of 75-100 watts from 6.6 W of power by synchronous pumping using a mode locked fiber laser at 1064 nm with a repetition rate of 109 MHz and duration of 10 ps which generated 132 W of power at 1.5 THz from an 11 layer GaAs sample. A 6 layer sample with a 1.57 mm period designed for 1 THz generated 10 W after atmospheric absorption. A 6 mm long diffusion bonded sample with a 504 m period produced 4 W at 2.8 THz using a 1.4 THz line spacing and multiple line pairs. The 15 layer OC-GaAs sample (=1.06 mm)produced 12 W due to the significantly narrowed acceptance band width and lower transparency.

8023-20, Session 4

InP and InGaAs Schottky type terahertz emitter excited at a wavelength of 1560nm

M. Tonouchi, M. Suzuki, K. Serita, I. Kawayama, H. Murakami, Osaka Univ. (Japan)

Efficient TH emitters operative at a wavelength of 1560nm are indispensable for fiver-based compact THz time domain spectroscopy system. Although InGaAs photoconductive antennas can work as THz emitters, the emission band is rather small and emission amplitude is still small. In the present work, we examine InP and InGaAs Schottky type photoconductive antenna for the THz generation at a wavelength of 1560nm. Au PC antennas are fabricated on InP wafer or InGaAs layer. Since InP has an energy gap of 1.3 eV, which is much larger than photon energy of fs laser. For the InGaAs emitters, a half of the layer is removed to bias high field to the PC antennas. We obtained THz wave generation from both PC antennas with sufficient THz amplitude, which is comparative to that of low temperature grown GaAs.

8023-21, Session 5

Terahertz spectroscopy of energetic materials

E. Witko, T. M. Korter, Syracuse Univ. (United States); J. Wilkinson, W. Ouellette, J. Lightstone, Naval Surface Warfare Ctr. Indian Head Div. (United States)

Terahertz (THz) radiation, an electromagnetic wave with its spectrum (0.3 THz - 10 THz) between the infrared and microwave bands, is now an attractive research field in many sectors, especially in defense and homeland security. THz radiation has potential since various materials and substances demonstrate their unique vibrational responses (fingerprints) within the terahertz spectrum. Two other

important features of THz waves are its "see-through" capability, which provides detection of explosives underneath cloth and other packaging materials via the reflection of THz radiation, and it is non-ionizing and safe at the power levels generally available. This presentation provides insight into the practical application of terahertz spectroscopy for remote explosives detection. Our investigations of scattering and absorption from dust and atmospheric moisture will be discussed as well as our observations on spectral differences in THz signatures of explosives due to these external scattering sources. Also, current challenges in populating a THz database for explosives will be discussed in the presentation. These challenges include material quality, purity, and morphology as well as method of manufacture. The method of manufacture is especially important in the THz spectra of home made explosives (HMEs), where polymorphs are often found, in addition to occluded solvents, precursors and high-explosive byproducts. Recent results from our THz explosives signatures database including our HME results will be discussed.

8023-22, Session 5

Terahertz remote sensing

A. V. Kellarev, D. Sheffer, IARD Sensing Solutions Ltd. (Israel)

The subject of this article is implementation of terahertz remote sensing for detection and imaging of concealed objects from distances of several metres. Many materials used for packaging and clothing are partially transparent in the spectral range 0.1 - 10 THz. The transparency property can be utilised to detect objects concealed by the materials, which are often opaque in other spectral regions. This can be achieved by detecting the radiation from these objects through the use of an appropriate detector, which is sensitive at THz frequencies. The radiation from the concealed objects can be either self-emitted or reflected.

The use of THz remote sensing is being pursued in IARD by both theoretical and practical approaches. The article contains a short review

on the detectors, sources and components, which can be used for remote sensing systems operating at THz frequencies, and describes energy calculations and system design considerations. Characteristic and exemplar performance of the components, which are being used in IARD, is presented. The article then describes prototypes of a passive THz radiometer and an active THz system which were built in IARD. Performance characteristics of both systems are described. The results of measurements of the optical properties of various materials, people and combinations of them, which were performed with IARD's THz systems, are presented as well as examples of THz images obtained by the active system.

8023-23, Session 5

The method of the spectral dynamics analysis of reflected signal for problem of identification of substance

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The method of spectral dynamics analysis (SDA-method) is used for detection and identification of substances by reflected THz signal. It allows to obtain the spectrogram and to analyze the dynamics of many spectral lines of the signal by one set of measurements. We discuss an efficiency of SDA method for identification of substance in a mixture of substances, which possess the similar spectra.

We consider the THz pulse with a few cycles. This pulse falls on the PFTE, Sucrose, L-Tartaric Acid and RDX. We analyze the reflected signal by SDA method. Our investigations show that spectrograms and dynamics of several spectral lines allow us to detect the presence of the material in the compound sample. The efficiency of the SDA-method for the problem of the detection and identification by using of reflected pulses is discussed and shown.

8023-24, Session 5

Spectroscopic terahertz imaging for food safety inspection

T. Arnold, M. De Biasio, R. Leitner, Carinthian Tech Research AG (Austria)

Recent developments in THz instrumentation in combination with a better understanding of the mechanisms behind the interaction of THz radiation and materials make THz spectroscopy and in particular THz spectroscopic imaging promising technologies for a wide range of applications. Current THz techniques show great potential e.g. in security screening, medical diagnostics, pharmaceutical quality control and in quality control of food products. As food packaging materials like plastics are transparent for THz radiation, foreign bodies and food additives can be detected and identified through the packaging. The present work describes a laboratory measurement system consisting of a state of the art femtosecond fiber laser based THz time domain imaging spectrometer. The system is used to investigate the possibilities to detect foreign bodies like wood, stone, glass, metal or plastic particles in dry food. Moreover, the chemical composition and moisture content are analyzed. The moisture content is especially a critical value for different kinds of dried food. Due to the close relationship between THz spectroscopy and spectral imaging the existing algorithmic competence was used to analyze the THz spectra. Preliminary results show that THz time domain spectroscopy and imaging is a promising technology for contactless control and analysis of food products even in industrial applications.

8023-25, Session 5

Terahertz imaging with InP high-electron-mobility transistors

T. Watanabe, K. Akagawa, Y. Tanimoto, Tohoku Univ. (Japan); D. Coquillat, W. M. Knap, Univ. Montpellier 2 (France); T. Otsuji, Tohoku Univ. (Japan)

High-electron-mobility transistors (HEMTs) have been shown to be candidates for the realization of suitable detector arrays, because they exhibit a rectifying response to terahertz (THz) radiation via electron-plasma effects.

This perspective is intriguing because it may link the development of THz cameras to mainstream semiconductor technology.

In this work, we confirmed that 50-nm gate-length InP-based HEMTs with a cutoff frequency of 298 GHz work as a terahertz detector of 0.3 THz radiation and demonstrated imaging for leaves and teabag packages with the device.

We performed raster-scan imaging in transmission mode.

The 0.3 THz radiation source is a continuous-wave emitter from Radiometer Physics consisting of a quartz-stabilized Gunn oscillator followed by a 3x multiplier cascade.

The radiation is collimated and focused with parabolic mirrors.

The object-under-test is mounted onto a mechanical stage and raster-scanned in two dimensions through the focus of the THz radiation.

The HEMT, positioned in the focus of a mirror is operated at room temperature without antenna or lens attached to it.

The radiation is guided to the HEMT gate.

The transistor is operated at zero drain current and a gate voltage Vg of -0.92 V.

The source-to-drain voltage ΔVds induced by the THz radiation is measured with the help of a lock-in amplifier (chopping frequency: 540 Hz) with an integration time of 10 ms.

Images are generated from single amplifier readings per pixel without further averaging.

The imaging results show a nice S/N ratio and resolution.

The value of responsivity and NEP are under evaluation.

8023-26, Session 6

Laser terahertz emission microscope

M. Tonouchi, S. Kim, S. Fujiwara, I. Kawayama, H. Murakami, Osaka Univ. (Japan)

[Invited] Recent progress of laser terahertz (THz) emission microscope (LTEM) is reviewed. Femtosecond lasers can excite the THz waves in various electronic materials due to ultrafast current modulation. The current modulation is realized by acceleration or deceleration of photo-excited carriers, and thus LTEM visualizes dynamic photo-response of substances. The developed systems have a scanning speed of 6.5x10-5 sec/pixel, and a minimum spatial resolution better than 0.6 μm, which is defined by the laser beam diameter. We also developed pump and probe type LTEM to visualize spatial dynamic carrier response and applied it to study photoconductive switches. In addition, we will discuss its application to material science, device evaluation, etc.

8023-27, Session 6

Plasmon resonance response to millimeter-waves of grating-gated InGaAs/InP HEMT

N. Nader Esfahani, G. Medhi, Univ. of Central Florida (United States); H. Saxena, Zyberwear, Inc. (United States); C. J. Fredricksen, R. E. Peale, Univ. of Central Florida (United States);

W. R. Buchwald, Air Force Research Lab. (United States); O. J. Edwards, Zyberwear, Inc. (United States)

Tunable resonant absorption by plasmons in the two-dimensional electron gas (2DEG) of grating-gated MOSFETs and HEMTs is known for a variety of semiconductor systems, giving promise of chip-scale frequency- agile THz imaging spectrometers. However, a useful tunable resonant electrical photo-response has been less widely realized [1. Shaner et al. 20xx]. Saxena et al.[2] reported tunable THz absorption lines in InGaAs/InP HEMTs but a possible corresponding electrical response was masked by a large non-linear non-resonant photoresponse that was difficult to subtract due to shot-to-shot intensity variations of the free-electron laser used [3]. In this work, we present measurement of electrical responses to millimeter waves from ultra-stable continuous-wave backward-wave oscillators (BWO) in the range 40-110 GHz for similar InP-based HEMTs. Frequency-modulation of the BWO with lock-in amplification of the source-drain current gives an output proportional to the change in absorption with frequency dA/df, without contribution from non-resonant response. Calculations indicate large dependence in dA/df on gate-voltage and frequency for plasmon resonances at mm-wavelengths, giving an opportunity to demonstrate any resonant electrical response by comparing observations with theory. This is a first step in optimizing such devices for man-portable or space-based spectral-sensing applications.

1. Shaner et al.
2. Saxena et al., J. Appl. Phys. 105, 113101 (2009).
3. Peale et al., Proc. SPIE 7311-17 (2009).

8023-28, Session 6

Absorption spectroscopy of energetic materials using a 0.075 cm-1 resolution Fourier transform spectrometer

E. J. Slingerland, M. K. Vallon, E. G. E. Jahngen, T. M. Goyette, R. H. Giles, Univ. of Massachusetts Lowell (United States); W. E. Nixon, National Ground Intelligence Ctr. (United States)

The absorption spectra of nitromethane, acetone, and TATP were previously reported at a resolution of 0.12 cm-1 [1]. Additional measurements have been performed at a resolution of 0.075 cm-1 to acquire the absorption spectra for nitromethane over path lengths of 2 to 6 meters. Since the goal of this research is to explore absorption frequencies that can be used to identify highly energetic molecules of interest to the remote sensing community, particular attention was paid to the frequency ranges located within the terahertz atmospheric water-absorption transmission windows. The absolute absorption coefficients for each chemical will be reported.

[1] Slingerland, E. J., Vallon, M. K., Jahngen, E. G. E., Giles, R. H., Goyette, T. M., "Terahertz absorption spectra of highly energetic chemicals," in Terahertz Physics, Devices, and Systems IV: Advanced Applications in Industry and Defense, edited by Mehdi Anwar, Nibir K. Dhar, Thomas W. Crowe, Proceedings of SPIE Vol. 7671 (SPIE, Bellingham, WA, 2010). April 2010

8023-29, Session 6

Handheld terahertz spectrometry with the micro-Z

T. D. Tongue, B. J. Schulkin, Zomega Terahertz Corp. (United States); X. Zhang, Rensselaer Polytechnic Institute (United States)

The application of THz sensing and imaging to standoff detection and identification is one of the most challenging and desired research topics. Many energetic, organic and pharmaceutical compounds have their molecular fingerprints and phonon signatures in the terahertz frequency range. However, real-time identification presents several technical challenges before in-the-field applications in security, pharmaceutical and NDE areas can be realized. In this paper, we present the first results of a novel handheld THz Time Domain Spectrometer (the micro-Z), the world's first handheld, tetherless, battery-operated THz TDS platform. The system is evaluated for stand-off real-time detection and identification of 8 selected samples in pressed-pellet, powder, and under cloth cover. In the experiment, the micro-Z was configured for normal-incidence reflection geometry, operating at a waveform acquisition rate of 100 Hz. Samples were placed on a metal mirror for bulk-reflection measurement. Samples were composed of HDPE powder mixed with up to 5% concentration (by weight) of the target compound, and pellets were formed using a 5-ton press, while powders were placed directly on the mirror for measurement. Based on the instrument dynamic range and the strength of the absorption feature for a target compound, we are able to determine the minimum concentration required for detection. For real-time (100Hz) measurement using the micro-Z, concentrations as low as 250µg/cm2 of RDX, 2HBP and 2,4 DNT can be detected. This work also allows us to determine the Relative Operating Characteristic (ROC) curve, which shows the trade-off between false-positive and false negative rates for different acquisition times and sample preparation. Based on measurements acquired at 100Hz and 10Hz, the possibility of stand-off explosive (RDX, PETN, etc.) detection with better than 0.1% false positive rate is discussed.

8023-30, Session 6

Computing methods for THz materials characterization

A. U. Sokolnikov, Visual Solutions and Applications (United States)

Characterization of materials with THz waves is not trivial at the moment. Expensive and often bulky equipment, usually laboratory (rather then portable) set-up realization, possible water content, low depth of penetration, etc. are some typical problems. As a result, the desired characteristics of the material are not reliable and often difficult to obtain. In this situation, computational methods may be helpful in alleviating the above difficulties. In the long run, sophisticated mathematical model building may make THz characterization devices more suitable for field applications, implementing portable THz devices and set-ups as well as minimizing the measurement error without repetitive measurements. The computational methods based on Network Theory are described and results provided

8023-31, Session 6

Demonstration of sweep-and-zoom sensing of RNA and DNA in nanofluidic channels using a THz coherent photomixing transceiver

E. R. Brown, Physical Domains, LLC (United States); E. A. Mendoza, Redondo Optics, Inc. (United States); S. R. J. Brueck, The Univ. of New Mexico (United States)

THz vibrational signatures have been predicted in biomolecular nucleic acids for a long time, and have been observed with FTIR, time-domain-, and frequency-domain spectrometers. However, they are rather weak and often buried in the instrumental noise, sample interference, other "clutter" effects that makes positive identification challenging. In this work, we have combined a nanofluidic-cell technology with a customized coherent (homodyne) photomixing spectrometer to produce a sensor that can sweep broadly in frequency during initial interrogation, and then follow up with a stable, fixed-frequency characterization over time. Key developments reported here for the first time are the THz monitoring of electrophoretic flow in the nanofluidic cell, and a sliding-window matched-filter in the signal processing to notch out the coherent-interference fringe and other standing-wave effects. Experimental results are presented for the strong signature centered around 830 GHz in small-interfering RNA and low-molecular-weight DNA. This signature yields about 10% depth of absorption and a linewidth of roughly 40 GHz in nanofluidic channels having submicron width and height. Over the course of about 10 minutes, a steady increase in electric bias from 0 to 300 V enhances the depth of absorption, and a decrease in bias back to 0 V reverses the THz effect. This is the first known electrophoretic control of a THz signature in nucleic-acid biomolecules.

8023-32, Poster Session

Ground state resonance structure calculated by density functional theory for estimating the dielectric response of the high explosive PETN

A. Shabaev, George Mason Univ. (United States) and U.S. Naval Research Lab. (United States); S. G. Lambrakos, N. Bernstein, V. L. Jacobs, U.S. Naval Research Lab. (United States); D. Finkenstadt, U.S. Naval Academy (United States)

We present calculations of ground state resonance structure associated with the high explosive PETN using density functional theory (DFT), which is for the construction of parameterized dielectric response functions for excitation by electromagnetic waves at compatible frequencies. These dielectric functions provide for different of types of analyses concerning the dielectric response of explosives. In particular, these dielectric response functions provide quantitative initial estimates of spectral response features for subsequent adjustment with respect to additional information such as laboratory measurements and other types of theory based calculations. With respect to qualitative analysis, these spectra provide for the molecular level interpretation of response structure. The DFT software NRLMOL was used for the calculations of ground state resonance structure presented here. A significant aspect of using response spectra calculated by density functional theory, DFT, for the direct construction of permittivity functions is that it adopts the perspective of computational physics, according to which a numerical simulation represents another source of "experimental" data. This perspective is significant in that a general procedure may be developed for construction of permittivity functions using DFT calculations as a quantitative initial estimate of spectral response features for subsequent adjustment with respect to additional information such as experimental measurements and other types of theory based calculations. That is to say, for the purpose of simulating many electromagnetic response characteristics of materials, DFT is sufficiently mature for the purpose of generating data complementing, as well as superseding, experimental measurements.

8023-33, Poster Session

Optimization of plasmonic resonances in the two-dimensional electron gas of an InGaAs/InP high electron mobility transistor

J. W. Cleary, Solid State Scientific Corp. (United States); R. E. Peale, Univ. of Central Florida (United States); H. Saxena, Zyberwear, Inc. (United States); W. R. Buchwald, Air Force Research Lab. (United States)

The experimental observation of plasmon resonances in the two dimensional electron gas (2DEG) of an InGaAs/InP high electron mobility transistor (HEMT) is reported. Excited via incident THz radiation, the properties of these grating based, gate-voltage tunable resonances, observed in the 10-100cm-1 wavenumber range, are shown to be adequately modeled using commercial finite element method (FEM) software when the HEMT layer structure, gate geometry and measured sheet charge concentration are taken into account. The finite element method used is also shown to produce results consistent with standard analytical theories, but is shown to be superior at predicting response when device properties, not specifically accounted for in other analytic methods, are introduced. Optimization of the plasmonic modes based on parameters of the grating structure and layers in the device are explored. The calculational method demonstrated here and confirmed by experiment, has the potential to greatly aid in the design of future detection devices that require specifically tuned plasmonic modes in the 2DEG of a HEMT, as well as giving new insights to aid in the development of more complete analytic theories.

8023-34, Poster Session

Plasmonic parametric oscillator via coupling between optically and electrically induced plasmons

J. Khoury, B. Haji-saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States)

In this paper we propose a plasmonic parametric oscillator based on coupling between optically generated and electrically induced surface plasmon waves. The device can be used for a variety of applications, involving spectrum analysis, widely tunable electromagnetic emitters, heterodyne detection, and amplification. We developed the theoretical modeling using Maxwell's equations. The coupling between the two kinds of plasmons depends on the skin depth of each. The skin depth of an optically generated plasmon is well known, while the skin depth of an electrically induced plasmon vanishes as the grating frequency becomes small or the injected current becomes large.

8023-35, Poster Session

Plasmon modulation using high-frequency current

J. Khoury, B. Haji-saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States)

We have observed a split in plasmon radiation from a nano-grating when a high-frequency current was applied. We have developed Maxwell's equations based on a theoretical model explaining the experimentally observed split. In our theoretical model, it was found that the plasmon frequency is split into the frequency of its sum and its difference with the AC modulation frequency, if the propagation constant is unchanged. The effect essentially creates two plasmon waves with different propagation group velocities. We have designed an ultrafast optical modulator that takes advantage of this effect.

8023-36, Poster Session

An investigation of parallel plate waveguide terahertz radiation input coupling

J. A. Higgins, F. A. Kernan, C. L. Cowen, B. Pejcinovic, Portland State Univ. (United States)

The Parallel plate waveguide (PPW) is an excellent device for material sensing and parameter characterization because of the ease in which they are manufactured, their well-known theory of operation and material-EM field interactions that occur over longer distances than in free space measurements. However, it supports multimode propagation which can result in additional losses. As material sample volume decreases these interactions become weaker and we must increase the field strength inside the PPW to compensate. In this work we present an investigation into PPW radiation input coupling in the terahertz region. PPW coupling methods for both the Transverse Electric (TE) and Transverse Magnetic (TM) modes of operation are investigated using broadband time-domain

Return to Contents

(TDS) and narrowband continuous wave (CW) frequency-domain systems. The TDS system operates in the 0.2 - 2 THz range and the CW operates in the 0.07 - 0.7 THz range. The input coupling methods investigated include: cheap, off-the-shelf cylindrical rod lenses made of High Density Polyethylene (HDPE), 6 degree taper on both plates of the entrance to the PPW and plain flanged PPW. Preliminary results indicate that the 6 degree taper couples more energy into the PPW over a wider range of frequencies than HDPE lenses of equivalent effective aperture size. It is also less susceptible to systematic errors introduced by misalignment. TE and TM modes show similar coupling behavior for all coupling methods. The same output coupling methods are currently under investigation where it is believed that similar performance enhancements will be observed. Measurements will also be compared to finite difference time-domain (FDTD) simulations.

Conference 8024: Advanced Environmental, Chemical, and Biological Sensing Technologies VIII

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8024-01, Session 1

Enzyme detection by surface plasmon resonance using specially engineered spacers and plasmonic labelling

A. Francois, S. Heng, R. Kostecki, T. Monro, The Univ. of Adelaide (Australia)

Surface Plasmon Resonance (SPR) is a powerful label free optical biosensing technology which relies on the measurement of the refractive index or change of mass in close vicinity of the sensor surface. Therefore, there is an experimental limitation in the molecular weight of the molecule that can be detected and consequently small molecules are intrinsically more difficult to detect using SPR. To overcome this limitation, as a rule of thumb, smaller molecules are adsorbed first onto the sensor surface and are followed by their higher molecular weight antibodies counterparts which ensure the specificity. Although this has been demonstrated with some success, it is not applicable in every case. In this paper, we present an alternative method which utilises specifically engineered spacers attached on one end to the sensor surface and on the other end to a nanoparticle which behaves as a plasmonic label. These spacers are design to specifically react with the biomolecule to be detected and release the (relatively large) plasmonic label which in turn results in a measurable SPR shift. As a proof of concept, a novel SPR optical fibre sensor which relies on the measurement of the re-emitted light by surface scattering of the plasmonic wave rather than transmission through the fibre was used to detect an enzyme, chymotrypsine (25kDa) which is involved into intestinal and pancreatic diseases.

8024-04, Session 1

Optofluidic-nanoplasmonic sensors for biochemical detection

H. Altug, A. A. Yanik, M. Huang, A. E. Cetin, Boston Univ. (United States); T. Chang, Massachusetts Institute of Technology (United States); A. Artar, Boston Univ. (United States)

Label free biosensors are offering a rapid way to detect biomarkers and pathogens, and to determine the kinetics of biomolecular interaction. In particular, nanophotonic biosensors based on resonances are taking significant attention for detection of low concentrations of analytes with large multiplexing capabilities and signal-to-noise ratios. However, performances of surface biosensors are often controlled by the analyte delivery rate to the sensing surface instead of sensor's intrinsic detection capabilities. For biosensors integrated with conventional microfluidic channels, analyte transportation to the sensor surface by diffusion severely limiting the performance. At low concentrations, this limitation known as mass transport limitation causes impractically long detection times. Previous approaches based on stirring and mixing strategies resulted in moderate performance improvements. One of the main conceptual constraints so far is that microfluidics and biosensing are always considered as different parts of a sensor platform rather than a fully merged single entity. In this talk, we demonstrate a new biosensing platform merging nanophotonics and nanofluidics. Unlike conventional approaches where the analytes simply stream pass over the surface, our optofluidic-plasmonic sensor enables active delivery to the sensing surface. Our platform utilizes suspended nanohole arrays supporting plasmonic resonances. The nanoholes also act as nanofluidic channels connecting the fluidic chambers on both sides of the sensors. Using our platform, we show 14-fold increase in mass transport rate constant appearing in the exponential term. Such an improvement means superior analyte delivery to the biosensor surface and dramatically improves sensor response time at low concentrations.

8024-10, Session 1

An optical biosensor using MEMS-based V-grooves

Y. Tian, X. Ma, N. Wu, X. Zou, K. Sun, X. Wang, Univ. of Massachusetts Lowell (United States)

An optical biosensor featuring miniature size, low cost, and immunity to electromagnetic interference is presented. The FP cavity was formed by aligning two metal-deposited single-mode optical fiber endfaces within a microchannel in a silicon chip. The mirror upon the fiber endfaces were thermal-coated metal films in order to get high finesse and therefore high sensitivity. The microelectromechanical systems (MEMS) techniques are applied to precisely control the shape and the depth of the microchannel on the silicon chip. During the biotest, the biotin-terminated thiol molecule (5mM in PBS) is firstly immobilized on the gold surface. Subsequently, the molecules of Neutravidin (0.15 mg/ml in HEPES/NaCl, pH 7.4) are specifically bound to the biotin-terminated self-assembled monolayers (SAMs). The refractive index change of the bonded layer upon the gold surface leads to an optical path change of the FP cavity, which is detected by demodulating the transmission spectrum phase shift. The sensitivity and finesse of the transmission spectrum are conveniently controlled by adjusting the cavity length and the metal deposition thickness. By taking advantage of MEMS technology, the sensor has the potential to be manufactured repeatedly with a high yield, and multiple sensors can be integrated into one small silicon chip for detecting various biomolecule targets simultaneously.

8024-03, Session 2

Interaction of stochastic electromagnetic beams with human eye

S. Sahin, O. Korotkova, Univ. of Miami (United States)

In majority of the cases optical fields received by a human eye are beam-like, with partial polarization and not perfectly coherent.

Therefore it is of interest to analyze how the major properties of electromagnetic stochastic beams are changed on passing through the eye layers, especially thought its strongest optical element, which is known to be the crystalline lens. Based on one analytical model for the (gradient-index) human crystalline lens we study its interaction with stochastic light beams. To be able to obtain the analytic expressions for light statistics after passage through the lens we employ the generalized Huygens-Fresnel principle in the form of the Collins integral involving the ABCD matrix of the lens.

Recently, two models of the lens, called "plane-parallel end faces" and "curved end faces" models were developed and propagation of monochromatic light beams through such model lenses were extensively studied. In this paper we generalize the preceding analysis to electromagnetic and random domain, considering the passage through the "curved end faces" model of the crystalline lens. In particular, we determine quantitatively and qualitatively how the spectrum and the polarization properties of the light beams change on transmission through the lens. We find that between entering the eye and being received by the eye nerve the light undergoes drastic changes, both spectrally and polarimetrically. Our study is of utmost importance for medical studies of the eye and cognitive science.

Return to Contents

8024-05, Session 2

Distributed fiber optic chemical sensors for security safety, and environmental applications

R. A. Lieberman, M. Beshay, Intelligent Optical Systems, Inc. (United States)

Intrinsic fiber optic chemical sensors, in which the entire length of an optical fiber serves as the chemo-optical transducer, provide unique advantages for large-scale monitoring of chemical concentration. This talk discusses recent results obtained with fibers fabricated specifically as sensors of toxic industrial compounds (HCN, Cl2, H2S) and hydrogen.

8024-38, Session 2

Plasmonics SERS nanochip sensing platforms for chemical and biological sensing

A. Dhawan, H. Wang, T. Vo-Dinh, Duke Univ. (United States)

No abstract available

8024-02, Session 3

Infrared surface waves on semimetals, semiconductors, and conducting polymers

M. Shahzad, G. Medhi, R. E. Peale, Univ. of Central Florida (United States); W. R. Buchwald, Air Force Research Lab. (United States); J. W. Cleary, Solid State Scientific Corp. (United States); O. J. Edwards, Zyberwear, Inc. (United States)

Conductors with infrared plasma frequencies are potentially useful hosts for surface electromagnetic waves with sub-wavelength mode confinement in sensing applications. Such materials include semimetals, semiconductors, and conducting polymers. We present experimental and theoretical investigations of surface waves on antimony, bismuth, graphite, doped silicon, polyaniline, polypyrrole and polythiophene. Resonant absorption features were measured in reflection from lamellar gratings made from these materials for various p-polarized laser wavelengths in the range 6 - 10 microns. Such absorption resonances occur when the conditions for excitation of surface plasmon or surface exciton polaritons are satisfied, below or above the plasma frequency, respectively. The angular reflectance spectra are calculated and compared with the experiments using both analytical and numerical approaches and using experimental complex permittivities determined from IR ellipsometry data. A specific goal is to identify a conductor having tight mode confinement, sharp reflectivity resonances, and capability to be functionalized for biosensor applications.

8024-07, Session 3

Steam distribution and energy delivery optimization using measurement and control over wireless sensors

G. O. Allgood, M. M. Olama, P. T. Kuruganti, S. R. Sukumar, J. E. Lake, Oak Ridge National Lab. (United States)

The Extreme Measurement Communications Center at Oak Ridge National Laboratory (ORNL) explores the deployment of wireless sensors within a real-time measurement-based energy efficiency optimization framework in large campuses. With particular focus on the 12-mile long steam distribution network in our campus, we propose an integrated, holistic, system-level approach to optimize the energy flow within the steam distribution system. We address the goal of achieving significant energy-saving in steam lines by monitoring and acting on leaking steam valves and improved safety from the pressure building up in failed traps. Our approach is through wireless sensor system integration and real-time control. We make assessments on the real-time status of the steam distribution system by mounting acoustic sensors on the steam traps/valves and observe the state measurements of these sensors. Our assessments are based on real-time acoustic algorithms operating on the wireless sensor measurements. We describe a spectrogram based approach acting on the acoustic vibration sensor data to characterize flows and classify the steam system status.

We are able to present the sensor readings, steam trap status and the assessed alerts as an interactive overlay within a web-based Google Earth geographic platform that enables decision makers to take remedial action. Based on our promising results, we envision integrating several sensor sources into a unified site-wide monitoring framework. We believe our demonstration serves as an instantiation of a platform that extends implementation to include newer modalities in managing water flow, sewage, energy consumption that is reproducible in other DOE and non-DOE sites such as in production lines of manufacturing companies.

8024-08, Session 3

Lensfree sensing on a chip using plasmonic nano-apertures

B. Khademhosseinieh, G. Biener, I. Sencan, T. Su, A. F. Coskun, A. Ozcan, Univ. of California, Los Angeles (United States)

Nano-scale metallic apertures couple free space radiation into surface plasmon waves, which can then also couple out to propagating transmission waves, enabling far-field sensing of the near-field effects occurring at the aperture region. These unique properties of plasmonic nano-structures have already been successfully utilized to create various optical sensor architectures.

Here we introduce an alternative sensing technique based on lensfree on-chip imaging. For this purpose, we use quasi-monochromatic illumination, which has partial spatial coherence. Under this illumination condition, the coherent diffraction pattern of each nanoaperture region can be sampled using an opto-electronic sensor array. This lensfree pattern can then be digitally processed to retrieve the missing phase of optical diffraction, enabling back-propagation of the fields to an arbitrary depth below the nano-aperture surface. These lensfree diffraction patterns reconfigure their transmission behavior in response to the local refractive index surrounding the near-field of the apertures. Therefore by performing cross-correlation among these reconstructed diffraction patterns, lensfree on-chip sensing of minute local refractive index changes would be feasible. By recording the lensfree diffraction patterns of our plasmonic nano-aperture array on a compact chip we can faithfully track refractive changes as small as ~0.002. This lensfree on-chip sensing platform uses the entire active area of the opto-electronic detector-array, and therefore enables high throughput sensing of multiple spots on the same chip within a short amount of time. Furthermore, this platform also makes it rather compact and light-weight which are important features for implementations of the same platform for point-of-care and field use.

8024-09, Session 3

Development of an optically interrogated chemical tag

R. R. Boye, C. M. Washburn, D. A. Scrymgeour, B. G. Hance, S. M. Dirk, D. R. Wheeler, W. G. Yelton, T. N. Lambert, Sandia National Labs. (United States)

We report on the progress of an optical tag designed to indicate the presence of HF. The approach we followed uses a high spatial frequency grating consisting of lines of conductive polymer. The conductive polymer has been designed to be sensitive to HF; changing its conductivity upon exposure. This material change results in a change in the polarization

response of the grating which can be read out remotely using optical techniques. The use of a polarization response makes the signal more robust to intensity fluctuations in the background or interrogation system. Additionally, the use of optical interrogation allows for stand off detection in instances where hazardous conditions may be present. A review of the material development work will be presented as well as the device fabrication efforts. Examples of material and device responses will be shown and directions for further investigation discussed.

8024-11, Session 3

Simultaneous ultra-high harmonic detection wavelength modulation spectroscopy for resolving congested spectra

B. M. D. Sawyer, K. D. Mohan, A. N. Dharamsi, Old Dominion Univ. (United States)

Wavelength modulation spectroscopy (WMS) with simultaneous detection at high harmonics (up to and including N=11) is reported for the first time. A Vertical Cavity Surface Emitting Laser (VCSEL) is used to probe atmospheric oxygen using a multi-pass optical cell. The laser frequency is modulated at a low modulation index while synchronous detection is performed simultaneously at all harmonics up to the 11th. These higher harmonic signals allow for better resolution of congested spectra. Comparisons between theoretical and experimental results are used to detect and resolve absorption features in the A-band region of oxygen. The high harmonic signals are used to distinguish between stronger rotational-vibrational absorption lines in oxygen and weaker absorption lines formed by low-density isotopic oxygen. This detection method also allows for the resolution of overlap between these weaker isotopic spectra. Higher harmonic signals resolve additional structure, which does not appear at direct absorption measurements, or even in lower harmonic signals (N<3). Since harmonic signal power decreases rapidly with detection order (N), the technique employed clearly shows that the commonly used signal-to-noise power ratio, while important, is not the only criterion for a good measurement. We examine the effects of optical pathlength saturation for these weak isotopic lines by measuring the effect of an optically thick path (at fixed density) on the signal. Furthermore, we compare the differences in optically thick materials, where the density is high but the pathlength is small, to those in which the density is low but the pathlength is high.

8024-12, Session 4

671 nm microsystem diode laser based portable Raman sensor device for in-situ identification of meat spoilage

K. Sowoidnich, H. Schmidt, Technische Univ. Berlin (Germany); F. Schwägele, Max Rubner-Institut (Germany); H. Kronfeldt, Technische Univ. Berlin (Germany)

Based on a miniaturized optical bench with attached 671 nm microsystem diode laser we present a portable Raman system for the rapid in-situ characterization of meat spoilage. It consists of a handheld sensor head (dimensions: 210 x 240 x 60 mm3) for Raman signal excitation and collection including the Raman optical bench, a laser driver, and a battery pack. The backscattered Raman radiation from the sample is analyzed by means of a custom-designed miniature spectrometer (dimensions: 200 x 190 x 70 mm3) with a resolution of 8 cm-1 which is fiber-optically coupled to the sensor head. A netbook is used to control the detector and for data recording.

Selected cuts from pork (musculus longissimus dorsi and ham) stored refrigerated at 5 °C were investigated in time-dependent measurement series up to three weeks to assess the suitability of the system for the rapid detection of meat spoilage. Using a laser power of 100 mW at the sample meat spectra can be obtained with typical integration times of 5 seconds.

The complex spectra were analyzed by the multivariate statistical tool PCA (principal components analysis) to determine the spectral changes occurring during the storage period. Additionally, the Raman data were correlated with reference analyses performed in parallel. In that way, a distinction between fresh and spoiled meat can be found in the time slot of 8 - 10 days after slaughter. The applicability of the system for the rapid spoilage detection of meat and other food products will be discussed.

8024-13, Session 4

High sensitivity calixarene SERS substrates for the continuous in-situ detection of PAHs in seawater

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In-situ monitoring of pollutant chemicals in sea-water is of worldwide interest. For that purpose, fast response sensors based on Raman spectroscopy are suitable for a rapid identification and quantification of these substances. Surface-enhanced Raman scattering (SERS) was applied to achieve the high sensitivity necessary for trace detection. In the project SENSEnet, funded by the European Commission, a SERS sensor based on calixarene-functionalized silver nanoparticles embedded in a sol-gel matrix was developed and adapted for the in-situ detection of polycyclic aromatic hydrocarbons (PAHs).

The laboratory set-up contains a microsystem Raman diode laser with two slightly different emission wavelengths (670.8 nm and 671.3 nm) suitable also for shifted excitation Raman difference spectroscopy (SERDS). The output power at each of both wavelengths is up to 200 mW. For the detection of the SERS spectra integration times of typically 1 - 10 seconds were chosen. The SERS substrate is located inside a flow-through cell which provides continuous flow conditions of the analyte. The spectra were recorded using a laboratory spectrograph with a back-illuminated deep depletion CCD-detector.

We present scanning electron microscope images of the developed calixarene SERS substrates as well as results for the SERS adsorption properties of major PAHs (pyrene, fluoranthene, and phenanthrene) in artificial sea-water and their limits of detection (e. g. 0.3 nM for pyrene). The Raman signal response from pyrene concentration change on the sensor operation and the effect of air bubbles will be discussed in respect of the suitability as an in-situ SERS sensor on a mooring or buoy.

8024-14, Session 4

Remote mid-infrared sensing using chirped laser dispersion spectroscopy

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A Chirped Laser Dispersion Spectroscopy (CLaDS) technique suitable for remote trace-gas detection will be presented. Our method is based on detection of the optical dispersion observed around molecular ro-vibrational transitions. In the presented setup light from a frequency-chirped 5.2um quantum cascade laser (QCL) is divided into two frequency-shifted beams using an acousto-optical modulator. These two beams are recombined into one using the Mach-Zehnder Interferometer configuration. The dual-frequency beam is expanded and sent towards a retro-reflector allowing for path-integrated remote sensing of nitric oxide (NO). Returning light is collected with a telescope and focused on a photodetector. The two frequency-shifted waves are also frequency-chirped over the NO absorption line, which affects the wave propagation due to molecular dispersion. The dispersion is proportional to the molecular concentration and can be used for quantitative trace-gas detection. The CLaDS signal is measured using optical heterodyne detection and FM-demodulation. Because dispersion signal is measured as an instantaneous frequency of the heterodyne

beatnote its main advantage is high immunity to intensity noise and laser power fluctuations. Moreover application of mid-IR QCLs enables access to the strongest fundamental molecular vibrational bands and provides high frequency chirp-rates. Since both component waves propagate together through the medium, the measurement distance is not limited by the coherence length of the source. These features allow for long distance remote sensing and open-path monitoring with high sensitivity and immunity to transmission fluctuations. In this paper we will present performance, discuss main limitations and show CLaDS suitability to remote sensing of hazardous gases.

8024-15, Session 4

Long range trace detection by radar REMPI

A. Dogariu, C. Stein, A. Glaser, R. B. Miles, Princeton Univ. (United States)

We demonstrate the feasibility of using microwave scattering from free electrons generated by selective laser ionization (REMPI) for trace species detection. The laser is tuned to ionize only the selected molecular trace species in ambient air. We achieve detection of parts-per-billion of NO in atmospheric pressure nitrogen, in dry air and in laboratory air with 50% humidity.

In addition we performed at-range measurements in order to prove the feasibility of using the Radar REMPI detection technique in a remote configuration. We obtained reliable backscattered microwave signal 1m away while focusing a laser from 10m distance from the target.

We have extended the use of the Radar REMPI detection scheme to more complicated molecular systems by pre-dissociating the molecule into smaller fragments which can be detected with high specificity. We demonstrate the detection of SF_6 by laser dissociation of the SF_6 molecule, and measuring the Radar REMPI signals obtained from the SF_2 product. The SF_2 is produced by the UV REMPI laser pulse itself, and a scattered microwave signal is detected from the SF_2 molecule. Significant enhancement is achieved using a pre-ionizing pulse from a Nd YAG laser shortly before the measurement. The short time between fragmentation and detection allows transient fragments and fragments in vibrational nonequilibrium to be detected. This approach may allow for the identification of complex molecules by remotely detecting even short lived molecular constituents or fragments which are produced either during or just shortly before the Radar REMPI measurement.

8024-16, Session 4

Remote air lasing for trace detection

A. Dogariu, J. Michael, R. B. Miles, Princeton Univ. (United States)

Many remote detection methods rely on the use of lasers in an attempt to identify and quantify trace species at long distance. The distance at which optical methods can be reliably used for trace species detection is limited by the ability to collect photons from afar. Incoherent light emitted at the target is non-directional, while phase-matching forces nonlinear processes to generate coherent light away from the source. We demonstrate coherent light propagating backwards from a remotely generated high gain air laser. A short UV laser pulse tuned to a two-photon atomic oxygen electronic resonance at 226 nm simultaneously dissociates the oxygen molecules in air, and excites the resulting atomic oxygen fragments. Due to the long focal region of the pumping laser, a long region of high gain is created in air for the atomic oxygen emission at 845nm. We demonstrate that the gain in excess of 60 cm^{-1} is responsible for both forward and backwards emission of a strong, collimated, coherent laser beam. We present evidence for coherent emission and characterize the backscattered laser beam while varying the pumping conditions. The optical gain and directional emission allows for six orders of magnitude enhancement for the backscattered emission when compared with the fluorescence emission collected in the same solid angle as the stimulated emission. This opens new opportunities for the remote detection capabilities of trace species, and provides much greater range for the detection of optical molecular and atomic features from a distant target.

8024-06, Session 5

Gallium nitride nanowire-nanocluster hybrids for environmental sensing

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Developing highly sensitive and selective sensors for detecting environmental pollutants is of immense technological significance. Nanowire-nanocluster hybrid sensors were realized by functionalizing gallium nitride nanowires with titanium dioxide (TiO_2) nanoclusters for selectively sensing Benzene and related aromatic compounds. Gallium nitride nanowires with diameter in the range of 150 nm to 250 nm were grown using Molecular Beam Epitaxy. These nanowires were aligned on a nonconducting substrate by dielectrophoresis and complete sensor structures were fabricated using standard microfabrication techniques. The TiO_2 nanoclusters were deposited on the nanowires devices utilizing RF magnetron sputtering system. The GaN/TiO_2 nanowire-nanocluster hybrid devices use the photocatalytic properties of TiO_2 to sense specific volatile organic compounds at ambient temperature. These hybrid sensor devices exhibited resistance change when exposed to various organic compounds in air only in the presence of ultraviolet light. Various gases including benzene, chlorobenzene, toluene, xylene, ethyl benzene when exposed to the sensors resulted in resistance change. On the other hand, gases like ethanol, methanol, isopropyl alcohol, chloroform, and acetone did not show any change in the electrical characteristics of the devices, which clearly demonstrate the selective behavior of the sensors to the aromatic compounds. We were able to detect xylene, ethyl benzene, benzene, toluene, and chlorobenzene at concentration levels of 50ppb, 50ppb, 200ppb, 500ppb and 1ppm respectively. Response times of the devices to ppm levels and ppb levels of concentrations of the compounds are 60s and 180s respectively. Recovery times of the devices to ppm levels and ppb levels of concentrations are 60s and 120s respectively.

8024-17, Session 5

Nanopillars array for surface enhanced Raman scattering

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We present a new type of Surface-Enhanced Raman Scattering (SERS) substrate based on a large area, high-density two-dimensional rectangular array of vertical nanopillars. The array has a pitch of 360 nm and the height of the pillars is designed to be between 250 nm to 1 micron. These nanopillars are fabricated by a high-precision interference lithography and ion-beam etching process, followed by conformal deposition of metal such as gold to make them SERS-active. The gap between each pair of nanopillars is small enough (< 50 nm) such that highly confined plasmonic cavity resonances are supported between the pillars when light is incident upon them, and the anti-nodes of these resonances can act as three-dimensional hotspots for SERS. Finite Element Method simulation results show that confinement factor up to 103 is possible in these hotspots. Simulation results also show that the resonances can be tuned by varying the height of the pillars and/or gap size, thereby providing design freedom to optimize SERS signals.

Time-dependent SERS experiments were carried out on these substrates using various concentrations of 1,2 bis-(4-pyridyl)-ethylene (BPE) or benzenethiol (BT) molecules at laser wavelength of 660 nm and power of 2 mW. The results show SERS enhancement factor of up to 108, and BPE can be detected at femto-molar concentration level with short exposure time. Current work is on application of these substrates for SERS detection of gases and volatile organic compounds. Our results show that this type of substrate can be attractive as a high-sensitivity chemical sensor.

8024-18, Session 5

Far-UV LIBS for biological and organic samples

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Laser-Induced Breakdown Spectroscopy has shown its capabilities to identify organic and biological samples via their atomic constituents. For both these materials, the major signal from atomic carbon has long been only identified to the emission line at 247.8 nm (and if the detection system allows further detection, the line at 193.1 nm). For biological materials, where the profile of emitters besides C, H, O, N is needed, accurate determination of the complete atomic signal is crucial, including Phosphorus and Zinc for example.

For application of quantification algorithms such as Calibration-Free LIBS (CF-LIBS), temperature measurements is needed. But for a reliable temperature evaluation via the Boltzmann plot, more data from the carbon emitter are needed. The far-UV region (defined between 122 and 200 nm by the ISO 21348) is the richest and most intense region for atomic emission at temperature as high as several eV, typical of LIBS plasmas. For pattern recognition techniques in LIBS spectra, the abundance of spectral lines leads to more variables on which to base calculations and as a consequence less errors in the detection and discrimination of samples.

We demonstrate the use of a compact far-UV spectrometer with a spectral range between 140 and 250 nm for the LIBS analysis of graphite and biological samples. Discussion on the advantages of such compact systems for an extended LIBS towards its standardization to the far-UV will be held and suggestions towards adapted technology will be given.

8024-19, Session 5

Analyte focusing at self assembling hotspots for SERS by leaning silver coated silicon nanopillars

M. S. Schmidt, A. Boisen, Technical Univ. of Denmark (Denmark)

Currently, the widespread use of Surface enhanced Raman scattering (SERS) systems has been limited by the inability to produce reproducible SERS active substrates with sufficient Raman enhancement. Using a simple maskless fabrication method we show how freestanding high aspect ratio silicon nanopillars covered with silver can be produced over large areas in a highly reproducible cleanroom process.

After being exposed to the analyte in the gas phase a droplet of water or other solvent is deposited onto the substrate. As the solvent evaporates, surface tension will cause the nanopillars to lean towards their nearest neighbours thus creating self assembled electromagnetic “hot spots”. Analyte molecules adsorbed at the tips of the pillars will now be located exactly in the “hot spots” as the pillars lean together. This leaning / analyte focusing mechanism creates an enormous number of “hot spots” inside the laser excitation area, drastically increasing the Raman signal compared to non-leaning pillars. Furthermore, the large enhancement of the Raman signal is reproduced uniformly across the wafer.

Using these substrates we demonstrate the capability to detect trace amounts of explosives in the gas phase (for landmine clearance) and pesticide remnants in the liquid phase (environmental monitoring).

Being a solid substrate this material is very practical to use and can be applied in current Raman systems. As the fabrication method is low cost and reproducible over large areas (wafer scale), we believe that these substrates will enable SERS to become more applicable in the field of chemical sensing.

8024-20, Session 5

Battery-operated planar-geometry micro-plasmas on postage-stamp size chips: some fundamentals

S. Weagant, V. Karanassios, Univ. of Waterloo (Canada)

For the last few years [1, 2], we have been developing and characterizing miniaturized, self-igniting, atmospheric-pressure, battery operated, planar-geometry microplasmas for use with liquid micro-samples. These relatively inexpensive micro-size and nano-volume plasmas are hybrid, either two-substrate (e.g., quartz-plastic) or three-substrate (e.g., quartz-plastic-plastic) structures and are formed on chips with area the size of a small postage-stamp. 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 micro-plasmas require about 10 W of power and a few 100 mL/min of support gas. In this case, the support gas was either He-Hydrogen or an Ar-Hydrogen mixture.

In order to improve their already impressive detection limits, we are now embarking on fundamental studies of these cold micro-plasmas. Specifically, we made spectroscopic measurements of the excitation temperatures using either He-Hydrogen or Ar-Hydrogen mixtures.

In this presentation, spectroscopic fundamentals, development, characterization, detection limits obtained using liquid micro-samples, a portable, fiber-optic linear-CCD spectrometer and postage stamp-size micro-plasmas and will be described in detail.

[1] V. Karanassios, “Mobile micro- and nano-instruments: Fast, cheap and under wireless control”, Transactions of the electrochemical society, invited, in press

[2] S. Weagent and V. Karanassios, Helium-hydrogen microplasma device (MPD) on postage-stamp-size plastic-quartz chips, Analytical and Bio Analytical Chemistry, 395, 577-589 (2009).

[3] V. Karanassios, K. Johnson and A. T. Smith, Micromachined, planar-geometry, atmospheric-pressure, battery-operated microplasma devices (MPDs) on chips for microsamples of liquids, gases or solids by optical emission spectrometry, Anal. Bioanal. Chem., 388, 1595-1604 (2007).

8024-23, Session 5

Deforestation modeling for Zagros forests using RS and GIS techniques (case study: forests of Ilam)

D. Oladi, D. Bozorgnia, A. A. Jafarzadeh, Univ. of Mazandaran (Iran, Islamic Republic of)

In this study, the spatial modeling of forest changes was applied aiming at predicting the deforestation spatial distribution in western forests of Iran using RS and GIS techniques. In order to identify the deforested areas and their locations in the study area, the forest map of 1965 was prepared using aerial photographs. Then, the forest map of 2008 was produced using LISSIII images. In the next step, two above mentioned maps were overlaid to locate the deforested areas in that determined period of time. The prepared deforestation map associated with two physiographic and human spatial variables were included in the model to evaluate the affective factors on the deforestation processes. A forward conditional stepwise logistic regression was used for modeling and evaluating the deforestation spatial distribution. Then, the statistical model was provided based on the most influensive factors on the

deforestation including distance from residential areas, distance from roads, height from sea surface and slope percentage. Finally, this model was transferred into Arc View environment to obtain the deforestation spatial distribution map for the study area.

8024-24, Session 6

Spectrally tailored pulsed thulium fiber laser system for broadband lidar CO_2 sensing

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Thulium doped pulsed fiber lasers are capable of meeting the spectral, temporal, efficiency, size and weight demands of defense and civil applications for pulsed lasers in the eye-safe spectral regime due to inherent mechanical stability, compact “all-fiber” master oscillator power amplifier (MOPA) architectures, high beam quality and efficiency. Thulium fiber’s longer operating wavelength allows use of larger fiber cores without compromising beam quality, increasing potential single aperture pulse energies. Applications of these lasers include eye-safe laser ranging, frequency conversion to longer or shorter wavelengths for IR countermeasures and sensing applications with otherwise tough to achieve wavelengths and detection of atmospheric species including CO2 and water vapor. Performance of a portable thulium fiber laser system developed for CO2 sensing via a broadband lidar technique with an etalon based sensor will be discussed. The fielded laser operates with ~280µJ pulse energy in 90-150ns pulses over a tunable 110nm spectral range and has a uniquely tailored broadband spectral output allowing the sensing of multiple CO2 lines simultaneously, simplifying future potentially space based CO2 sensing instruments by reducing the number and complexity of lasers required to carry out high precision sensing missions. Power scaling and future “all-fiber” system configurations for a number of ranging, sensing, countermeasures and other yet to be defined applications by use of flexible spectral and temporal performance master oscillators will be discussed. The compact, low mass, robust, efficient and readily power scalable nature of “all-fiber” thulium lasers makes them ideal candidates for use in future space based sensing applications.

8024-25, Session 6

Characteristics of polar and nonpolar ZnO nanostructure based gas sensors

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ZnO has attracted a lot of attention because it’s large band gap energy of 3.4 eV at room temperature, large excitonic energy, low electron affinity, and high mechanical strength. In our previous study, polar and nonpolar ZnO nanostructure were successfully grown on GaN templates with different orientation using chemical vapor deposition. For the application of sensors, GaN templates with different orientation were ion implanted first for insulating. Polar and nonpolar ZnO nanostructure with average diameter around 300nm were grown on insulated GaN templates and Ti/Au was deposited as ohmic contacts. Because the difference of electrical properties between polar and nonpolar ZnO. We wish we can improve the sensitivity of ZnO based gas sensor with polarized ZnO nanostructure. Futher experimental data will shown in the conference.

8024-26, Session 6

High sensitivity detection of NO_2 employing off-axis integrated cavity output spectroscopy coupled with multiple line integrated spectroscopy

G. N. Rao, A. Karpf, Adelphi Univ. (United States)

We report on the development of a new sensor for NO2 with ultra-high sensitivity of detection. This has been accomplished by combining off-axis integrated cavity output spectroscopy (OA-ICOS) (which can provide large path lengths of the order of several km in a small volume cell) with multiple line integrated absorption spectroscopy (MLIAS) (where we integrate a molecular species’ absorption spectra over a large number of rotational-vibrational transitions to further improve sensitivity). Employing an external cavity quantum cascade laser operating in the 1601 - 1670 cm-1 range and a high finesse optical cavity, the absorption spectra of NO2 over 100 transitions in the R-band have been recorded. From the observed linear relationship between the integrated absorption and concentration of NO2, we report an effective sensitivity of detection at the 100 ppt level. To the best of our knowledge, this is among the most sensitive levels of detection of NO2 to date. A sensitive sensor for the detection of NO2 will be helpful to monitor: ambient air quality; combustion emissions from sources such as automobiles, power plants, and aircraft; as well as for the detection of nitrate based explosives (which are commonly used in improvised explosive devices (IEDs)). Additionally, such a sensor would be valuable for the study of complex chemical reactions that occur in the atmosphere and result in the formation of photochemical smog, tropospheric ozone and acid rain.

8024-27, Session 6

A low-volume microstructured optical fiber hydrogen peroxide sensor

E. P. Schartner, D. F. Murphy, H. Ebendorff-Heidepriem, T. M. Monro, The Univ. of Adelaide (Australia)

The ability to measure the concentration of hydrogen peroxide (H2O2) in solution is critical for quality assessment and control in many disparate applications, including wine, aviation fuels and IVF. The objective of this research is to develop a rapid test for the hydrogen peroxide content that can be performed on very low volume samples (i.e. sub-µL) that is relatively independent of other products within the sample.

For H2O2 detection we use suspended core fibers for a high evanescent overlap without the constraint of limited interaction length that is generally inherent with nanowire structures. By filling the holes of the fiber with an analyte/fluorophore solution we seek to fabricate a quick and effective sensor which should enable detection of desired species within liquid media. By choosing a fluorophore that reacts with our target species to produce an increase in fluorescence, we can correlate observed fluorescence intensity with the concentration of the target molecule.

Through the use of microfluidic technologies we are able to perform these measurements using a minimum volume of analyte (approximately 10 nL within the fiber itself) enabling measurements to be performed on exceptionally small volume samples with potential applications including the monitoring of the early health and viability of IVF embryos. By choosing fluorescent dyes that react with different target species potential applications are significantly extended, and this type of sensor is currently being developed for aluminium ions, Potassium in addition to hydrogen peroxide that will be the main focus of this paper.

8024-28, Session 6

Tin oxide nanowire sensors for highly sensitive detection of the toxic gas H_2S

A. Koeck, E. Brunet, Austrian Institute of Technology (Austria); G. Mutinati, Pirelli & C. S.p.A. (Austria); S. Steinhauer, Austrian Institute of Technology (Austria)

The employment of nanowires is a very powerful strategy to improve gas sensor performance. Due to a high surface to volume ratio they show a strong interaction with the surrounding gas. We present nanosensors based on single-crystalline SnO2-nanowires, which are very sensitive to the highly toxic gas H2S. The nanowires are fabricated in a two-step atmospheric pressure synthesis process directly on the Si-chip by spray pyrolysis and subsequent annealing. In a first step nanocrystalline SnO2-films with thickness ~200 nm are fabricated by a spray pyrolysis process, the second process is an annealing process at 900°C. Our two-step SnO2-nanowire fabrication procedure is very simple, requires no vacuum, and allows for straightforward upscaling the possible substrate to 4"-wafer size. Exposure of the nanowire sensors to the toxic gas H2S with a concentration of only 2.5 ppm decreases the resistance by ~85%, which demonstrates the extraordinary sensitivity of the nanowire sensors. The nanosensors provide sensitivity in the sub-ppm range and are thus able to measure concentrations well below the threshold limit value of 10ppm. This makes the nanowire based sensors well suited as smart sensing devices for personal safety issues as well as for industrial applications. We believe that in particular our nanowire fabrication procedure might be the technology of choice for the controlled fabrication of SnO2-nanowires as highly sensitive gas sensing elements on a wafer scale.

8024-29, Session 6

Standoff identification and quantification of flare emissions using infrared hyperspectral imaging

K. C. Gross, Air Force Institute of Technology (United States); S. Savary, Telops (Canada); P. Tremblay, Univ. Laval (Canada); J. Gagnon, V. Farley, M. Chamberland, Telops (Canada)

There is growing interest in measuring gaseous emissions of multiple sources to understand their environmental impact. It is desired to not only identify, but also quantify such emissions, ideally from standoff distances. Recent technological advancements have enabled to produce high performance infrared imaging Fourier-transform spectrometers. These sensors, also referred to as hyperspectral imagers, enable to combine spectroscopy and imaging capabilities, both very useful to well understand, image, identify and quantify gaseous emissions.

AFIT and Telops have performed several field experiments, using the Telops Hyper-Cam infrared hyperspectral imager to perform identification and quantification of gaseous emissions from various pollution sources. Smokestack emissions have been analyzed and presented in past publications, as well as turbojet exhausts. More recent experiments have focused on the measurement of gaseous emissions from other turbulent sources of great interest from the environmental protection community, such as emergency flares. Emergency flares are typically used to burn large quantities of gas in case of emergencies, but are also often used to burn low-flow gas in steady operation of certain industrial plants. It is of interest to understand the flare emissions under varying operating conditions. This paper presents the first results of flare emission measurements with the Hyper-Cam.

8024-30, Session 6

Trace gas detection and monitoring with the digital array gas-correlation radiometer (DAGR)

M. J. McHugh, L. L. Gordley, M. E. Hervig, GATS, Inc. (United States)

We present the first results from a Digital Array Gas-correlation Radiometer (DAGR) prototype sensor, and discuss applications in remote sensing of trace gases. The sensor concept is based on traditional and reliable Gas Filter Correlation Radiometry (GFCR), but overcomes the limitations in solar backscatter applications. The DAGR sensor design can be scaled to the size of a digital camera and is ideal for downlooking detection of gases in the boundary layer, where solar backscatter measurements are needed to overcome the lack of thermal contrast in the IR. Ground-based portable DAGR sensors can monitor carbon sequestration sites or industrial facilities. Aircraft or UAV deployment can quickly survey large areas and are particularly well suited for gas leak detection or carbon monitoring. From space-based platforms, Doppler modulation can be exploited to produce an extremely fine spectral resolution with effective resolving power exceeding 100,000. Such space-based DAGR observations could provide near-global sensing of climatically important species such as such as CO¬2, CO, CH4, O3 and N2O. Planetary science applications include detection and mapping of biomarkers in the Martian atmosphere.

8024-31, Poster Session

Effects of design parameters of passive FTIR spectroscopy system using Michelson interferometer on the detection probability of stand-off hazardous compounds

H. K. Ahn, K. S. Shim, H. J. Kong, M. S. Oh, KAIST (Korea, Republic of)

In this paper, the effects of design parameters of passive Fourier transform infrared (FTIR) spectroscopy system using Michelson interferometer on the detection probabilities of stand-off hazardous compounds (gases, vapors, aerosols) are investigated. Stand-off detection of hazardous compounds by passive FTIR spectroscopy is based on measurements of spectral radiance difference, ΔL, between the spectral radiance affected by the hazardous compounds and the spectral radiance from the background. There are three steps to predict the effects of design parameters on the detection probabilities. First, moderate resolution atmospheric transmission (MODTRAN) is used to calculate spectral radiances from the site of interest where hazardous compounds of various concentrations are distributed. Second, a theoretical model of passive FTIR spectroscopy system using Michelson interferometer is established with several design parameters (detector noise, jitter of sweep speed, misalignment) and proved by experiments in laboratory. The theoretical model of passive FTIR spectroscopy system transforms the spectral radiance acquired by MODTRAN to the spectral radiance acquired by the FTIR spectroscopy system. Third, spectral angle mapper (SAM) algorithm, an automated method for directly comparing unknown spectra to a known spectra, is applied to decide correlation coefficients between gas library and the transformed spectral radiance. The detection probabilities of stand-off gas are able to be predicted with the correlation coefficients. As a result, the relation among the design parameters, the concentrations of hazardous compounds, and the detection probabilities are shown.

8024-33, Poster Session

Strong room-temperature chemiresistive effect of TiO2-B nanowires to nitro-aromatic compounds

D. Wang, A. Chen, Q. Zhang, G. Cao, Univ. of Washington (United States)

We report a new type of explosive sensor based on semiconducting TiO2-B nanowires thin film. It was found that, in a chip-size device with greatly reduced size, weight, and power consumption, both the sensitivity and response speed of the TiO2-B nanowire sensor had surpassed those of current technologies. The TiO2-B nanowires thin film not only possesses a porous structure with huge internal surface area, but also has its specific electrical and structural characteristics such as higher charger carrier transfer ability than anatase TiO2, less compact structure and higher level of oxygen vacancies due to Ti4+ ions. Therefore, TiO2-B nanowires are believed to be a promising material that can be used as a chemiresistive sensor.

The TiO2-B nanowires were synthesized with a typically hydrothermal method. As-synthesized nanowires were dispersed in ethanol to form a suspension solution. This solution was then drop-casted on glass substrates and heated to attain a thin film of nanowires about 10 μm in film thickness. To fabricate a sensor, patterned titanium electrodes were deposited through a shadow mask over the nanowire film by sputtering.

The sensing performance of nanowire film samples were tested in ambient air. During the test, the resistance of the sample was recorded while air flow to the sample was switched between pure air and air that contained explosive vapor at intervals of several seconds to a few tens of seconds. The response of TiO2-B nanowires to 2,4,6-trinitrotoluene (TNT) has exhibited a high sensitivity up to 1 ppb level of TNT and a fast response about 3.9 second.

8024-34, Poster Session

Gas cloud infrared image enhancement based on anisotropic diffusion

J. Li, L. Wang, C. Zhang, Y. Long, B. Zhang, Beijing Institute of Technology (China)

Leakage of dangerous gases will not only pollute the environment, but also seriously threat public safety. Thermal infrared imaging has been proved to be an efficient method to qualitatively detect the gas leakage. But some problems are remained, especially when monitoring the leakage in a passive way. For example, the signal is weak and the edge of gas cloud in the infrared image is not obvious enough. However, we notice some important characteristics of the gas plume and therefore propose a gas cloud infrared image enhancement method based on anisotropic diffusion. As the gas plume presents a large gas cloud in the image and the gray value is even inside the cloud, strong forward diffusion will be used to reduce the noise and to expand the range of the gas cloud. Adjacent frames subtraction and K-means cluttering pop out the gas cloud area. Forward-and-Backward diffusion is to protect background details. Additionally, the best iteration times and the time step parameters are researched. Results show that the gas cloud can be marked correctly and enhanced by black or false color, and so potentially increase the possibility of gas leakage detection.

8024-35, Poster Session

Monitoring organic volatiles and flammable gases with a holographic sensor

J. L. Martinez-Hurtado, C. R. Lowe, Univ. of Cambridge (United Kingdom)

A holographic sensor was produced by a diffusion method of silver salts in a silicon elastomer (PDMS). The salts are reduced to produce silver nanoparticles, that upon ablation with a pulsed laser form fringes, generate fringes of silver grains. The fringes are separated by about half of the wavelength of the laser (266nm) producing a photonic effect that can be measured as a colorful reflection. A CCD spectrophotometer was used to detect the reflected wavelength of the hologram illuminated with a white light source. The molecular affinity of PDMS for organic molecules has certain differences that can be expressed as intermolecular forces in terms of the cohesive energy density. This parameter is used to predict with great accuracy the sensor performance. Hydrocarbon gases at different concentration were tested for 3 sets of temperatures. Alkanes, alkenes and alkynes from 2 to 4 carbon atoms in structure were detected. The sensor responds in less than 5s to the set of hydrocarbon gases tested in a range of concentrations from 0% to 100% v/v. Liquid organic compounds exhibit a slower response, however, the results agree with the prediction imposed by the comparison with the cohesive energy densities. The capabilities of the sensor make it ideal for applications in indoor environment monitoring or dangerous environments enriched with such organic compounds.

8024-36, Poster Session

Compact mobile ELISA-based pathogen detection: design and implementation challenges

D. S. Starodubov, A. Asanbaeva, I. V. Berezhnyy, C. Chao, R. Koziol, D. Miller, E. Patton, S. Trehan, C. Ulmer, Physical Optics Corp. (United States)

POC presents a novel Mobile ELISA-based Pathogen Detection system for multiple-threat detection and a highly sensitive portable fluorescence measurement unit with automated control of samples and reagents flow. The fluorescence detection solution provides more than 100 dB of excitation suppression in the signal detection channel. The instrument design is capable of detecting the presence of target analytes through fluorescence data collection from multiple test spots with the following transfer of the results to a laptop for analysis. Concentrations below 100 ng/mL can be reliably identified. The presence of pathogens is determined with high accuracy within a 30-min time window. The entire instrument is powered from a notebook PC and operates as Plug-and-Play Human Interface Device, resulting in a truly peripheral biosensor that can be used by non-experts. The operation of the system is fully automated, requiring minimal user intervention throughout the detection process. The evolution of the optical, mechanical, and fluidic approaches with a focus on a low-cost, point-of-care user-friendly design will be presented in detail.

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8025-01, Session 1

Optimization of SAM-based multilayer SERS substrates for intracellular analyses: the effect of terminating functional groups

C. K. Klutse, B. M. Cullum, Univ. of Maryland, Baltimore County (United States)

Surface-enhanced Raman scattering (SERS) has become an attractive analytical tool for intracellular analyses due to its minimally invasive nature and molecular specificity. However, highly reproducible and optimized SERS substrates have been seen as key to developing efficient SERS method. This research focuses on optimizing SAM multilayer SERS substrates for a wide range of applications, including ultratrace detection of biomolecules within individual living cells.

Multilayer SERS substrates are comprised of alternating layers of metal film and dielectric spacer cast on a monolayer of nanostructures. Using these substrates, varying degrees of SERS enhancement factors (EF) have been achieved, some as large as 10-fold relative to optimized single film over nanostructures substrates. To gain a mechanistic understanding of multilayered SERS enhancements, SAMs have been used to systematically vary spacer thickness. The results revealed spacer-dependent SERS EFs. To further the understanding of multilayer SERS enhancement, this talk discusses the use of terminating functional groups in the optimization of SAM multilayer SERS substrates. SAMs having various functional groups were used as dielectric spacers to systematically vary the dielectric constant. To investigate the cumulative effect of the multiple layers, the number of dielectric/metal film layers was increased sequentially. The corresponding SERS EFs for the various substrates were evaluated. It was shown that using appropriate SAM and number of layers, the SAM multilayer can achieve SERS EF as much as 1010 and the substrates yielded highly reproducible SERS signals. This talk will also discuss the functionalization of individual SERS-active of SAM multilayer particle to form SERS immuno-nanosensors.

8025-02, Session 1

Nitrocellulose-based SERS based immuno-sensor for detection of biological molecules

A. C. Dykes, L. E. Kamemoto, A. K. Misra, S. K. Sharma, Univ. of Hawai'i (United States)

We have developed a simple, low-cost method for the sensitive detection of target proteins via surface-enhanced Raman scattering (SERS). The immunosensor constructed by the conjugation of monoclonal antibodies to 20 nm diameter gold nanoparticles via the bifunctional Raman reporter molecule, 5, 5 -dithiobis (succinimidyl-2-nitrobenzoate) (DSNB) is the basis of a membrane-bound detection system. Traditionally a common laboratory technique called a dot blot is a colorimetric method where detection of proteins is accomplished through the application of assorted dyes followed by their measurement via a densitometer. A convenient and time-saving method, dot-blotting involves the spotting of a protein onto an immobilizing matrix, such as nitrocellulose (NC) or polyvinylidene fluoride (PVDF) membrane. We have found that for detection via SERS spectroscopy NC is the matrix of choice, offering low background, minimal preparation prior to protein application, and optimal position of Raman bands. Furthermore, SERS detection of protein on NC requires only minimal sample preparation and demonstrates increased sensitivity to other dot blot detection methods. Depending on the dye used for visualization, dot blots analyzed by optical methods have limits of detection in the nanogram range, some as low as 20 pg/ml. Here we demonstrate the use of the dot blot method for detecting target proteins (e.g., prostate specific protein (PSA) and protein A) by SERS spectroscopy down to a concentration of 100 fg/ml.

8025-03, Session 1

Novel optical nanobiosensor encapsulated in erythrocytes

M. Dweik, Lincoln Univ. (United States)

Development of an in vivo optical Nanobiosensor 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.

8025-04, Session 1

Self-referencing luminescent optrodes for non-invasive, real time measurement of extracellular flux

E. S. McLamore, Univ. of Florida (United States); D. M. Porterfield, Purdue Univ. (United States)

Transport across cell membranes/organelles regulates growth, metabolism, bioenergetics, stress signaling, immune response, and morphology. Autonomous technologies are needed which are capable of sensing real time changes in biophysical transport across cell membranes/organelles. These technologies must not only be highly sensitive/selective, but must also be minimally invasive/intrusive, causing no significant physical/chemical effects on cell behavior. Challenges with mainstream technologies (e.g., assays, fluorescent dyes, microsensors) include signal noise/drift, low temporal resolution, requirement of large sample sizes, cytoxicity, organelle sequestration, and intracellular buffering. Recent advancements in fiber optics have greatly enhanced the performance of microsensors (e.g., increased sensitivity/selectivity, response time), but used in concentration mode near cells/tissues these sensors suffer from poor signal to noise ratio. Work over the last few decades has advanced microsensor utility through sensing modalities that extend and enhance the data recorded by sensors. This technique, known as self-referencing, converts static micro/nanosensors with otherwise low signal-to-noise ratios into dynamic flux sensors capable of filtering out signals not associated with active transport by acquisition and amplification of differential signals. Here, we demonstrate the use of a self-referencing referencing frequency domain fiber optic microsensor containing a quenched dye (platinum tetrakis-pentafluorophenyl porphyrin) for quantifying cell/tissue flux. Demonstrations include: muscle/tumor bioenergetics, Wharburg effect, and neural physiology. This non-invasive tool is combined with biosensors for measurement of other analytes (glutamate, glucose, lactate) and used for diagnostics/monitoring, pharmacology, and basic cell/tissue physiology experiments.

The ability to monitor real time transport with high temporal/spatial resolution provides invaluable information about the physiology of cells, tissues, and/or organisms.

8025-05, Session 1

Sensor for detection and classification of nano particles and biological agents in situ based on optical resonance in dielectric microspheres

V. A. Saetchnikov, E. A. Tcherniavskaia, Belarusian State Univ. (Belarus); G. Schweiger, A. Ostendorf, Ruhr-Univ. Bochum (Germany)

A novel emerging technique for the label-free analysis of nano particles including biomolecules using optical micro cavity resonances is being developed. Various schemes based on mechanically fixed microspheres as well as microspheres melted by laser on the tip of a standard single mode fiber have been investigated to make further development for microbial application.

Water solutions of ethanol, HCl, glucose, vitamin C and biotin have been used to test refractive index changes by monitoring the magnitude of the whispering gallery modes spectral shift. Particular efforts were made for effective fixing of the micro spheres in the water flow, an optimal geometry for micro resonance observation and the selection of microsphere material most appropriate for microbial applications. Optical resonance of free micro spheres from PMMA fixed in micro channels produced by photolithography has been observed at a laser power of less then 1 microwatt. Resonance shifts of C reactive protein water solutions as well as albumin solutions in pure water and with HCl modelling blood have been investigated. Introducing controlled amount of glass gel nano particles into the surrounding of the microsphere caused a correlative resonance shift (400 nm in diameter) as well as a total reconstruct of resonance spectra (57 nm in diameter).

We have demonstrated that the method described is a a promising technologic platform for sensitive, lab-on-chip type diagnostics for different biological molecules, e.g. proteins, oligonucleotides, oligosaccharides, lipids, small molecules, viral particles, cells as well as in different experimental contexts e.g. proteomics, genomics, drug discovery, and membrane studies.

8025-06, Session 2

Electrical/electrochemical impedance biosensors/biochips for rapid detection of foodborne pathogenic bacteria

L. Yang, North Carolina Central Univ. (United States)

Diseases caused by foodborne pathogens have been a serious threat to public health and food safety for decades and remain one of the major concerns of our society. The realization of rapid, sensitive, and specific methods to detect foodborne pathogenic bacteria is central to implementing effective practice to ensure food safety and security.

Based on electrophysiological and impedance properties of biological cells, we present here three major mechanisms of impedance measurements that can be used for detection/quantification of bacterial cells: (i) impedance measurements based on the metabolic activity of biological cells. We have investigated different electrode systems for detecting foodborne bacteria based on their growth. (ii) impedance measurement based on the insulating properties of the cell membrane. Because of their highly insulated cell membrane, cells are attached on an electrode surface effectively reduce the electrode area that the current reaches and hence increase the interface impedance. We have investigated an interdigitated microelectrode-based label free impedance biosensors based on this principle for detection of E. coil O157:H7. (iii) Impedance measurement based on the release of highly ionic cytoplasm of the cells. We developed a new, simple and rapid impedance method to detect bacterial cells using interdigitated microelectrodes based on the release of intracellular ion in low conductivity medium. In addition, the integration of dielectrophoresis (DEP) with the microelectrode detection system for capture and separation of foodborne bacterial cells is also achieved.

8025-07, Session 2

Micro-Raman discrimination of bacterial strains using multilayered microcavity substrates

S. K. Sharma, A. C. Dykes, A. K. Misra, L. E. Kamemoto, D. E. Bates, Univ. of Hawai'i (United States)

The use of microcavity substrates coated with alternating layers of metallic thin films has enabled the discrimination of four strains of E. coli. Study of the four strains (One Shot OmniMAX 2-T1, Mach1-T1, Stbl3, and TOP10 chemically competent E. coli, Invitrogen Corporation, Carlsbad, CA) on an aluminum substrate by Raman spectroscopy yielded few obvious spectral differences. However, in subsequent studies using multilayered microcavities, spectral differences could be recognized. To confirm this observation, we also incorporated the use of multivariate analysis for positive identification and discrimination between the strains. Principal Component Analysis (PCA) of the spectra revealed the presence of four distinct E. coli strains. Microcavities were prepared by placing glass microspheres (35-41 micro-m diameter) between two polished aluminum substrates and pressing them together using a standard lab press. After removing the glass microspheres from the aluminum substrates by ultrasound in a methanol bath, the substrates were coated with thin films (ranging from 15 to 70nm) of chromium, silver and gold in a precise order. The use of these substrates results is an enhancement of the entire normal Raman spectrum. This enhancement is due to the combined effects of surface-enhanced Raman scattering (SERS) and microcavity resonance, believed to be caused by multiple excitation of the sample with the laser and reflection of the forward-scattered Raman photons toward the collection optics in the back-scattered Raman geometry.

8025-08, Session 2

Fluorescence intensity measurements with display screen as excitation source

S. Park, S. Achanta, C. Kim, Missouri Univ. of Science and Technology (United States)

Rapid technological progress in digital display devices, such as LCD (liquid crystal display), LED (light-emitting diode), OLED (organic light-emitting diode) and DLP (digital light projectors) make these optoelectronic products nearly ubiquitous around our daily lives. Several new techniques are recently emerging where these devices act as a new type of light source for analytical purpose. These examples include illuminating samples for transmission/absorption measurements and exciting luminescent samples for emission measurements. In this work, we demonstrate the use of an LCD computer screen (about 12 x 14 inch) as excitation light source for imaging two-dimensional oxygen distribution over a relatively large area. As a proof-of-concept model system, meso-scale device platforms are prepared with glass plates incorporating fluidic channels and commercial oxygen sensor patches. Fluorophores immobilized in these patches are excited by blue wavelength range (about 470 nm peak) from the LCD computer screen. The detection mechanism is based on the quenching of fluorescence emission by oxygen, thus resulting in a decrease of emission intensity with increasing oxygen content. A color CCD camera takes the image of the entire display screen. The capability of uniform illumination over a large area with variable colors (i.e. different wavelength ranges) enables to record the spatial distribution of chemicals over a large area and to analyze multiple-target simultaneously. Therefore, the display screens exhibit a great potential as light source for high-throughput, quantitative chemical analysis.

8025-09, Session 2

Development of a depolarized Raman spectrometer for potential surface-enhanced Raman optical activity (SEROA) measurements

H. Li, Biotools Inc. (United States); L. A. Nafie, Syracuse Univ. (United States)

Raman optical activity (ROA) spectroscopy is a chiral sensitive vibrational spectroscopic technique that measures the difference of molecular responses to either left or right circularly polarized photon radiation. As a structural sensitive probe, ROA has great potential for fabricating bio-molecular sensors based on their capturing molecular structure changes. Extension of ROA to widely sensing applications can be accelerated by combining it with plasmon resonance effect, surface-enhanced Raman spectroscopy (SERS), allowing for trace chemical detections.

In this paper, we will discuss the development of a depolarized Raman spectrometer, with modulation of left and right circularly polarized light in both the incident and scattered radiation path. This newly developed depolarized Raman instrument is based on the Biotools' ChiralRaman-2X scattered circularly polarized (SCP) ROA spectrometer and has been modified into a dual circularly polarized ROA spectrometer with the introducing a pair of quarter waveplate and half waveplate for circularity conversion in the incident radiation path. Combing the simultaneous detection of left and right circularly polarized scattering photons, newly developed Raman instrument are capable of modulate both incident and scattered light simultaneously resulting dual circularly polarized (DCP) ROA measurements from depolarized parent Raman scattering. The performance of the Raman spectrometer has been initially evaluated with standard sample of small molecules for the principle-proof measurements of DCP-ROA, which has been considered as one of the most feasible method to measure SEROA.

8025-10, Session 2

Colorimetric phosphorescence measurements with a color camera for oxygen determination

P. Bhagwat, S. Achanta, C. Kim, Missouri Univ. of Science and Technology (United States); D. B. Henthorn, Saint Louis Univ. (United States)

We develop a simple oxygen imaging platform with phosphorescent oxygen sensor films to demonstrate a quantitative oxygen determination method utilizing a color CCD camera. The basic principle behind oxygen detection is phosphorescence quenching of a luminophore, Pt(II) meso-tetrakis (pentafluorophenyl) porphyrin complex (PtTFPP), immobilized in a poly (dimethylsiloxane) (PDMS) matrix. This sensor material is cast to form a film on the bottom surface of a transparent petri dish. As levels of dissolved oxygen increase, phosphorescence of the complex decrease, allowing for the measurement of two-dimensional oxygen gradient formed on the surface of the sensor film. A camera with a charge-coupled device (CCD) is used in conjunction with processing software to quantify oxygen levels colorimetrically. Microscopic images were collected using a CCD camera and stored as a set of red/green/blue (RGB) images. Phosphorescence excitation (390 nm peak) is limited to the blue (B) pixels of the CCD chip and these values are discarded. While, oxygen-responsive phosphorescence emission (645 nm peak) is almost identical with the response range of the red (R) pixels. Red pixel intensity analysis effectively extracts color intensity information which directly relates to oxygen concentration. Color CCD cameras allow simultaneous acquisition of many types of chemical information by combining the merits of digital imaging with the attributes of spectroscopic measurement. Therefore, it is considered that the use of color CCD cameras is an inexpensive alternative to time-resolved imaging for relatively short-term monitoring.

8025-11, Session 3

Micro-Raman spectroscopic study of ALVAC virus infected chicken embryo cells

A. K. Misra, L. E. Kamemoto, Univ. of Hawai'i (United States); N. Hu, Indiana Univ. School of Medicine (United States); A. C. Dykes, Univ. of Hawai`i (United States); Q. Yu, Indiana Univ. School of Medicine (United States); S. K. Sharma, Univ. of Hawai'i (United States)

We explored possibility of utilizing micro-Raman spectroscopy to distinguish between virus infected and normal cells based on Raman spectral differences. Micro-Raman systems can measure Raman spectra of individual cells, which show several fingerprint spectral features. Because the batch of virus infected cells also contains a large number of normal cells, it was not possible to establish if the individual cell under Raman microscope was infected. To resolve this issue we approached the problem with two solutions. One of the approaches was to study chicken embryo fibroblast cells which show morphological changes when infected, providing a visual discrimination and identification of virus infected cells. And, secondly to use a virus that was labeled with green fluorescence protein (GFP). This procedure provides further confirmation of virus infection of the cells. Micro- Raman spectroscopic investigation of chicken embryo fibroblast cells infected with ALVAC virus labeled with green fluorescence protein (GFP) were performed with a 785 nm laser with 10 mW of laser power and 60 s integration time. Raman spectroscopy was able to distinguish the virus infected cells that show additional bands, in comparison to spectra of normal cells, at 536, 854, 925 and 1086 cm-1, respectively corresponding to δ(C-O-C) glycosidic ring, tyrosine ring breathing mode, protein α-helix and DNA (O-P-O) mode. Another finding was that the presence of GFP does not affect the Raman spectra of samples when using a 785 nm micro-Raman system because the green fluorescence wavelength of GFP is well below the Stokes shifted Raman spectral region.

8025-12, Session 3

UV Raman spectroscopy of HIV antigens

P. V. Zinin, L. E. Kamemoto, Univ. of Hawai'i (United States); Q. Yu, N. Hu, Indiana Univ. School of Medicine (United States); A. K. Misra, S. K. Sharma, Univ. of Hawai'i (United States)

Micro-Raman spectroscopy has been used for studying chemical bonds of human immunodeficiency virus (HIV1-HIV2) in human sera, DNA sequences related to HIV, and the surface-enhanced Raman gene probe was also applied for HIV detection. Raman scattering from HIV antigen has not been investigated so far. In this report, we present results of the Raman scattering measurements of HIV antigen, p24. The Raman spectra were excited with ultraviolet (244 nm) and infrared (875 nm) lasers. The spectrum of HIV antigen excited with infrared laser contains numerous Raman peaks among which the most prominent are broad bands at 1343, 1448 1610 and 1665 cm-1 characteristic to Raman spectra of biological cells. The UV Raman spectrum of the HIV antigen has completely different structure. It has two strong peaks at 1613 cm-1 and 1173 cm-1. The peak at 1613 cm-1 is associated with vibrations of aromatic amino acids tyrosine (Tyr) and tryptophan (Try). The second strongest peak at 1173 cm-1 can be associated with vibration of Tyr. The low fluorescent background in the UV Raman spectrum makes UV Raman spectroscopy a quantitative technique. It was demonstrated recently that UV Raman spectroscopy with 244 nm excitation is a useful means of detecting changes in the amounts of nucleic acid in bacteria. Results of this study suggest that UV Rama spectroscopy can be used as a quantitative tool for detection and characterization of the HIV antigen and may be HIV virus as well.

8025-13, Session 3

Two-photon photoacoustic spectroscopy for noninvasive subsurface chemical diagnostics

S. Dahal, B. M. Cullum, J. B. Kiser, Univ. of Maryland, Baltimore County (United States)

Photoacoustic spectroscopy is a powerful optical biopsy technique that enables rapid tumor diagnosis in situ. It has been reported that photoacoustic spectroscopy can also be used to diagnose pre-malignant tissue based on the chemical differences between healthy and pre-malignant cells. Since resulting acoustic signals obtained from tissues suffer from minimum damping, there is minimal loss of signal. Our research focuses on the development of a novel method for margining of malignant and pre-malignant tissues using two-photon photoacoustic spectroscopy.

Preliminary studies have revealed that a two-photon excitation process in tissues using nanosecond laser pulses produces ultrasonic signals that transmit through tissue with minimal loss. Additionally, the two-photon excitation process is highly localized because only non-scattered, or ballistic, photons contribute to the excitation process. This eliminates undesired absorption from parts of the tissue not of interest and thereby increases the spatial resolution of the diagnostic technique to that achievable via optics. This talk will discuss proof-of-principle studies of two-photon excitation on model compounds. It was found that photoacoustic signals obtained from compounds like rhodamine 6G, rhodamine B and naphthalene, using two-photon excitation, suffered from less noise than when single-photon excitation was employed. Additionally, photoacoustic signals obtained from samples embedded in gelatin media, made to mimic tissues, have also shown a great deal of promise for moving towards real-time tissue diagnostics and margining.

8025-14, Session 3

Studies of MRI relaxivities of gadolinium-labeled dendronized gold nanoparticles

H. Pan, M. F. Daniel, Univ. of Maryland, Baltimore County (United States)

In cancer detection, imaging techniques have a great importance in diagnosis. The more sensitive the imaging technique and the earlier the tumor can be detected. Contrast agents have the capabilitity to increase the sensitivity in imaging techniques such as computed tomography (CT) or magnetic resonance imaging (MRI). Until now, gadolinium-based contrast agents are mainly used for MRI, and show good enhancement. But improvement is needed for detection of smaller tumors at the earliest stage possible. Gold nanoparticles (GNPs) coated with paramagnetic Gd(DOTA) complex attached on poly(propylene imine) dendron were synthesized and evaluated as a new MRI contrast agent. Well-dispersed functionalized spherical GNPs were synthesized and purified with a mean size of 23-27nm. Particle stability, surface charge and polydispersity were also measured. The transverse and longitudinal relaxation effects were tested and compared with Gd(DOTA) derivatized poly(propylene imine) dendrons.

8025-15, Session 4

Temperature elevations in prostatic tumors during laser photothermal therapy

L. Zhu, A. Attaluri, H. Cai, R. Edziah, E. Lalanne, C. Bieberich, R. Ma, A. M. Johnson, Univ. of Maryland, Baltimore County (United States)

In laser photothermal therapy, the near infrared laser at ~800 nm is attractive due to its deep optical penetration in tissue. The laser is maximally absorbed in the tumor region congregating by gold nanorods, with minimal laser absorption by normal tissue. In this study, in vivo experiments were performed to measure temperature elevations in prostatic tumors implanted in mice during laser photothermal therapy. Ti:Sapphire laser tuned at 800 nm irradiating the surface of the tumor delivered an average laser power of 0.5 - 1.0 W, equivalent to a laser radiance of 1.3-2.6 W/cm^2. Temperatures measured by two thermocouples located at the center and bottom of the tumor have shown a non-uniform tumor temperature field. Using only 0.2 cc of the nanorod solution (NTracker by NanPartzTM, longitudinal length: 45 nm, axial diameter: 10 nm, 10^13 NPS/cc) via intratumoral injection, one observed large temperature elevations of 10-30C above the baseline temperature of 37C. The results have suggested a minimal laser power of 0.5 W to induce a minimal temperature at the tumor bottom above 45C, a threshold temperature to cause irreversible thermal damage. Although a higher laser power on the tumor surface will result in larger temperature elevations, collateral thermal damage to the surrounding healthy tissue is likely to occur. The experimental studies have demonstrated the capability of confining laser energy in tumors by a very small amount of nanorod solution. However, a more carefully designed laser treatment protocols is needed to balance killing tumor cells and minimization of collateral damage.

8025-16, Session 4

Synthesis and biological studies of highly concentrated lisinopril-capped gold nanoparticles for CT tracking of angiotensin converting enzyme (ACE)

W. E. Ghann, Univ. of Maryland, Baltimore County (United States); O. Aras, T. Fleiter, Univ. of Maryland Medical Ctr. (United States); M. F. Daniel, Univ. of Maryland, Baltimore County (United States)

For patients with a history of heart attack or stroke, the prevention of another cardiovascular or cerebrovascular event is crucial. Computed Tomography (CT) imaging is so far considered the best choice for assessing suspected acute stroke, but this technique needs improvement in order to be used for accurate prevention. Recently gold nanoparticles have shown great potential as CT contrast agents. Because of their easy derivatization, they can provide targeted imaging. Since lisinopril is an ACE inhibitor, it has been used as coating on gold nanoparticles for targeted imaging of tissue ACE in prevention of fibrosis. Herein, lisinopril-capped gold nanoparticles (GNPs) were synthesized up to a concentration of 54 mgAu/mL. Their contrast was measured using computed tomography (CT) and the results were compared to the commonly used Omnipaque contrast agent. The biodistribution of these lisinopril-capped GNPs was also assessed, as well as their targeting abilities.

8025-17, Session 4

Securing medical monitoring devices using advanced RFID technology

D. Engels, Massachusetts Institute of Technology (United States)

RFID technology is making a significant impact on defense operations through many medical devices and sensors. Doctors are now able to monitor patient health using the wireless programmable capabilities made possible through RFID implementation. However, as these new technologies continue to advance, the healthcare industry poses high concerns for the overall security in wirelessly transmitting private information over sensor networks is particularly critical in military medical monitoring applications. Although these new medical advances could be significant in increasing efficiency, lowering operations costs and keeping combat soldiers safer, the concern is securing information that is transmitted wirelessly through sensors and chips embedded into medical devices or monitoring patients/soldiers. With the use of unsecure medical devices, transference through sensor networks can be intercepted by anyone with a nearby computer and enough smarts to hack into military personnel and access soldiers' medical statuses at their fingertips. This creates major privacy concerns which violate HIPPA regulations not to mention critical military information regarding the health and combat status of soldiers that is vital to defense efforts. Because there has never been an actual case where hackers have been able to intercept military information or medical records via RFID-enabled medical devices or physiological monitoring sensors, securing communications has been of little importance. The reality, however, is the overall credibility of our national defense and security can be compromised at a very high cost. Securing medical devices that lack resources and computational power to support current encryption standards is crucial and therefore should be examined immediately.

8025-18, Session 4

An innovative non-contact ECG sensor

Y. Sun, X. Yu, J. Berrilla, Case Western Reserve Univ. (United States)

This paper describes the development of a non-contact sensing platform to monitor the ECG signals. The non-contact sensing will be based on capacitive coupling the bioelectricity produced by cardiovascular activities around the heart. High sensitivity sensor and electronics are designed to amplify the signals. Our preliminary study has pointed to the promise of this sensing concept. A sensor prototype was able to clearly detect the ECG signals from 10 cm away from the body. Research tasks continue improving the sensor design to detect the polarization in the ECG signals. The final goal is a non-contact sensing platform for ECG signals and for real time diagnostics of the mental distress and cardiovascular diseases.

8025-19, Poster Session

Anti-sleepiness sensor systems for sober mental condition

W. H. Han, H. S. Jung, H. G. Lee, Hana Academy Seoul (Korea, Republic of)

Anti-sleepiness sensor systems have been devised for soldier's sober mental condition. These apparatuses judge whether or not the soldier is sleepy, on one hand by directly monitoring his/her open or closed eyes, on the other hand by measuring the heart beat and rate on the carotid artery of his/her neck. They usually adopt one of the following sensing methods such as the optical, mechanical, magnetic impedance and piezoelectric sensor and so on.

In order to directly monitor the soldier's open or closed eyes(their temperature difference $\geq$ 0.5), we employ MWIR(Medium wavelength Infrared) sensors which is equipped on goggles(that is to say, anti-sleepiness glasses). To measure the soldier's heart beat and rate, the piezoelectric PMN-PT crystal sensor(its max. output voltage-400mV) is used with other modules on the necklet(namely, anti-sleepiness necklet), and of course the other sensors such as the optical, mechanical and magnetic impedance sensors can be used for the same purpose but we confirm the piezoelectric PMN-PT crystal sensor is the best. In this paper, the characteristics of the sensors are compared and subsequently the suitable ones are proposed from the viewpoint of high measurement reliability. The proposed sensor systems and relevant ideas can be applicable to the civilian usage as well; for instance, the student preparing for an examination and car driver.

8025-21, Poster Session

Two-stage microfluidic device for acoustic particle manipulation

M. C. Jo, R. O. Guldiken, Univ. of South Florida (United States)

No abstract available

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8026-01, Session 1

PFO hydrogen detection sensor systems for space applications

A. A. Kazemi, ARK International (United States)

This paper describes the first successful Plastic Optical Fiber (POF) hydrogen detection sensor systems developed for the Boeing Delta IV Launch Vehicle. Hydrogen detection in space application is very challenging; the hydrogen detection is priority for rocket industry and every transport device or any application where hydrogen is involve. H2 sensors are necessary to monitor the detection possible leak to avoid explosion, which can be highly dangerous. The hydrogen sensors was used on the Common Booster Core (CBC) of Delta IV had to perform in temperatures between -10 F and +140 F. The response of the sensor in this temperature regime was characterized to ensure proper response of the sensors to fugitive hydrogen leakage during vehicle ground operations. We developed the first 1 km POF H2 sensors. Performed detail investigation of POF cables for attenuation loss, module distribution, tension, bend, thermal, humidity, temperature, shock, flammability, accelerate testing for life expectancy. Also evaluated absorption, Rayleigh scatter, Fresnel reflection, bending losses as well as of the insertion loss, return loss, mating durability, operating and high/low temperatures, shock and vibration, retention, and harsh environmental for POF cables connectors. The same test procedures were performed for glass single mode fiber part of the H2 and O2 sensors. Extensive networking using wavelength division multiplexing (WDM) and neural-network were carried out. Sub-element testing of POF was performed to quantify the element of the sensor package that was responsible for temperature response during temperature cycling.

8026-02, Session 1

Viability of guided-wave ultrasound-based diagnostics for sharply curved composite structures

I. F. Saxena, Intelligent Optical Systems, Inc. (United States); V. Dayal, Iowa State Univ. (United States); L. U. Kempen, Intelligent Optical Systems, Inc. (United States)

Guided wave ultrasound is well suited for inspection of laminate composite structures. Compared to nearly flat or gently curved composites, performing accurate NDT on sharply curved structures is more complicated. Limitations of standard ultrasound test methodologies, such as pulse-echo and pitch-catch methods, will be discussed for highly curved structures. We have shown that removable Fiber Bragg gratings can be used for guided wave ultrasound field mapping. Ultrasound propagation in curved composite structures will be investigated for various geometries using removable Fiber Bragg gratings. Experimental results will be presented on sample curved composite geometries as encountered in aircraft structures.

8026-03, Session 1

Advances towards the qualification of an aircraft fuel tank inert environment

E. A. Mendoza, Redondo Optics, Inc. (United States)

An all optical pressure and temperature compensated fiber optic oxygen sensor (FOxSense) system is under qualification for use in the in-situ closed-loop-control of the inert atmosphere environment inside fuel tanks of military and commercial aircraft. The all-optical oxygen environment control sensor is a passive, intrinsically safe, fiber-optic sensor device with no electrical connections leading to the sensors installed within the fuel tanks of an aircraft. To control the fuel tank environment, an array of multiple sensors is deployed throughout the fuel tanks of an aircraft, and a remote multi-channel optoelectronic system is used to monitor the status of all the sensors in real time to provide feedback oxygen environment information to the on-board inert gas generating system (OBIGS). A multichannel frequency-domain fiber-optic sensor read-out is used to interrogate the optical signals of all three sensors in real-time and to display the fuel tank oxygen environment in a “safe (green light)”, “warning (yellow light)”, and “alarm (red light)” visual display suitable for aircraft fuel tank ullage status and alarm applications. Qualification testing of the all optical sensor have demonstrated the ability to monitor the oxygen environment inside a simulated fuel tank environment in the oxygen range from 0% to 21% oxygen concentrations, temperatures from (-) 40°C to (+) 60°C, and altitudes from sea level to 40,000 feet.

8026-04, Session 1

Intrinsically safe oxygen and hydrogen optical leak detector

M. Beshay, S. Garon, D. Ruiz, L. U. Kempen, Intelligent Optical Systems, Inc. (United States)

Cryogenic leak detection is critical in space missions specifically to avoid launch delays. Thus, real-time, multi-location, early leak detection of oxygen and hydrogen down to ppm levels is extremely important for safety, reliability, and economic reasons. This paper discusses the advances in fiber optic leak detection of oxygen and hydrogen specifically for space applications. Emphasis on operational conditions such as low temperature (-150 C) and vacuum environment, and performance characteristics such as sensitivity (10 ppm) and response time (~ 3 seconds) are addressed in this paper.

8026-05, Session 2

Miniaturized real-time monitor for fuel cell leak applications

M. Beshay, J. G. Chandrasekhar, J. Delgado, C. Boehr, R. A. Lieberman, Intelligent Optical Systems, Inc. (United States)

Intrinsically safe detection of hydrogen leaks in fuel cells vehicles (FCV) is becoming a critical barrier to ensure the operational safety of these systems. Early indication of a leak will not only allow to trigger an alarm in unsafe situations, but will also dramatically reduce the risk and cost associated with fuel cell malfunction. In this paper we discuss the applicability of optical hydrogen leak detection technology developed at our company for on-board, real-time, and intrinsically safe monitoring applications. With sensitivity of 0.05% (500 ppm) in atmospheric air, response time of 3-5 seconds, Operation in a wide range of environmental conditions (5-90 % RH, 0-55 ˚C), and power consumption that does not exceed 0.5 W, this leak detection technique offers a promising solution to meet FCV on-board sensing requirements.

8026-06, Session 2

Online automatic measurement of deflection for automobile based on digital CCD sensors

C. Chen, Y. Liu, G. Wang, Wuhan Univ. (China); Y. He, Wuhan Univ. of Technology (China)

As we know, the track of a vehicle that runs on a flat road must be straight. If deflection exists, the vehicle will run along a curve. Vehicles with big deflection will easily lead to many kinds of dangers and cause serious accident. But until now, automobile companies haven't effective methods and equipments to measuring the deflection of automobile. Most of the testing is handled by drivers themselves with manual estimate when they feel big aberrancy with the vehicle.

A typical configuration of test field is road with about 150 meters long. In this field, the car move with a certain speed (such as 60KM/H) from point A to point B and reached point C. Reference to geometric relationship of A, B and C, if we get the coordinates of A, B and C, we can calculate the deflection of the vehicle.

In our research, three CCD cameras were installed at three positions over the roadway. Three cameras capture digital image of vehicle when it pass these three positions and transfer the digital images to the host computer. The computer analysis the digital images to extract the vehicle and the target points on the vehicle by image segmentation, feature extraction and image matching technique. After the vehicle and the target points are extracted from the images, according the theory of photogrammetry, we can get the coordinate of vehicle in each position.

As the car can not enter the test field exactly along the road center line or parallel to road center line, dynamic baseline method (Line from A to B) is convenient for tester drive the vehicle to finish the test. The driver adjusts entering-angle to approximately parallel to road center line before entering the test field, and then free his hand from steering wheel of the vehicle. After the vehicle pass position C, the test finished.

8026-07, Session 2

AUV-portable temperature-compensating fiber optic hydrophone

I. F. Saxena, N. Guzman, K. J. Hui, S. Pflanze, Intelligent Optical Systems, Inc. (United States)

Passive acoustic monitoring hydrophones for autonomous underwater vehicles (AUVs) with low power consumption are desirable for long term unmanned monitoring of marine mammals and man-made ocean acoustics. Fiber optic hydrophones offer wider bandwith and high sensitivity alternatives to conventional PZT based devices. Operation with AUVs requires operation under a wide range of temperature and depth conditions, hence, maintaining the sensitivity and reliability over the operating range is crucial.

A resonant hydrophone using a fiber Bragg grating (FBG) transducer is described with a read-out mechanism that compensates for, and reliably operates over a wide temperature range. Its compact footprint and battery-powered readout system operation enables portability on AUVs.

8026-08, Session 3

Incoherent light guide imager for harsh and complex environments

L. R. Gauthier, Jr., The Johns Hopkins Univ. (United States)

Fiber optic imaging systems are used in many applications, including medical imaging, machinery diagnostics, and remote sensing. Most commonly, coherent bundles of optical fibers are used that maintain the spatial positioning of each fiber throughout the length of the bundle, resulting in a recognizable proximal image that is almost identical to the distal image projected into the bundle by the distal lens. While coherent fiber bundles provide excellent solutions for many imaging applications, their limited flexibility and thermal stress intolerance may prohibit them from being used in harsh or complex environments. The flexibility and thermal tolerance of a fiber imaging system can be significantly improved by using an incoherent bundle of fibers wherein the spatial positioning of each fiber is not preserved throughout the length of the bundle. Incoherent bundles need to be calibrated to provide the means to reconstruct distal imagery. In reported calibration schemes, the calibration time is strongly dependent on the ratio between the bundle size and the fiber size. The calibration time can thus become prohibitive for highly resolved images using many fibers. A novel calibration scheme is described for incoherent bundles where the calibration time is proportional to the size ratio, resulting in significantly reduced processing time and enabling more highly resolved images. As an added benefit for medical and remote sensing applications, the implicit encryption of using incoherent fiber bundles may provide a desirable level of security for safeguarding the information.

8026-09, Session 3

Digital micromirror device-based robust object boundary mapping sensor

P. J. Marraccini, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); C. Baxley, Univ. of Central Florida (United States); N. A. Riza, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

This paper presents a novel, non-intrusive, non-contact object boundary mapping sensor using a Digital Micromirror Device (DMD). The proposed sensor is a free-space-based optical sensor that uses DMD-based agile optics to direct light from an object source that requires boundary mapping within the viewed scene. The presented compact design makes the proposed sensor ideal for use in environments where brightly illuminated or radiating objects are in a hazardous environment such as in environments with radiation, heat, cold, harmful machine parts, etc. The proposed design uses a few optical components and smart signal processing hardware for making its object boundary measurements. The presented sensor can find potential remote sensing applications in military target recognition, machine parts inspection and in chemical, transportation and aerospace industries.

8026-10, Session 3

High resolution wide dynamic range distance sensor using spatial signal processing

P. J. Marraccini, N. A. Riza, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

This paper presents a non-intrusive, non-contact object distance mapping sensor using an Electronically Controlled Variable Focus Lens (ECVFL). The proposed sensor is a free-space-based optical sensor that uses ECVFL-based agile optics to direct light from a object that requires terrain height mapping. The presented compact design makes the proposed sensor ideal for use in environments where laser illuminated objects are in a hazardous environment such as in environments with radiation, heat, cold, harmful machine parts, etc. The proposed design uses a few optical components and smart detection optics for making its object distance/terrain measurements. The presented sensor can find potential remote sensing applications in ground and space vehicle maneuvering, machine parts inspection and in chemical, transportation and aerospace industries.

8026-11, Session 3

Multimode laser beam characterization using agile digital-analog photonics

P. J. Marraccini, N. A. Riza, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

This paper presents a multimode laser beam analyzer using a Digital Micromirror Device (DMD) and an Electronically Controlled Variable Focus Lens (ECVFL) that serve as the digital and analog agile optics, respectively. The proposed analyzer is a broadband laser characterization device that uses the agile optics to smartly direct light to the required point photo detectors. The proposed system has the ability to measure the following laser beam parameters: waist size, minimum beam waist location, beam divergence and the beam propagation parameter (M2). The proposed system can also take into account variation in irradiance of the source and can also be used to map arbitrary optical targets. The presented design can find potential applications in laser beam characterization, target detection, and in chemical, transportation and aerospace industries.

8026-26, Session 3

Evanescent wave absorption measurements of corroded materials using ATR and optical fibers

J. S. Namkung, Naval Air Warfare Ctr. Aircraft Div. (United States); M. L. Hoke, Air Force Research Lab. (United States); A. Schwartz, Naval Air Systems Command (United States)

The purpose of this research effort is to develop an in-situ corrosion sensing capability. The technique will permit detection of corrosion on and within aircraft structures, and component junctions that are susceptible to corrosion, but which are not accessible for visual inspection. The prototype experimental configuration includes long wave infrared transmitting optical fiber probes interfaced with a Fourier Transform Infrared (FTIR) interferometer for evanescent wave absorption spectroscopic measurements. The mature and fielded technique will allow periodic remote sensing for detection of corrosion and general onboard structural health monitoring. An experimental setup using an Attenuated Total Reflection (ATR) crystal which is integrated to FTIR spectrometer has been assembled. Absorption spectra of pure Al(OH)3, have been collected with this ATR/FTIR experimental setup as reference spectral signatures. Aluminum Hydroxide [Al(OH)3] is one main corrosion component of aluminum, which is the principle structural metal of aircraft. The spectra of samples from a simulated corrosion process have been collected and compared with the reference Al(OH)3 spectra. Also absorption spectra of corrosion collected from the fielded aircraft part have been obtained and compared with the spectra from the simulated corrosion.

8026-12, Session 4

Wireless/integrated strain monitoring and simulation system

F. Abdi, AlphaSTAR Corp. (United States)

This paper addresses the development and real time test validation of an integrated hardware and software environment that will be able to measure real-time in-situ strain and deformation fields using a state-of-the-art wireless sensor system to enhance structural durability and damage tolerance (D&DT), reliability via real-time structural health monitoring (SHM) for sensorized aerospace structures. The tool will be a vital added extension of existing suite of structural health monitoring (SHM) and diagnostic prognostic system (DPS). The goal of the extended SHM-DPS is to apply a multi-scale nonlinear physics-based finite element analyses (FEA) to the "as-is" structural configuration to determine multi-site damage evolution, residual strength, remaining service life, and future inspection intervals and procedures. Information from a distributed system of wireless sensors will be used to determine the "as-is' state of the structure versus the "as-designed" target. The approach enables active monitoring of aerospace structural component performance and realization of DPS-based conditioned based maintenance. Software enhancements will incorporate information from a sensor network system that is distributed over an aerospace structural component. As case study DPS application a realistic composite stiffened panel representative of fuselage/wing components is selected. Two stiffened panels is manufactured and instrumented; a) embedded internally between composite layers, and b) surface mounted with wireless sensors; the second of which with an optimized sensor network. The panels will be tested in compression following low-velocity impact. The sensor system output will be routed and integrated with a finite element analysis (FEA) tool to determine the panel's, multi-site damage locations, and associated failure mechanisms, residual strength, remaining service life, and future inspection interval. The FEA will utilize the web/internet based GENOA progressive failure analysis commercial software suite, durability and damage tolerance (D&DT), and reliability software capable of evaluating both metallic and advanced composite structural panels under service loading conditions. The proposal will utilize a building block validation strategy, and real-time structural health monitoring system.

8026-13, Session 4

All optical O_2 sensors using innovative phase fluorimetry for monitoring of headspace in ullage for FAA mandated inerting fuel tanks of commercial airlines

A. S. Panahi, Accro USA, LLC (United States)

Fluorescence quenching has proven to be the leading technique for measuring oxygen in all optical sensors. In order to trap a fluorescent compound in an oxygen permeable medium, optically clear sol gel matrix is utilized. The fluorescence of this compound is excited by blue LEDs or low cost LASER like those used in Blu-Ray players. O2 molecules collide with the excited state of the fluorophore and release the energy non-radiatively. This quenching effect is measured by phase fluorimetry as the average decay time, and is use to determine pO2 in the sensor. For monitoring the O2 generated in head space in the ullage of inerting fuel tanks the sensor requires intrinsically safe operation that is both temperature and pressure compensated during of the aircraft flight conditions. It is shown that the proposed sensor calibration is straightforward, as the quenching follows the Stern-Volmer quenching equation.

This paper compares the various techniques available to measure the lifetime of the fluorescent decay in some depth, and concludes with a very cost effective, efficient, and lightweight optical sensor is that use COTS and is superior to the methods and circuit techniques in existence to date.

8026-14, Session 4

Compact and fast read-out for wavelength-encoded sensors

P. Kiesel, K. Bellmann, N. M. Johnson, Palo Alto Research Center, Inc. (United States)

Many new optical sensor concepts rely on the detection of small wavelength changes in response to changes of temperature, strain, adhesion of bio-particles, or change in the chemical environment. Examples include Fiber Bragg Grating (FBG) sensors, laser cavity sensors, micro-sphere or micro-ring based sensors, surface plasmon resonance sensors as well as photonic crystal sensors. The major advantages of these sensors over electronic sensors are their sensitivity and the possibility of remote and distributed sensing, making them

suitable for harsh environments and immune to electromagnetic interferences. However, commercially available interrogation systems that are capable of resolving the small wavelength shifts (sub pm to few nm) produced by these sensors are bulky and expensive.

We will describe a compact and fast wavelength monitor that can resolve sub-pm wavelength changes. It combines a photosensor array or position detector element with a linear variable filter that converts the wavelength information of the incident light into a spatial intensity distribution on the detector. Differential read-out of two adjacent elements of the photosensor array or the position detector is used to determine the centroid of this distribution. A wavelength change of the incident light is detected as a shift of the centroid of the distribution. The wavelength monitor can be used as read-out unit for any optical sensor that produces a wavelength shift in response to a stimulus. The wavelength interrogation unit has been applied to measure temperature and strain with FBG sensors at 1550nm (C-band). We were able to resolve wavelength changes as small as 50fm with a bandwidth of more than 100Hz. The resolution at 10KHz was still better than 300fm which allows to clearly monitor 10 kHz vibrations with amplitude as small as 0.25 µm.

8026-15, Session 4

Development of an ultrafast response fluorescence hydrogen sensor for leak detection in hazardous explosive environments

E. A. Mendoza, Redondo Optics, Inc. (United States)

A new fluorescence based fiber optic hydrogen gas sensor is under development for use in the ultra-fast and reliable detection of hydrogen gas leaks in hazardous explosive environments. The fiber optic hydrogen sensor (H2Sens) consists of an optical fiber coated with an environmentally robust sol-gel derived gas permeable membrane that incorporates a fluorescence indicator with a fast millisecond response to the presence of hydrogen leaks. The H2Sens uses an environmentally robust probe that incorporates a second optical fiber coated with a temperature sensitive fluorescence indicator to provide real-time in-situ temperature compensation to the hydrogen sensor. The fiber optic H2 sensor interrogation system uses an microsecond response frequency-domain fluorescence lifetime fiber-optic sensor read-out to interrogate the optical signals of the sensors in real-time, process the signals, and to display the status of the hydrogen environment in a “safe (green light)”, “warning (yellow light)”, and “alarm (red light)” visual display.

8026-16, Session 4

Battery outgassing sensor for electric drive vehicle energy storage systems

M. Beshay, J. G. Chandrasekhar, L. U. Kempen, Intelligent Optical Systems, Inc. (United States)

Lithium-ion batteries have proved their efficiency as high power density and low self-discharge rates energy storage systems specifically in electrical drive vehicles. An important safety factor associated with these systems is potential outgassing of hazardous chemical vapors such as hydrogen fluoride (HF), hydrogen sulfide (H_2S), and relatively elevated levels of carbon dioxide (CO_2). The possible accumulation of these gases emphases the need for in-line monitoring; they are also reliable indicators of leakage of damage to the battery packs. IOS has identified a viable approach for an on-board optical sensor array to monitor battery outgassing. The system approach that meets the sensitivity and response time requirements is discussed.

8026-17, Session 5

High speed laser communication network for satellite systems

A. S. Panahi, Accro USA, LLC (United States); A. A. Kazemi, ARK International (United States)

Using optical links in space and building high speed communications network 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. 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. 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.

8026-18, Session 5

Wireless optical links for avionic applications

E. Y. Chan, D. G. Koshinz, W. Krug, H. Hager, The Boeing Co. (United States)

Since our initial paper presentations on wireless white LED (WELD) optical link at IEEE Avionics Fiber Optics and Photonics (AVFOP) Conference and SPIE Defense, Security and Sensing (DSS) Conference in 1998 and 1999 respectively, we have drawn considerable interest in the aerospace and automotive industry in our research and development effort. Recently, we have made significant progress in the development of high quality and error free wireless optical communication links for aerospace applications. We have developed wide dynamic range and high power small form factor (SFF) transceivers that are suitable for use in aerospace platforms; our experimental results have demonstrated using different optical sources to achieve the optimum optical link performance in distance, bandwidth and bit-error-rate (BER) for avionic applications.

8026-19, Session 5

Towards development of a fiber optic-based transmission monitoring system

C. S. Baldwin, J. S. Kiddy, Aither Engineering, Inc. (United States)

There is interest in the rotorcraft community to develop health monitoring technologies. Among these technologies is the ability to monitor the transmission planetary gear system. The gearbox environment does not lend itself to traditional sensing technologies due to the harsh environment and crowed space. Traditional vibration-based diagnostics are based on the output from externally mounted sensors, usually accelerometers fixed to the gearbox exterior. This type of system relies on the ability of the vibration signal to travel from the gears through the gearbox housing. These sensors are also susceptible to other interference including electrical magnetic interference (EMI). For these reasons, the development of a fiber optic-based transmission monitoring system represents an appealing alternative to the accelerometer due to their resistance to EMI and other signal corrupting influences. Aither Engineering has been working on integrating the fiber optic sensors into the gearbox environment to measure strain on the ring gear of the planetary gear system. This application utilizes a serial array of wavelength division multiplexed fiber Bragg grating (FBG) sensors. Work in this area has been conducted at both the University of Maryland, College Park and more recently at the NASA Glenn Research Center (NGRC) OH-58 transmission test rig facility. This paper discusses some of the testing results collected from the fiber optic ring gear sensor array. Based on these results, recommendations for system requirements are addressed in terms of the capabilities of the FBG instrumentation.

8026-20, Session 5

A low cost disposable hydrogen sensor using guided optics : review for an optimal sensor

C. Perrotton, P. P. Meyrueis, Ecole Nationale Supérieure de Physique de Strasbourg (France)

We introduce here the concept of a new disposable hydrogen sensor using plasmonics effects and photonics waveguiding. We use a classical telecom fiber that we select for its performances and we modify its architecture replacing a part of the coating by a modulated material having a physics interaction with hydrogen. We have investigated several materials for their properties and we justify the reason of our choice. We introduce a review concerning previous hydrogen sensors and we discuss the best ways to proceed on these basis. We introduce also simulations to validate approaches of an ideal hydrogen photonic sensor.

In previous papers, we have introduced some principles for photonics hydrogen sensing methods through guided optics. In this paper, we present the first step toward industrial developments. In further papers, we will describe the results of experimental validations now in process.

8026-21, Session 6

Speckle reduction technique for laser based automotive HUD projectors

B. Kress, USI Photonics Inc. (United States)

Recently various HUD (Head Up Display) projection engines have been introduced, suited for the automotive market, and therefore being very small and low cost. Some of the most promising projectors are laser based and project directly a far-field image superimposed onto the driver's field of view by the mean of an optical combiner.

One of the major drawbacks of such technology is the parasitic speckle produced by the coherent nature of the illumination (laser light), which has been proven to be very annoying and distracting for the driver. We propose a method to overcome the parasitic speckle phenomenon in the HUD application, not by reducing it directly but rather by uniformizing the speckle within the integration time of the eye, through generation of an orthogonal set of speckle modes for a single projected image.

8026-22, Session 6

Diffractive elements manufactured by grey tone mask and global laser lighting for transportation applications

P. P. Meyrueis, Ecole Nationale Supérieure de Physique de Strasbourg (France)

In transportation optical interconnection systems are more and more necessary for processing embarked data flow as for instance for entertainment for plane or multiplexed sensing for automotive.

Digital diffractive devices are necessary as emitting or receiving antenna in data com interconnection. These devices have to be industrially produced for being integrated but at low cost and with a good quality level. Classical lithography is a well known tool for digital diffractive component manufacturing with a set of mask used in a sequence for instance for etching with 64 levels.

We introduce here a method with only one mask with grey tone and global laser lighting. We show that the quality is more stable. We consider some problems related to the necessity to control the response for every photosensitive material used. We show the advantages of the proposed global method compared to the pixel by pixel laser ablation.

We conclude by some examples of uses in transportation system.

8026-23, Session 6

A low cost virtual reality system for automotive surrounding display using only one video beamer

T. Blandet, Ecole Nationale Supérieure de Physique de Strasbourg (France)

Virtual reality systems are more and more used for an extended range of applications in industry, business, bio medical, defense, education, entertainment, etc.

The advantages of virtual reality are now well known and the virtual reality technologies made significant progresses these last years. The demand for virtual reality use is growing.

One inconvenient of virtual reality general uses is that virtual reality hardware is expensive of the quality of the displays has to be good.

We have recently issued a demonstrator with an optimized virtual reality technology using some dedicated components and many mass produced ones that the device to be produced at low cost without using a sophisticated facility.

We describe the design of the virtual reality device that we propose that is using one beamer for 3D rendering instead of 3.

We use a polymer screen that is not destroying the polarization image separation can be operated by transparency. We use also for separating the stereo images a polarization rotation device on one imaging channel that allow to produce good quality stereo imaging by standard high frequency beamer.

We detail the model that we used and we analyze the displays results.

We conclude by a presentation of some achievements and a prospective overview of the open market for the low cost virtual reality system that can be now mass produced.

8026-24, Session 6

Novel diffractive HUD combiner fabrication method

P. St. Hilaire, Holox Inc. (United States); B. Kress, USI Photonics Inc. (United States)

One of the challenge in introducing low cost HUD (Head Up Displays) into the transportation industry is to produce low cost mass replicable optical combiners, and preferably low cost flat holographic combiners which implement not only the combining functionality but also the image formation functionality (virtual image formation ahead of the vehicle). Dichroic curved optical combiners and conventional holographic combiners have been produced since a few decades. The straightforward fabrication way is traditional holographic exposure onto expensive and low MTBF holographic materials such as dichromated gelatin, silver halides, photopolymers or even photo resist and subsequent embossing into plastic. We propose a novel low cost fabrication technique for the production of synthetic holographic HUD combiners composed of sub-wavelength tilted structures, which can provide similar functionality as traditional index modulation holograms.

8026-25, Poster Session

ARCADIS: IED detection and logistic infrastructure security

D. Monnin, E. Bieber, G. Schmitt, A. L. Schneider, J. Moeglin, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Improvised Explosive Devices (IEDs) are one of today's major threats that anti-terrorism actors have to cope with. We propose a platform for on-board detection of suspicious objects using advanced computer vision. The system allows the driver to be warned of the presence of changes, i.e. potential IEDs along his itinerary. The applications are: IED detection in military operations, airport runways security and railways security.

Return to Contents

Conference 8027: Sensing for Agriculture and Food Quality and Safety III

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8027-01, Session 1

Combination of LIBS and Raman for food quality monitoring

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Raman and Laser-Induced Breakdown Spectroscopy (LIBS) are two common techniques emerging now in the field of food monitoring. Their use is complementary since Raman will probe the molecular and structural aspect of the samples when LIBS is mainly an elemental plasma technique, sensitive to atomic and ionic constituents in the sample. As a consequence, the use of these two techniques for food monitoring is explored in order to provide a complete diagnostic of the samples with a simple technical configuration where the excitation and the spectroscopic analysis is shared for both techniques: same laser source, same spectrometer, same detector.

Structural changes in aging cheese has been studied in cheese with Raman. LIBS allowed monitoring of the degree of humidity and fat content of the cheese by monitoring the atomic constitution (principaly carbon, hygrogen and oxygen).

Discussion on the implementation of such combination for food monitoring will also be discussed, as well as for other environmental studies.

8027-02, Session 1

Evaluating carotenoid changes in tomatoes during postharvest ripening using Raman chemical imaging

J. Qin, K. Chao, M. S. Kim, U.S.D.A. Agricultural Research Service (United States)

Carotenoid content in tomatoes varies considerably with the postharvest ripening stage, thus evaluating changes of major carotenoids in tomatoes (e.g., lycopene and -carotene) can be used for monitoring ripeness of the tomato fruits. Raman chemical imaging technique is promising for mapping constituents of interest in complex food matrices. In this study, a benchtop point-scanning Raman chemical imaging system was developed to assess carotenoid changes in tomatoes at different maturity stages. 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 102.2-2538.1 cm-1 with a spectral resolution of 3.7 cm-1, and an area of 127×127 mm2 with a spatial resolution as high as 0.1 mm. Tomato samples were handpicked at mature-green stage from a local orchard. The samples were kept in room temperature during the whole postharvest ripening process (i.e., from mature-green to full-ripe). Fruits at different ripeness stages (i.e., green, breaker, turning, pink, light red, and red) were selected and cut before imaging. Hyperspectral Raman images were acquired from cross sections of the tomatoes with a spatial resolution of 1 mm. Raman spectra of pure lycopene and -carotene standards were measured as references. An image classification method was developed based on spectral matching algorithms to identify the carotenoids on the cross sections of the fruits. Raman chemical images were created to visualize quantity and spatial distribution of the carotenoids at different ripeness stages of the tomatoes.

8027-03, Session 1

Polarized Raman investigations of oriented animal muscle fibers affected by storage time applying a 671 nm diode laser

H. Al Ebrahim, K. Sowoidnich, H. Schmidt, H. Kronfeldt, Technische Univ. Berlin (Germany)

Due to its analytical ability and sensitivity to molecular vibrations, Raman spectroscopy provides valuable information of the secondary structures of proteins. Moreover, polarized Raman spectroscopy is shown to be a useful instrument to investigate the structural changes resulting from the aging and spoilage process of meat.

In this work, polarized Raman spectra were measured of selected cuts of pork and turkey. Fresh meat slices were stored at 5 °C and measured for a consecutive time period of 10 days. A 671 nm microsystem diode laser was used as excitation light source. The laser power at the sample was 50 mW and the integration time was set to 5 seconds. Measurements were performed with a laser beam orientation perpendicular to the long axis of the muscle fibers. In that arrangement, the fibers were aligned either parallel or perpendicular to the polarization direction of the laser source.

By using the statistical method of principal components analysis (PCA), a clear separation of the meat samples can be found for fresh meat according to the orientation (parallel or perpendicular) using the first two principal components. During the storage period, this separation subsequently vanishes due to the aging process and due to an increase of the microbial spoilage of the meat surface. For the latter effect, a time-dependent distinction of the Raman spectra is presented as well. Furthermore, specific changes of conformation-sensitive Raman bands were recognized, notably a decrease of the intensities of -helical protein conformation.

8027-04, Session 1

A quantitative study for determination of sugar concentration using attenuated total reflectance terahertz (ATR-THz) spectroscopy

D. Suhandy, T. Suzuki, Y. Ogawa, N. Kondo, Kyoto Univ. Graduate School of Agriculture (Japan); T. Ishihara, Y. Takemoto, Panasonic Corp. (Japan)

The objective of our research was to use ATR-THz spectroscopy together with chemometric for quantitative study in food analysis. Glucose, fructose and sucrose are main component of sugar both in fresh and processed fruits. The use of spectroscopic-based method for sugar determination is well reported especially using visible, near infrared (NIR) and middle (MID) infrared spectroscopy. However, the use of terahertz spectroscopy for sugar determination in fruits has not yet been reported. In this work, a quantitative study for sugars determination using attenuated total reflectance terahertz (ATR-THz) spectroscopy was conducted. Each samples of glucose, fructose and sucrose solution with different concentrations were prepared respectively and their absorbance spectra between wavenumber 20 and 450 cm-1 (between 0.6 THz and 13.5 THz) were acquired using a terahertz-based Fourier Transform spectrometer (FARIS-1S, JASCO Co., Japan). This spectrometer was equipped with a high pressure of mercury lamp as light source and a pyroelectric sensor made from deuterated L-alanine triglycine sulfate (DLTGS) as detector. Each spectrum was acquired using 16 cm-1 of resolution and 200 scans for averaging. The spectra of water and sugar solutions were compared and discussed. The results showed that increasing sugar concentration caused decreasing absorbance. The correlation between sugar concentration and its spectra was investigated using multivariate analysis. Calibration models for glucose, fructose and sucrose determination were developed using partial least squares (PLS) regression. The calibration model was evaluated using some parameters such as coefficient of determination (R2), standard error of calibration (SEC), standard error of prediction (SEP), bias between actual and predicted sugar concentration value and ratio prediction to deviation (RPD) parameter. The cross validation method was used to validate each calibration model. It is showed that the use of ATR-THz spectroscopy combined with appropriate chemometric can be a potential for a rapid determination of sugar concentrations.

8027-05, Session 1

THz spectroscopy based high sensitivity measurement of protein using a metal mesh device

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Recently, technologies to detect a small amount of protein are necessary for many kinds of medical tests and life science studies. Conventional methods have problems that they require much time, high cost and a special skill. To solve these problems, we have investigated a sensor using metal mesh devices (MMDs) that work in Terahertz (THz) frequency region. THz waves, which fill in the gap between microwaves and far infrared regions, have been recently applied to real-world problems in industries and in medicine research fields. Here, the THz waves are defined as the electromagnetic waves ranging roughly from 0.1 to 10 THz (3 mm to 30 μm). In this research, effectiveness of the MMD at higher frequencies was investigated for obtaining high sensitivity. Electric fields on the surface of 2 types of the MMDs containing peak transmittances at 1 THz and 10 THz (MMD-1 and MMD-10) were calculated, and decay length of the electric field from the surface of the MMD-10 at peak transmittance was 0.1 times longer than that of the MMD-1. Spectra at a 2-μm-thick dielectric film sample; polyethylene terephthalate (PET) on the MMDs were measured. The sensitivity of the MMD-10 was over 60 times higher than of the MMD-1. These results indicate that MMDs working on higher frequencies can detect small amount of substance because the localized area is smaller. In the presentation, the result of quantitative analysis using protein will be also reported.

8027-06, Session 2

AOTF hyperspectral microscopic imaging for foodborne pathogenic bacteria detection

B. Park, J. Sundaram, G. W. Heitschmidt, S. C. Yoon, K. C. Lawrence, W. R. Windham, U.S.D.A. Agricultural Research Service (United States)

Although conventional microbiological method for cell counting is accurate and still gold standard for foodborne pathogenic bacteria detection, this method is laborious and takes time from days to a week for results. Therefore, new method with sensitive, accurate and rapid pathogen detection is needed for a practical use. Optical detection method is promising for a real-time, in-situ foodborne pathogen detection. In order to understand optical properties of foodborne pathogenic bacteria, a hyperspectral microscopic imaging method which provides both spatial and spectral information can be an effective tool. The objective of this research is to develop a hyperspectral microscopic imaging (HMI) method to evaluate spectral characteristics of foodborne bacteria. The HMI system consists of a Nikon upright microscope, acousto-optic tunable filters (AOTF), a high performance cooled CCD camera, and lighting sources including bright-filed and dark-field illumination. The HMI system was used to scan Salmonella typhimurium with different dilutions. The hyperspectral microscopic images were collected at the wavelength ranges from 450 to 850 nm, 10-nm interval for high quality image acquisition. In this paper, the AOTF-based hyperspectral microscope imaging method to characterize optical properties of Salmonella typhimurium to apply for rapid detection of foodborne pathogen will be presented.

8027-07, Session 2

The detection of Salmonella typhimurium on egg shell using a phage-based biosensor

Y. Chai, S. Horikawa, S. Li, W. Shen, M. Park, V. J. Vodyanoy, B. A. Chin, Auburn Univ. (United States)

In early July 2010, the Salmonella outbreak in eggs gained the attention of mainstream America. One of the possible sources of Salmonella is the contamination of egg shells. The disadvantages of the current bacterial detection are that it is time consuming and manpower intensive. This paper presents the direct detection of Salmonella typhimurium on egg shells using a phage-based magnetoelastic (ME) biosensor. The ME biosensor consists of a ME resonator as the sensor platform and E2 phage as the bio-recognition element that is genetically engineered to specifically bind with Salmonella typhimurium. The ME biosensor vibrates with a characteristic resonance frequency under an externally magnetic field. When the ME biosensor comes in contact with target pathogens, the pathogen will be captured on the sensor, causing an increase in the mass on the sensor surface and a decrease in its resonance frequency. ME biosensors are wireless sensors. Multiple ME biosensors can easily be remotely monitored. In this experiment, Salmonella on egg shells was directly detected using multiple ME biosensors. Multiple measurement biosensors and control sensors were placed on the egg shell surface contaminated by a Salmonella typhimurium solution with known concentrations. The control sensors were identical with measurement sensors but without E2 phage coating. Both sensors were blocked with BSA to reduce non-specific binding. We measured the resonance frequency before and after Salmonella bounded onto the sensor surface. Measurement sensors showed a significant shift in resonance frequency; however, the shift in resonance frequency of control sensors is negligible. The binding of Salmonella on sensor surfaces was confirmed by scanning electron microscopy. The sensitivity and detection limit of Salmonella detection using multiple ME biosensors were studied.

8027-08, Session 2

Detection of Salmonella typhimurium on fresh spinach leaves using phage-coated magnetoelastic biosensors

S. Horikawa, S. Li, Y. Chai, V. J. Vodyanoy, B. A. Chin, Auburn Univ. (United States)

Detection of foodborne pathogens at any stage of a food cycle (i.e., production, packaging, transport, and consumption) necessitates the use of portable, cost-effective biosensors that should operate in an easy-to-use manner. Hence, this paper presents an investigation into the use of phage-coated magnetoelastic biosensors for the direct detection of Salmonella typhimurium on fresh spinach leaves. The biosensors used in this investigation were comprised of freestanding, gold-coated strips made of an amorphous, magnetostrictive alloy (1 mm × 0.2 mm × 15 μm) and an affinity-selected filamentous phage, immobilized onto the strip's surface. This phage layer is genetically engineered to selectively bind Salmonella typhimurium, one of the leading foodborne pathogenic bacteria. Both measurement (phage-coated) and control (no phage-coated) sensors were surface-blocked with bovine serum albumin prior to the experiments to minimize non-specific binding of Salmonella. These biosensors were placed on fresh spinach leaves that have been spiked with Salmonella typhimurium and dried naturally in air. Incubation was performed in a high-humidity environment at room temperature to allow the immobilized phage on the sensor's surface to bind the bacteria. The changes in resonance frequency of the sensors due to the Salmonella attachment were then measured by placing the sensors in an alternating magnetic field. The frequency shifts for the measurement

sensors were found to be statistically different from those for the control sensors, indicating that selective capture of Salmonella typhimurium on the phage-coated sensors occurred. The binding of Salmonella to the sensors was confirmed by scanning electron microscopy.

8027-09, Session 2

Multiple phage-based magnetoelastic biosensors for the detection of Salmonella typhimurium on cantaloupe surfaces

W. Shen, S. Li, S. Horikawa, B. A. Chin, Auburn Univ. (United States)

Food contaminated with Salmonella is a major public health burden and a significant cause of lost productivity and human suffering. Traditional methods for identifying the source of a Salmonella outbreak require food sampling, followed by analyses in the lab and do not allow direct screening of the food in-situ. In this work, we present an investigation into a method that allows direct detection of S. typhimurium on cantaloupe surfaces using phage-based magnetoelastic biosensors. The magnetoelastic biosensors were coated with E2 phage, which is genetically engineered to bind with S. typhimurium. The resonance frequency of the biosensor is measured using a pulse detection system that allows simultaneous detection using multiple sensors. The resonance frequency of a magnetoelastic biosensor is highly sensitive to the change in mass when target pathogens bind to the biosensor. Multiple measurement and control biosensors were placed on cantaloupe surfaces that had been spiked with a known amount of Salmonella. Binding with bacteria was allowed to occur for 30 minutes in a humid air environment. The resonance frequencies of the multiple biosensors on the cantaloupe surface were then measured. SEM pictures of the sensor surface showed corresponding amounts of S. typhimurium cells bound to the biosensors.

8027-10, Session 2

Rapid detection of salmonella using surface enhanced raman spectroscopy with silver nanosubstrate

J. Sundaram, B. Park, U.S.D.A. Agricultural Research Service (United States); Y. Zhao, The Univ. of Georgia (United States); A. Hinton, Jr., W. R. Windham, S. C. Yoon, K. C. Lawrence, U.S.D.A. Agricultural Research Service (United States)

Various technologies have been developed for pathogen detection using optical, electrochemical, biochemical and physical properties. Conventional microbiological methods for cell counting need time from days to week to get the result. Though this method is very sensitive and accurate, rapid detection of pathogens is very much in need these days. Many researches proved that Surface Enhanced Raman Spectroscopy (SERS) can detect the pathogen in rapid and accurate. In SERS weak Raman scattering signals are enhanced by many orders of magnitude. In this study, silver metal surface was used. Silver nanorods were deposited on thin titanium coat over glass plates. This was used as metal substrate for SERS. Salmonella typhimurium a common food pathogen was selected for this study. Salmonella typhimurium bacteria cells were prepared in different concentrations in cfu/mL. Optical densities of these cell suspensions were using UV spectrophotometer at 625 nm absorption mode. After that small amount of these cells were loaded on the metal substrate individually, scanned and spectra were recorded using confocal Raman microscope. The cells were exposed to laser diode at 785 nm excitation and object 50x was used to focus the laser light on the sample. Raman shifts were obtained from 0 to 3500 cm-1. Spectral signatures of different bacterial concentrations were compared to differentiate them. Also multivariate data analysis was carried to predict the concentration of unknown sample using its spectra. The results showed that it could be possible to find out the Salmonella cells present as minute concentration in food samples using SERS.

8027-11, Session 3

Characterization of optical properties of bacterial micro-colonies via the comprehensive morphology analyzer

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The recently developed optical light scattering technique on bacterial colonies has shown differentiability among different genus and species. The remarkable resolving power comes from the accumulation of both microscopic structural and material differences existing among different bacterial colonies through an interrogating laser light. Different bacterial colonies have different morphological characteristics such as elevation, opacity, edges and so on, which have been used by microbiologists as visual inspection traits for presumptive identification. Inspired by this, some morphological parameters including colony diameter, elevation and their ratio have been numerically studied and correlated to the scattering features such as the number of rings and diffraction angles of the scattering patterns observed at the image plane based on the scalar diffraction theory. To experimentally analyze the morphological characteristics of different colonies and to predict the different scattering patterns resulted from that, an optical morphology analyzer has been constructed based on a laser confocal displacement meter to simultaneously obtain the profile and transmittance measurements of colonies. The profile data is accurately captured through a confocal laser triangulation technology and the transmitted light is collected by a photodiode. The analog signals are read into a data acquisition board in parallel for off line signal processing. The built platform has been calibrated to show the accuracy of the profile measurement. The transmitted light intensity measurement has been normalized to show the spatially-resolved amplitude attenuation property of the measured colonies. Microcolonies in the range of 100~300 μm have been analyzed to show the morphological differences exhibited by different species, which promises the use of light scattering for microcolonies differentiation.

8027-12, Session 3

Development of narrow-band fluorescence indices for the detection of aflatoxin contaminated corn

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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 is produced by the fungus Aspergillus flavus when the fungus infects corn kernels. 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 100 ppb in feed for interstate commerce. Currently, aflatoxin detection and quantification methods are based on analytical tests. These tests require the destruction of samples, and can be costly and time consuming. Thus, the ability to detect aflatoxin in a rapid, non-invasive way is crucial to the grain industry, to the corn industry in particular. Past studies indicated the potential of using fluorescence hyperspectral imagery for the detection of aflatoxin-contaminated corn. This paper describes how narrow-band fluorescence indices were developed for the detection of contaminants. The indices are based on two or three bands extracted from full wavelength fluorescence hyperspectral imagery. Since the data acquisition period is significantly lower for several image bands than for full wavelength hyperspectral data, it is anticipated that the results would be helpful in the development of real-time detection instrumentation for the corn industry.

8027-13, Session 3

Cepstrum based feature extraction method for fungus detection

O. Yorulmaz, E. A. Cetin, Bilkent Univ. (Turkey); T. C. Pearson, U.S.D.A. Agricultural Research Service (United States)

A new computer vision method using cepstrum features based for detection fungal infected corn kernels is presented. Mel-cepstrum is the most widely used feature extraction method in speech processing. Recently, mel-cepstrum was extended to two-dimensions and it is successfully used in face recognition. In this article, two-dimensional (2D) mel- and Mellin-cepstrum based features are extracted from corn kernel images for classification of infected kernels. Extracted feature vectors are classified using a Support Vector Machine (SVM). The Mellin-cepstrum method is selected for feature extraction because it produces image representation vectors which are independent of rotation, shifts and are robust to illumination changes. Other image feature extraction methods assuming rotation and shift-invariance are not suitable for corn kernel classification because captured corn images are not aligned with each other and they may be oriented at all angles. Furthermore fungi may corrupt any part of corn kernels. Since the 2-D Mellin-cepstrum is rotation and shift-invariant it provides feature vectors which can be effectively classified by an SVM. Experimental results are obtained for corn kernels with a fungal infection called blue-eye damage. The method is tested with 234 healthy and 234 damaged kernels. The statistical results are obtained using leave-one-out testing method. The success rate for healthy corn kernels was found to be 97.0% and the recognition rate for damaged corn kernels was found to be 88.2%. Extensive simulation studies will be presented in the final form of the manuscript.

8027-14, Session 3

Aflatoxin contaminated chili pepper detection by hyperspectral imaging and machine learning

M. Atas, Y. Yardimci Cetin, A. Temizel, Middle East Technical Univ. (Turkey)

Mycotoxins are the toxic secondary metabolites of certain filamentous fungi. They have been demonstrated to cause various health problems in humans, including immunosuppression and cancer. A class of mycotoxins, aflatoxins, has been studied extensively because they are potent carcinogens and have caused many deaths particularly in developing countries. Various regulatory agencies have enforced limits on the concentrations of these toxins in foods and feeds when they are involved in international commerce. Chili pepper is also prone to aflatoxin contamination during harvesting, production and storage periods. Generally accepted aflatoxin level varies between 1 to 50 ppb (parts per billion) depending on the country. Chemical methods to detect aflatoxins are slow, expensive and destructive in nature, yet they yield more accurate results. Hyperspectral and multispectral imaging are becoming increasingly important for rapid and nondestructive testing for the presence of such contaminants. We propose a compact machine vision system based on hyperspectral imaging and machine learning for detection of aflatoxin contaminated chili peppers. We used the difference images of consecutive spectral bands along with individual band energies to classify chili peppers into aflatoxin contaminated and uncontaminated classes. Both UV and halogen illumination sources are used in the experiments. The significant bands are selected based on their neural network connection weights. Higher classification rates are achieved with fewer numbers of spectral bands. This selection scheme is compared with an information-theoretic approach and it demonstrated robust performance with higher classification accuracy.

8027-35, Poster Session

Prediction of marked age of mature vinegar based on FT-NIRS

H. Lu, Z. An, North Univ. of China (China); Y. Ying, Zhejiang Univ. (China)

To evaluate the applicability of near infrared (NIR) spectroscopy for discrimination between mature vinegar with different marked age (1 year, 3 years, and 5 years), transmission spectra were collected in the spectral range from 800 nm to 2500 nm in 1, 2, and 5 mm optical path-length rectangular quartz cuvettes with air as reference at room temperature. Discriminant models were developed based on discriminant analysis (DA) together with raw, first and second derivative spectra. The calibration result for raw spectra was better than that for first and second derivative spectra. The percentage of samples correctly classified for raw were 100% for 1 year old, 100% for 3 years old and 97.5% for 5 years old, respectively. In validation analysis, for 1 year, 3 years, and 5 years old sample groups, the percentage of samples correctly classified was 100%, 100%, and 100%, respectively. The results demonstrated that NIR spectroscopy could be used as a rapid and reliable method for classification of mature vinegar with different marked age.

8027-36, Poster Session

Hyserspectral imaging for nondestructive quality and maturity evaluation in tomatoes

S. Kang, National Academy of Agriculture Science (Korea, Republic of); M. S. Kim, U.S.D.A. Agricultural Research Service (United States); K. Lee, National Academy of Agriculture Science (Korea, Republic of)

The fresh-market tomatoes are one of the major vegetables in US and make significant contributions to human nutrition throughout the world. Color in tomato (Lycopersicon esculentum) is one of the important external characteristic to assess ripeness and shelf-life of tomato. Usually, the degree of maturity has been estimated by human graders comparing the tomato color to a chart that classify fresh tomatoes into six maturity stages based on the USDA standard classification. This tomato maturity classification often results into errors due to human subjectivity, visual stress and tiredness. Color camera has been used to classify the tomato but it is not easy to define the six maturity stage based on color. Hyperspectral imaging system was used to find the relationship between the tomato maturity and hyperspectal reflectance images. Also, hyperspectal reflectance images were acquired for normal and defective tomatoes using a portable hyperspectral reflectance imaging system. The research showed that the hyperspectral imaging technique is useful for nondestructive quality and maturity determination in tomatoes.

8027-37, Poster Session

A control system of mobile navigation robot for precise spraying based ultrasonic detecting and ARM embedded technologies

X. Tang, C. Li, China Agricultural Univ. (China); X. Wang, National Engineering Research Ctr. for Information Technology in Agriculture (China); X. Yue, Y. Peng, China Agricultural Univ. (China)

This paper describes a control system of mobile navigation robot for precise spraying in Greenhouse environment. The system consists of main control module, motor driving module, ultrasonic detecting (avoiding obstacle) module and wireless remote control module. The hardware circuits of control system of robot are built in house. The main control module uses ARM7-based LPC2210 real-time micro-processing

controller, and the motor driving module consist of voltage amplifier circuit based 74LS245 and 74LS245 chips, RC filter circuit and HM-YZ-30 DC brush motor driver. The ultrasonic detecting module consist of 4 standard ultrasonic range sensing units which are arranged on the four sides around the mobile navigation robot, and uses GM8125 chip to expand serial communication interfaces. The C control program of mobile navigation robot is developed, and a precise obstacle-avoiding strategy and its algorithm are also proposed. The mobile navigation robot for spraying can realize the actions such as starting and stopping, forward and backward moving, accelerate and decelerate moving, and swerve differential controlling etc. The functional experiments of the mobile navigation robot were conducted in the laboratory environment. The results show that the ultrasonic detecting range of the robot is 0.05-9.99m, the detecting accuracy is 0.01m, the detecting blind zone is 0.05m, the detecting angle of single ultrasonic sensing unit is 45.66º, and the straight-line navigation accuracy along the vertical axis line of the movement direction of robot is ±0.5mm. The control system shows a promising for practical applications.

8027-38, Poster Session

A Raman chemical imaging system for detection of contaminants in food

K. Chao, J. Qin, M. S. Kim, U.S.D.A. Agricultural Research Service (United States)

Raman chemical imaging technique combines Raman spectroscopy and machine vision to visualize the composition and structure of a target, and it offers great potential for food safety research. Commercially available systems generally perform Raman measurements at a microscopic level, and consequently cannot easily meet the requirements for evaluating whole surfaces of individual food items. A bench-top point-scanning Raman chemical imaging system was designed and developed in the laboratory for food safety inspection. The system is able to acquire hyperspectral Raman images in a Raman shift range from 102.2 to 2538.1 cm-1 with a spectral resolution of 3.7 cm-1. It can cover a square area of 127×127 mm2 with a spatial resolution as high as 0.1 mm, making the system capable of acquiring Raman images from food and biological samples such as fruits and vegetable leaves. This paper describes the use of this system for two example applications. First, the detection of melamine particles in dry milk samples demonstrated that the Raman chemical imaging technique can identify specific chemicals at low concentrations. Second, the system was used to investigate the detection and differentiation of fecal contaminants and soil samples on leafy green vegetables. This work demonstrates that Raman scattering information can be useful for mapping spatial distribution of constituents in complex food systems. This laboratory Raman chemical imaging system is a versatile platform that will be useful to other qualitative and quantitative applications in the area of food safety.

8027-39, Poster Session

Development of whole-surface imaging technique for online inspection of leafy green vegetables

X. Tang, China Agricultural Univ. (China); M. S. Kim, J. Qin, C. Yang, U.S.D.A. Agricultural Research Service (United States); Y. Peng, China Agricultural Univ. (China); D. E. Chan, K. Chao, U.S.D.A. Agricultural Research Service (United States)

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. To this end, 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 device, conveyors, and line-scan imager are integrated as a laboratory prototype for automated high-speed online inspection of leafy green vegetables. 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.

8027-40, Poster Session

Automatic eggshell crack detection system using acoustic response

K. Lee, National Academy of Agriculture Science (Korea, Republic of); W. Choi, Nongsim Engineering (Korea, Republic of); H. Lee, Seoul National Univ. (Korea, Republic of)

Among the quality evaluation methods for the egg, a candling method is common to identify eggs with cracked shells and interior defects. But this is time-consuming and laborious. In addition, practically, it is challenging to detect hairline and micro cracks. In this study, an on-line inspection system based on acoustic resonance frequency analysis was developed to detect hairline cracks on eggshells. A roller conveyor was used to transfer eggs along one lane to the impact position where each of eggs rotated by the roller was excited with an impact device at six different locations on the eggshell equator. The impact device consisted of a plastic ball and a rotary solenoid. The acoustic response of the egg to the impact was measured with a small condenser microphone at the same position as the impact device was installed. Two acoustic parameters, correlation coefficient for normalized power spectra and standard deviation of peak resonant frequencies, were used to detect cracked eggs. Intact eggs showed relatively high correlations among the six normalized power spectra and low standard deviations of the six peak resonant frequencies. On the other hand, cracked eggs showed low correlations and high standard deviations as compared to the intact. This method allowed a crack detection rate of 94% above.

8027-15, Session 4

Fast and accurate image recognition algorithms for fresh produce food safety sensing

C. Yang, M. S. Kim, K. Chao, U.S.D.A. Agricultural Research Service (United States)

The research reported the development of image recognition algorithms to detect fecal pollution on fresh produce using hyperspectral line-scan images. The algorithms were developed to satisfy the requirements of fast operation and calculation as well as accurate detection and sensing performance. The algorithms could be easily installed and calibrated to manage the machine vision system. With the algorithms, the line-scan machine vision system can be applied to the real-world food processing line to ensure food safety.

8027-16, Session 4

Hyperspectral imaging technique for determination of pork freshness

Y. Peng, L. Zhang, China Agricultural Univ. (China)

Freshness of pork is an important quality attribute, which can vary greatly in storage and logistics. The specific objectives of this research were to develop a hyperspectral imaging system to predict pork freshness based on quality attributes such as total volatile basic N (TVB-N), pH value and color parameters (L*,a*,b*). Pork samples were packaged in seal plastic bags and then stored at 4°C. Every 12 hours. Hyperspectral

scattering images were collected from the pork surface at the range of 400 nm to 1100 nm. Two different methods were performed to extract scattering feature spectra from the hyperspectral scattering images. First, the spectral scattering profiles at individual wavelengths were fitted accurately by a three-parameter Lorentzian distribution (LD) function; second, reflectance spectra were extracted from the scattering images. Partial Least Square Regression (PLSR) method was used to establish prediction models to predict pork freshness. The results showed that the PLSR models based on combinations of LD “parameter spectra” was better than reflectance spectra in prediction of TVB-N with a correlation coefficient (r) = 0.89, a standard error of prediction (SEP) = 6.30. Moreover, a prediction model for pork freshness was established by using a combination of TVB-N , pH and color parameters. It could give a good prediction results with r = 0.90 and SEP = 5.05 for pork freshness. The research demonstrated that hyperspectral scattering technique is a valid tool for real-time and non-destructive detection of pork freshness.

8027-17, Session 4

Infrared imaging technology for detection of bruising damages of ‘Singo’ pear

B. Cho, Chungnam National Univ. (Korea, Republic of); M. S. Kim, U.S.D.A. Agricultural Research Service (United States); H. Lee, Chungnam National Univ. (Korea, Republic of); S. R. Delwiche, U.S.D.A. Agricultural Research Service (United States)

Of the quality attributes of pear bruising damage is the most crucial external quality factor which should be detected in sorting processes. Development of sensitive detection methods for the defects is necessary to ensure accurate quality measurement. Infra-red imaging technique has good potentials for identifying and detecting anomalies due to defects on agricultural materials. In this study, feasibility of hyperspectral infra-red imaging technique for the detection of bruising damages underneath the pear skin was investigated. Damages exist underneath the skin are not easily discernable by using conventional imaging technique at visible wavelength ranges. Simple image combination methods as well as multivariate image analyses were explored to develop optimal image analysis algorithm to detect bruising damages of pear. Results demonstrated good potential of the infra-red imaging for detection of bruising damages underneath the pear skin.

8027-18, Session 4

Hyperspectral near-infrared imaging for detection of cuticle cracks on tomatoes

H. Lee, Chungnam National Univ. (Korea, Republic of); D. Jeong, M. S. Kim, Agricultural Research Service, USDA (United States); B. Cho, Chungnam National Univ. (Korea, Republic of); S. R. Delwiche, K. Chao, Agricultural Research Service, USDA (United States)

Cuticle cracks on tomatoes could be potential harbor sites of pathogenic infection which may cause deleterious consequences to consumer health in fresh cut markets. The feasibility of hyperspectral near-infrared imaging technique with the spectral range of 1000 nm to 1700 nm was investigated for detecting defects on tomatoes. Spectral information obtained from the regions of interest on both defected and whole areas were analyzed to determine optimal wavebands ratio used for further image processing to discriminate the defected areas from the whole tomato surfaces. Unsupervised multivariate analysis method, such as principal component analysis was also explored to improve the detection accuracy. Threshold values for the optimized features were determined using linear discriminant analysis. Results showed that the defected tomatoes could be differentiated from the sound ones with accuracy of 94.4%. Spectral wavebands and image processing algorithm determined in this study could be used for multispectral inspection of defected tomatoes.

8027-19, Session 4

Detection of fruit fly infestation in pickling cucumbers using hyperspectral imaging

R. Lu, Agricultural Research Service (United States); D. P. Ariana, Michigan State Univ. (United States)

Fruit fly infestation can be a serious problem in pickling cucumber production. Currently, processors have to rely on human inspectors to detect and remove fruit fly-infested cucumbers, which is not cost effective and also prone to error due to the limitation of human abilities and fatigue. In this research, a hyperspectral imaging system was used to detect fruit fly-infested pickling cucumbers. Hyperspectral reflectance (450-740 nm) and transmittance (740-1000 nm) images were acquired simultaneously for 329 normal (no pest) and pest-infested pickling cucumbers of three size categories. After imaging, the pickling cucumbers were cut open and visually inspected; they were then graded into four grades (i.e., control (no pest), slight, medium, and severe) according to the level of pest infestation. Mean spectra were calculated from a specific area of interest for each cucumber and they were then corrected to minimize spectra variations caused by fruit size. Partial least squares discriminant analysis (PLSDA) was applied for differentiating normal (pest free) from pest-infested pickling cucumbers for three different imaging modes (i.e., reflectance, transmittance and their combination). With reflectance mode, an overall classification accuracy of 82.4% was achieved, while transmittance mode gave an overall classification accuracy of 87.8%. Combination of reflectance and transmittance only led to marginal improvements with an overall accuracy of 88.5%. These results were considerably better than the human inspection result of 75.4%, which was especially evident in grading smaller size cucumbers. This research demonstrated that hyperspectral imaging can be used for detecting fruit fly-infested pickling cucumbers.

8027-20, Session 5

Peach maturity/quality assessment using hyperspectral imaging-based spatially resolved technique

H. Cen, R. Lu, F. A. Mendoza, D. P. Ariana, Michigan State Univ. (United States)

Hyperspectral imaging-based spatially-resolved (HISR) method is an advanced optical technique for characterization of the optical properties of fruit. In order to develop an effective optical system for maturity and quality assessment of peaches, it is important to understand their optical absorption and scattering properties as related to the physiological states. The objective of this research was to measure the absorption and scattering properties of peaches for their maturity and quality assessment. A newly developed optical property measuring instrument was used in this study. Five hundred ‘Redstar’ peaches, harvested at four different dates in 2010, were used in the experiment. Measurements for the optical properties and maturity/quality indices (i.e., firmness, soluble solids contents (SSC), and color) were performed on the same day of harvest. Spatially-resolved hyperspectral images were first acquired from each sample. Firmness measurements were then conducted with a texture analyzer, followed by SSC with a digital refractometer, and peel and flesh color with a colorimeter. An inverse algorithm for a diffusion model was used to extract the spectra of absorption and reduced scattering coefficients of peaches at wavelengths of 500-1,000 nm. Predictive models relating the measured optical properties to maturity/quality indices were established. In addition, classification models for peach maturity/quality based on the optical properties were developed.

Return to Contents

8027-21, Session 5

Multisensor data fusion for improved prediction of apple fruit firmness and soluble solids

F. A. Mendoza, Michigan State Univ. (United States); R. Lu, U.S.D.A. Agricultural Research Service (United States); H. Cen, Michigan State Univ. (United States)

Several sensing technologies (i.e., sonic, near-infrared (NIR) spectroscopy, bioyield, and spectral scattering among others) have been developed for nondestructive measurement of apple firmness and/or soluble solids content (SSC). However, each technology has its limit in predicting these quality parameters. With the concept of multi-sensor data fusion, these sensor systems can work collectively and be complementary to each other to improve the quality prediction of apples. In this research, combinations of four different sensing systems (sonic sensor, NIR spectroscopy, bioyield tester, and hyperspectral scattering) were evaluated for nondestructive prediction of the firmness and SSC of 'Jonagold' (JG), 'Golden Delicious' (GD), and 'Red Delicious' (RD). Each of the four sensing systems showed different abilities to predict apple firmness and SSC. Using partial least square regression, better predictions of the firmness and SSC were obtained by sensor fusion than by individual sensors, as measured by number of latent variables, correlation coefficient and standard error of prediction. By using multiple sensors against the individual ones, the standard errors of prediction (SEP) for JG, GD and RD apples were reduced by 21.9, 22.5, and 13.0% for firmness (Rval-values of 0.96, 0.92, and 0.90 and the number of latent variables of 19, 11, and 13), and by 11.4, 5.5 and 6.8% for SSC (Rval-values of 0.85, 0.90, and 0.81 and the number of latent variables of 16, 13, and 13), respectively. These results indicate that with a more complete set of features, the fused systems are more powerful than the individual systems in prediction of apple quality.

8027-22, Session 5

LED induced fluorescence imaging technology for detection of cuticle cracking on cherry tomatoes

I. Baek, B. Cho, Chungnam National Univ. (Korea, Republic of); M. S. Kim, U.S.D.A. Agricultural Research Service (United States); Y. Kim, SangMyung Univ. (Korea, Republic of)

Nondestructve quality measurement is one of the most important postharvest processes in cherry tomato industry. Of the quality attributes of cherry tomatoes, cuticle cracking which are fine hair-like cracks on surfaces produces quality and safety problems. Cracking is the main cause of retailers' rejection and common site for pathogenic penetration and infection. Hence, the cherry tomatoes exposed on the defects should be discriminated in quality sorting processes. In this study, optimal excitation wavelength was investigated using fluorescence emission and excitation matrix of sound and defected areas on cherry tomatoes. High power LEDs of the optimal wavelength were used for hyperspectral fluorescence imaging system to explore the best combination of the emission spectral images. The LED induced fluorescence imaging technique showed excellent potential for discriminating cracked cherry tomatoes.

8027-23, Session 5

Dried fruits quality assessment by hyperspectral imaging

S. Serranti, G. Bonifazi, Univ. degli Studi di Roma La Sapienza (Italy)

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.

8027-24, Session 6

Dynamic flourescence-based method for measuring oxygen transmission rate of food packaging

B. Welt, Univ. of Florida (United States)

A new dynamic method for measuring oxygen transmission rate (OTR) of thin films using fiber optic oxygen sensing technology was developed. The method uses a thin film sample to separate two chambers. One chamber is initially purged with nitrogen while the other chamber is exposed to an oxygen rich air that is typically air or 100% oxygen. Oxygen transfers through the film and accumulates over time. The rate of oxygen accumulation is measured and converted into an OTR measurement for the film at the temperature studied. The new method allows for measurement of perforated films, which is not possible with the industry standard, steady-state, method described by ASTM D-3985. The new method was tested against a Mocon OxTran 2/20 (ASTM D-3985) using films with approximate OTRs of 1, 150, 800, and 10,000 cc/m2/day. Measurements were also performed on perforated films for demonstrated purposes. Results show that the new dynamic method provides similar results as the steady state method.

8027-25, Session 6

Fluorescence lifetime monitor for the remote inspection of hermetic packaged food

E. A. Mendoza, Redondo Optics, Inc. (United States)

This paper describes the development of miniature fluorescence lifetime monitoring (SeePhase) system for the remote real-time inspection of the hermetic environment of packaged foods. A multitude of food goods, meets, vegetables, and beverages are typically packaged within an inert environment to reduce the risk of bacteria growth and increase the storage life of the food product. The SeePhase system uses an oxygen sensitive patch that is placed within the food hermetic package. Upon the presence of oxygen inside the hermetic sealed food package, the oxygen patch produces a fluorescence lifetime signature characteristic of oxygen intrusion within the package. The SeePhase system uses a miniature fluorescence lifetime monitor device to remotely detect the status of the oxygen sensor patch with microsecond response times suitable for monitoring the food-packaged environment while in transit or storage.

8027-26, Session 6

Fluorescence excitation and emission wavebands for evaluation of freshness of pork meats

J. Kim, B. Cho, Chungnam National Univ. (Korea, Republic of); M. S. Kim, U.S.D.A. Agricultural Research Service (United States)

Development of sensitive measurement methods for freshness of meat is essential to ensure safe distribution of meat products in the current increasing meat market. Fluorescence has been shown to be very sensitive in quality and safety measurements for food and biological materials. In this study, fluorescence excitation-emission spectra of pork meats were measured and used to determine optimal wavebands for freshness evaluation. Chemical and microbial indicators of freshness were correlated with fluorescence emission intensities at optimal excitation wavelengths. The excitation and emission wavebands garnered in this study could be used for constructing a miniaturized real-time fluorescence imaging device for the monitoring of pork meat freshness.

8027-27, Session 6

Study on excitation and fluorescence spectrums of Japanese citruses to construct machine vision system for acquiring fluorescent images

M. A. Momin, N. Kondo, Kyoto Univ. Graduate School of Agriculture (Japan); M. Kuramoto, Ehime Univ. (Japan); Y. Ogawa, T. Shigi, Kyoto Univ. Graduate School of Agriculture (Japan)

Research was conducted to acquire knowleddge of the ultraviolet and visible spectrums from 300 -800 nm of some common varieties of Japanese citrus, to investigate the best wave-lengths for fluorescence excitation and the resulting fluorescence wave-lengths and to provide a scientific background for the best quality fluorescent imaging technique for detecting surface defects of citrus. A Hitachi U-4000 PC-based microprocessor controlled spectrophotometer was used to measure the absorption spectrum and a Hitachi F-4500 spectrophotometer was used for the fluorescence and excitation spectrums. We analyzed the spectrums and the selected varieties of citrus were categorized into four groups of known fluorescence level, namely strong, medium, weak and no fluorescence group.The level of fluorescence of each variety was also examined by using machine vision system. We found that around 340-380 nm LEDs or UV lamps are appropriate as lighting devices for acquiring the best quality fluorescent image of the citrus varieties to examine their fluorescence intensity. Therefore an image acquisition device was constructed with three different lighting panels with UV LED at peak 365 nm, Blacklight blue lamps (BLB) peak at 350 nm and UV-B lamps at peak 306 nm. The results from fluorescent images also revealed that the findings of the measured spectrums worked properly and can be used for practical applications such as for detecting rotten, injured or damaged parts of a wide variety of citrus.

8027-28, Session 6

Homgenization of a pulsed laser beam using a lightpipe

A. M. Lefcourt, P. Motabar, M. S. Kim, U.S.D.A. Agricultural Research Service (United States); U. Tasch, Univ. of Maryland, Baltimore County (United States); M. Camp, U.S.D.A. Agricultural Research Service (United States)

The expansion and homogenization of high-energy laser beams have become a key issue for many modern applications such as material processing, interferometry, signal processing, and illumination. This study investigated the design of an optical system to expand and homogenize a high-power pulsed-laser beam using a lightpipe for homogenization. Two optical assemblies to expand the beam of a pulsed laser, one with and one without the use of a homogenizing lightpipe, were constructed. To measure the homogenization of the expanded beam of a 355 nm pulsed laser using these assemblies, fluorescence images resulting from single laser pulses were captured using a gated, intensified, camera. A sequence of 30 replicate pulses was acquired using each assembly. Measures of homogenization included differences in average coefficients of variation, and spatial histograms of deviations from average values for intensities and coefficients of variation. Values for a one-sided tolerance test of coefficients of variation with a 98% tolerance limit at $p = .05$ were .108 and .023 for assemblies without and with a lightpipe, respectively. These results, along with the spatial histograms, demonstrate that a lightpipe can be used to effectively homogenize an expanded high-energy pulsed laser beam. The optical assembly incorporating the lightpipe is robust, simple, and relatively inexpensive, and has many potential uses.

8027-29, Session 7

Development of the pungency measuring system for red-pepper powder

C. Mo, K. Lee, J. Lim, S. Kang, H. Lee, Rural Development Administration (Korea, Republic of)

Many researchers have been tried to find a rapid pungency measuring method for the capsaicinoids, the main component of spicy, but methods, such as using the HPLC, are time-consuming and high cost for the multiple samples. In this research, the ultra violet, visible and near-infrared absorption spectrum (200 ~ 1050 nm) was used to develop a pungency measuring for red-pepper powder. Twenty two different variety samples from Youngyang-gun, Korea with three different granularities were used to measure 1,776 spectra. The Partial Least Square Regression Model (PLSR model) to predict the capsaicinoid content was developed with obtained spectra by the developed system and measured data of capsaicinoids by HPLC. The Standard Error of Prediction (SEP) for unknown sample with cross validation was ±10.2mg.

8027-30, Session 7

Improved egg crack detection algorithm for modified pressure imaging system

S. Yoon, K. C. Lawrence, D. R. Jones, G. W. Heitschmidt, B. Park, U.S.D.A. Agricultural Research Service (United States)

Eggs with cracked shells are prone to contamination by intrusion of bacteria from the outside. In the egg industry, mass candling equipment developed during the 1950s for egg crack detection has been replaced with mass scanning electronic equipment such as ultrasonic devices. However, USDA's professional egg graders are still using hand candling to detect cracked eggs for their routine examination to determine the detection accuracy of mass-scanning equipment. Eggs with hairline cracks (micro-cracks) are especially difficult to detect with hand candling. A new imaging technique utilizing modified negative pressure was developed to help professional graders detect eggs with micro-cracks. The imaging system momentarily drops the atmospheric pressure inside an enclosure to open cracked shells and then detects intensity changes of cracked eggs with a machine vision technique. Eggs are positioned on rollers and held in a sealed clear acrylic vacuum enclosure for imaging. This paper reports latest improvements in the crack detection algorithm. In spite of its high detection accuracy, the previously developed crack detection algorithm was sensitive to any physical movements of eggs or the apparent movement of eggs that is primarily created by the downward movement of the enclosure lid acting like a lens during imaging under negative pressure. A motion estimation algorithm was developed for compensating any motion errors of eggs and thus reducing false positive readings. An individual egg-based segmentation algorithm

was also developed to estimate the directions and amounts of individual eggs' movements. The performance of the improved crack detection algorithm was tested with 3,000 eggs.

8027-31, Session 7

Light reflection measurement on cattle pupil for serum vitamin A measurement

C. Sugimoto, T. Shigi, K. Yamamoto, Y. Ogawa, N. Kondo, Kyoto Univ. (Japan); N. Kohama, M. Fukushima, Hyogo Prefectural Hokubu Agricultural Institute (Japan); S. Mano, K. Yoshida, Kyoto Univ. (Japan)

This study evaluated the relationship between serum Vitamin A (VA) of beef cattle and light reflection of cattle's pupil. In Japan, serum VA level is an important indication to control the beef quality. The beef quality depends on serum VA level. In order to produce high quality beef, they must keep serum VA level at low level about 30 IU/dL from 16 to 24 months. If serum VA is, however, under 30 IU/dL, cattle may become VA deficiency and get sick easily. Although serum VA level is mainly detected by blood assay, it is time-consuming, expensive, and stressful to the cattle. Therefore, a non-invasive, rapid, and simple sensing system for monitoring serum VA level is desirable to produce the high quality beef and to keep the controlled VA data in database for safety and security of beef meet.

In the previous study, it was reported that pupil contraction was related to the serum VA level. The objective of this study was to predict serum VA level not only with pupil contraction but also light reflection on cattle's pupil using 2CCD (color [red, green and blue] and NIR) camera. In the experiment, eye images of about 50 live Japanese black cattle were acquired. After image processing, some correlation between serum VA level and gray scale dispersion on pupil was investigated. In addition, the light reflection change of individual cattle over time for a half year and data on sex were also discussed.

8027-32, Session 7

Quality measurement of Korean traditional rice beer 'Makgeolri' using VIS/NIR spectroscopy

D. Kim, B. Cho, Chungnam National Univ. (Korea, Republic of)

Even though Korean traditional rice beer 'Makgeolri' is popular alcoholic liquid domestically and internationally, non-destructive quality monitoring methods applicable to on-site processing lines have not been developed. For automated and accurate quality monitoring, real-time in-situ and robust quality monitoring methods need to be developed. Spectroscopic measurement techniques have shown good potential for non-destructive quality measurements for food and biological substances.

In this study, various multivariate analysis techniques with VIS/NIR spectra were explored for quality measurements of Makgeolri. Results demonstrate that the spectral analysis approaches might be able to replace the conventional quality monitoring methods of Makgeolri which have been dependent on the experience of the field experts and expensive off-line laboratory equipment.

8027-33, Session 7

Potential of using satellite remote sensing data for estimation of Aus rice yield in Bangladesh

M. Nizamuddin, L. Roytman, The City College of New York (United States); F. Kogan, M. D. Goldberg, National Environmental Satellite, Data, and Information Service (United States)

Application of remote sensing data have been explored for estimating aus rice yield in Bangladesh. The algorithm uses the Vegetation Health (VH) Indices (Vegetation Condition Index (VCI) and Temperature Condition Index (TCI)) computed for each week during a period of 15 years (1991-2008) from Advance Very High Resolution Radiometer (AVHRR) data. The weekly indices were correlated with the end of the season aus rice (AR) yield. A high correlation was found between aus rice yield and VCI (characterizing moisture conditions) during the period of aus rice development and productivity that occurs in March-April (weeks 8-14). Principal components regression (PCR) and stepwise regression method has been used to construct a model to predict yield as a function of the VCI computed for this period. The simulated results were compared with official agricultural statistics showing that the errors of the estimates of aus rice yield are less than 10%. Remote sensing is a valuable tool for estimating crop yields well in advance of harvest and at a low cost.

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8028-01, Session 1

Polarization properties of tilted fiber Bragg gratings for novel sensing modalities

J. Albert, L. Shao, A. Beliaev, Carleton Univ. (Canada); C. Caucheteur, Faculté Polytechnique de Mons (Belgium)

No abstract available

8028-02, Session 1

Chiral fiber sensors for harsh environments

V. I. Kopp, J. Singer, D. Neugroschl, A. Z. Genack, Chiral Photonics, Inc. (United States)

No abstract available

8028-03, Session 1

Long period grating in photonic crystal fiber as opto-microfluidic label-free biosensor

Z. He, F. Tian, Stevens Institute of Technology (United States); J. Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); N. Lavlinskaia, High Tech High School (United States); D. J. Trevor, OFS Labs. (United States); H. H. Du, Stevens Institute of Technology (United States)

We have shown that the cladding modes excited by long-period gratings (LPG) inscribed in photonic crystal fiber (PCF) with CO2 laser provide an excellent means of evanescent field-based chemical and biological sensing and detection. The PCF-LPG shows extremely high sensitivity to layer-by-layer thin film formation in the LPG region. We developed a novel optofluidic lab-in-fiber device for flow-based label-free micro-immuno/biosensors. As a sensitive refractive index transducer, the PCF-LPG experiences dramatic shift in resonance wavelength due to binding events taking place at the surface of the air channels in the LPG structure. The LPG was fabricated under continuous water flow through the PCF air channels to allow consistent positioning of the resonance band during fabrication and use under liquid-filled condition. We have demonstrated that the PCF-LPG scheme and our fabrication approach leads to excellent bio-sensitivity that requires microliter sampling volume.

8028-04, Session 1

Sensitive fluorescence detection with microstructured optical fibers

E. P. Schartner, H. Ebendorff-Heidepriem, T. M. Monro, The Univ. of Adelaide (Australia)

Optical fibers are ideal for environmental sensing applications because of their ability to transmit optical signals to and from the sensing region without the use of free-space optics. By accessing the evanescent field, the fiber itself can act as the sensing element and long interaction lengths can be achieved. Microstructured optical fibers are particularly suited to such applications as the species of interest can occupy the air spaces within the fiber.

Here we use a suspended nanowire design that provides the high evanescent overlap of a nanowire with the long interaction length and robustness of a conventional fiber. The fluorescence-detection approach proposed in this paper is attractive because of its simplicity. When one end of the fiber is dipped into the sample, capillary forces draw the liquid into the voids within the fiber. The evanescent field of the pump light excites the fluorescent labels and a portion of the fluorescence is captured by the fiber core and propagates to the fiber tips.

The aim of this work is to improve the sensing architecture to increase the sensitivity of the sensor, and to examine the primary factors such as the background glass fluorescence currently restricting the detection limit in this type of sensor. This work is focused on biological detection in liquid samples using Quantum dots, but through careful selection of the fluorescent dye this can be extended to a large number of alternative applications. Using this system we are able to detect quantum dot concentrations as low as 10 pM.

8028-05, Session 1

Photonic crystal fiber long-period gratings as refractive index transduction platform for gas sensing

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); D. J. Trevor, OFS Labs. (United States); H. H. Du, Stevens Institute of Technology (United States)

Long-period gratings (LPG) have been inscribed in photonic crystal fiber (PCF) using CO2 laser as an index transduction platform for gas sensing. The resultant LPG-PCF scheme has been shown to be sensitive to as low as 10-7 refractive index unit for the gas phase present inside of the cladding air channels of the PCF. We demonstrate that such sensitivity can be used to differentiate the gas type as well as to monitor gas pressure at a given temperature. A quantitative attempt has been made to correlate the resonance wavelength shift with gas pressure through the refractive index and the equation of state of the gas phase.

8028-06, Session 2

Thermally regenerated fiber Bragg gratings in air-hole microstructured fibers for high-temperature pressure sensing

K. P. Chen, T. Chen, J. B. Negley, Univ. of Pittsburgh (United States); D. Grobnic, S. J. Mihailov, Communications Research Ctr. Canada (Canada); J. Canning, The Univ. of Sydney (Australia)

Rapid and reliable pressure sensing at high temperature are essential for many industry applications, such as operations of power plants and gas turbines. Fiber Bragg grating based optical pressure sensors have been considered as excellent candidates for applications in harsh environments due to their compact size, low cost, electrical immunity and good multiplexing ability. However, Most of Type I fiber Bragg grating fabricated by deep ultraviolet lasers cannot survive at high temperature beyond 500°C. Recently, Type II fiber Bragg grating based pressure sensors fabricated in twin-hole fiber with a near IR ultrafast laser shows stable operation above 800°C. But the measurement sensitivity of pressure sensors was limited by large birefringence induced by the ultrafast laser irradiation.

In this paper, we report a thermally regenerated Type I FBG fiber pressure sensor that can operates beyond 800°C. Fiber Bragg grating sensors were inscribed in twin-hole microstructure fibers with a 248nm excimer laser and annealed at 800°C for the thermal regeneration. The regenerated fiber grating sensors show similar high temperature thermal stability as those found in Type II fiber Bragg gratings but with

much smaller intrinsic birefringence and spectral width. This paper demonstrates a rapid and reliable fabrication process to produce multiplexible fiber based pressure sensors for high temperature applications.

8028-07, Session 2

High speed measurements using fiber-optic Bragg gratings

J. J. Benterou, C. M. May, Lawrence Livermore National Lab. (United States); E. Udd, Columbia Gorge Research (United States)

To fully calibrate hydrocodes and dynamic chemistry burn models, initiation models and detonation models of high explosives, the ability to continuously measure the detonation velocity, detonation pressure and detonation temperature within an explosive is required. Progress on an embedded velocity diagnostic using a 125-micron diameter optical fiber containing a chirped fiber Bragg grating is reported. Experimental details of the associated equipment and data in the form of continuous detonation velocity records within PBX-9502 and C-3 Detasheet are presented. Work that has been done at Lawrence Livermore National Laboratory shows measurements of internal detonation velocities on the order of 6 to 8 mm/µsec along path lengths tens of millimeters long in combination with a multi-channel high-speed detection system with a rise time of about 5 ns. Columbia Gorge Research is working with extensions of the technology that allow high speed measurements of pressure and temperature. An overview of this technology will be reported.

8028-08, Session 2

Study of blast event propagation in different materials using a novel ultrafast miniature optical pressure sensor

X. Zou, N. Wu, Y. Tian, J. Li, K. Sun, X. Wang, Univ. of Massachusetts Lowell (United States)

Traumatic brain injury (TBI, also called intracranial injury) is a great potential threat to our soldiers. A helmet structure health monitoring system is used to study the effects of ballistic/blast events on the helmet and human skull to prevent the people from TBI. In order to study the characteristic of shockwave propagation in different medium, a shock-tube is designed to mimic the blast event and wave propagation in multiple layers. An ultrafast optical fiber sensor is presented to measure the blast signal. The sensor is based on the Fabry-Perot (FP) interferometric principle. The endface of the etched optical fiber tip and silica thin diaphragm on it form the FP cavity. The sensor is very small and can be installed on different locations of a helmet to measure blast pressure simultaneously. The multiple layer blast event tests were conducted to evaluate the sensor performance. The sensors were mounted in different layers of a shock tube, side by side with the reference sensors, to measure a rapidly increased pressure. Each layer was filled with different material. The home-made shock tube could provide a good resource to study propagation of blast event in different layers.

8028-09, Session 3

Advanced spectral fiber optic sensor systems and their application in energy facility monitoring

R. Willsch, W. Ecke, Institut für Photonische Technologien e.V. (Germany); T. Bosselmann, M. Willsch, Siemens AG (Germany); E. Lindner, H. Bartelt, Institut für Photonische Technologien e.V. (Germany)

Various spectral-encoded fiber optic sensor concepts and advanced system solutions for application in energy facility monitoring have been investigated. The technological maturity, high performance and reliability of multiplexed fiber Bragg grating (FBG) sensor arrays and networks for the measurement of temperature, dynamic strain, air flow, and magnetic field distribution in electric power generators increasing their efficiency will be demonstrated by selected examples of field testing under harsh environmental conditions. For high-temperature combustion monitoring in gas turbines, beside silica FBG with enhanced temperature stability also sapphire FBG and Fabry-Perot sensors as well as fiber-based black-body thermal radiation sensors have been tested and evaluated. Finally, the potential of FBG sensors for application in cryo-energetic facilities such as super-conductive high-power motors and experimental nuclear fusion reactors will be discussed.

8028-10, Session 3

All-optical vibration and temperature monitoring systems for large scale power generators

L. A. Ferreira, F. M. Araújo, FiberSensing (Portugal); E. V. Diatzikis, Siemens Power Generation, Inc. (United States)

No abstract available

8028-11, Session 3

Advanced draw-tower fiber Bragg gratings and their application in sensing

E. Lindner, Institut für Photonische Technologien e.V. (Germany); C. Chojetzki, J. Moerbitz, FBGS Technologies GmbH (Germany); M. Becker, S. Brückner, R. Willsch, M. Rothhardt, H. Bartelt, Institut für Photonische Technologien e.V. (Germany)

The idea of Bragg gratings generated during the drawing process of a fiber dated back almost 20 years. But only within the last years, a flexible high-performance and cost-efficient industrial fabrication technology of such draw-tower grating (DTG®) arrays has been established.

In this paper, new possibilities offered by the improved technology with respect to the grating type (type I gratings, type II gratings), the coating material (Ormocer, gold), and smaller fiber diameters will be demonstrated. Type II DTG®s, used in single grating or in array configuration up to three different wavelengths, enable low-cost high-temperature sensing up to 900°C. Metal coatings on DTG® fibers protect the fiber glass material in high-temperature environment and allow new fixing techniques like brazing. We will show results from a gold coated DTG® fiber for high temperature operation. Thanks to the flexibility of the fabrication process, also smaller fiber diameter below 80 µm can be realized, e.g., for embedding of DTG®s in composite materials. Limitations for reducing of the fiber diameter in a DTG inscription process will be shown.

Besides the geometrical and coating properties, the inscription process itself is of great importance. An advanced motor-controlled inscription of narrow-spaced DTG® arrays has been developed, e.g., for application in medical diagnostics. As an example, a sensor consisting of an array of 36 gratings in a 36cm long fiber piece for monitoring diseases in the human esophagus will be presented.

8028-12, Session 3

Automatic fiber Bragg grating fabrication system for mass production

Y. Wang, J. Gong, D. Y. Wang, B. Dong, A. Wang, Virginia

Polytechnic Institute and State Univ. (United States)

The large multiplexing number of FBGs exposes a requirement for the effective and repeatable fabrication method. In this paper we report the development of an automatic FBG fabrication system, which meets the requirement of mass production. There are four major functional parts in the system: fiber feeding system, CO2 laser coating removal system, FBG writing system and fiber collecting system. The fiber feeding system uses motors and gears to accurately move an optical fiber to where the FBGs will be made. The coating removal system is based on the heat effect of a CO2 laser, which will decompose and evaporate the selected coating of the optical fiber. The FBG writing system is based on the UV photosensitivity of the fiber. A phase-mask is placed between the UV light and the optical fiber to produce periodic interference pattern, which further modulates the refractive index along the fiber periodically. The fiber collecting system is driven by a linear motor and the fiber can be wound around a spool tightly and smoothly at a moderate speed. The whole FBG fabrication system is controlled and synchronized by a computer via some interface circuits and a Graphical User Interface (GUI). With this system, it takes 48 seconds to fabricate one FBG, and up to 500 FBGs can be made continuously, which is limited by the leakage of the gas inside the excimer laser. This mass production line not only improves the fabrication efficiency but also contributes to the multiplexing capability by reducing the splicing loss.

8028-13, Session 3

Innovative use of embedded FBG sensors in civil engineering and other applications

G. Nosenzo, Monitor Optics Solutions (Australia)

No abstract available

8028-14, Session 3

Next generation distributed fiber optic acoustic emission sensor (FAESense) system for condition-based maintenance

E. A. Mendoza, Redondo Optics, Inc. (United States)

This paper describes the development of a dynamically reconfigurable, adaptive fiber optic acoustic emission sensor (FAESense) system for the in-situ unattended detection and localization of shock events, impact damage, cracks, voids, and delaminations in new and aging critical infrastructures found in ships, submarines, aircraft, and in next generation weapon systems.

ROI's FAESense system is based on the integration of proven state-of-the-art technologies: 1) distributed array of in-line fiber Bragg gratings (FBGs) sensors sensitive to strain, vibration, and acoustic emissions, 2) adaptive spectral demodulation of FBG sensor dynamic signals using two-wave mixing interferometry on photorefractive semiconductors, and 3) integration of all the sensor system passive and active opto-electronic components within a 0.5-cm x 1-cm photonic integrated circuit microchip.

ROI's FAESense system represents a new, highly robust and reliable, technology that can be used for structural health monitoring and prognostics of military and commercial infrastructures. Its miniaturized package, low power operation, state-of-the-art data communications, and affordable price makes it a very attractive solution for a large number of applications in naval and maritime industries, aerospace, civil structures, the oil and chemical industry, and for homeland security applications.

8028-15, Session 3

A 40 ksamples/sec spectrometer based FBG interrogator, capable of simultaneously measuring more than 16 FBG sensors

J. P. Vermeiren, J. L. Bentell, D. De Gaspari, D. Uwaerts, P. Verbeke, Xenics NV (Belgium); J. Vlekken, OpticalFiberSensors.org BVBA (Belgium)

A fast spectrometer based FBG interrogator will be discussed. This unit is constructed around a fast linear InGaAs array with 1024 pixels and capable of reading out 40 000 lines per second and a SLED operating in the C+L band. This array is integrated in a double reflective grating spectrometer, dispersing the spectra in the [1510 - 1590 nm] band. The instrument is equipped with 2 spectrometers in order to treat the signals from 8 birefringent FBG sensors or 16 single FBG sensors. The firmware of the system is capable of determining at least 8 Center of gravity operations within 25 µsec per spectrometer. The noise on the Center of gravity determination is better than 1/20 of a pixel, yielding a 5 pm resolution reflection peak reading. The unit has also been calibrated for temperature variation of the unit with an absolute precision < 25 pm. The intensity of the reflection peaks can vary over more than 20 dBV without influencing the performance of the Center of gravity determination significantly. This project was executed in the framework of an ESA GSTP project.

8028-16, Session 3

A discrete liquid level sensor based on fiber Bragg grating

D. Song, J. Zou, J. Xie, H. cui, L.C. Pegasus Corp. (United States)

A discrete liquid level sensor based on fiber Bragg grating and carbon fiber laminate cantilever beam is proposed. The discrete liquid level sensor functions as a switch. when liquid rises to a set level, the sensor will give a warnig signal. Fiber Bragg grating is glued on the cantilever beam, at the end of the beam, an iron sheet is attached. besides that, a permanent magnet is sealed inside a float. switching occurs when the float rise or falls to the actuation level. the reason is that the magnet float will attract the iron sheet when water rises or fall to the actuation level, then strain will be induced on the cantilever beam, the Bragg wavelength shift will be induced due to the applied strain.

8028-17, Session 4

Fiber laser sensors: enabling the next generation of miniaturized, wideband marine sensors

G. A. Cranch, G. A. Miller, C. K. Kirkendall, U.S. Naval Research Lab. (United States)

No abstract available

8028-18, Session 4

Surface scattering plasmon resonance fibre sensors: demonstration of rapid influenza A virus detection

A. Francois, J. Boehm, The Univ. of Adelaide (Australia); S. Oh, T. Kok, Institute of Medical and Veterinary Science (Australia); T. Monro, The Univ. of Adelaide (Australia)

Return to Contents

The management of threats such as pandemics and explosives, and of health and the environment requires the rapid deployment of highly sensitive detection tools. Sensors based on Surface Plasmon Resonance (SPR) allow rapid, label-free, highly sensitive detection, and indeed this phenomenon underpins the only label-free optical biosensing technology that is available commercially. In these sensors, the existence of surface plasmons is inferred indirectly from absorption features that correspond to the coupling of light to the surface plasmon. Although SPR is not intrinsically a radiative process, under certain conditions the surface plasmon can itself couple to the local photon states, and emit light as first described by Kretschmann. Here we show that by collecting and characterising this re-emitted light, it is possible to create new SPR sensing architectures that are more compact, versatile and robust than existing approaches. This approach addresses existing practical limitations of current SPR technologies, including bulk, cost and calibration. It is applicable to a range of SPR geometries, including optical fibres, planar waveguides and prism configurations, and is in principle capable of detecting multiple analytes simultaneously. Moreover, this technique allows to combine SPR sensing and fluorescence sensing into a single platform which has never been demonstrated before and consequently use these two methods for a more reliable diagnostic. As an example, this approach has been used to demonstrate the rapid detection of the seasonal influenza virus.

8028-25, Poster Session

Computational analysis and considerations of an optical fiber sensor with multiple cladding

J. A. Betancur Ramírez, Univ. EAFIT (Colombia)

Today there is a growing motivation for the study of optical fiber sensors with a rate of space variant refraction, the same as the study of crystal photonic fibers for census taking. This work explains through MAPLE software, the computational analysis of the transverse electric and transverse magnetic modes generated in terms of Bessel functions, as a result of the light propagation through optical fibers with different settings, proper of the type of sensor analyzed. This research exposes fundamental characters of measurement focused on the register of attributes of an object in terms of its geometry and material, through the observation of its diffraction pattern. At the end, exposures and comments are made about the results obtained in graphics, showing the relation with the physics and mathematics model described. The research for applications of this kind of technology is still scarce, for which it results necessary to investigate new types of analysis that can make possible the expansion of the technique to other fields of knowledge.

8028-26, Poster Session

A research on polarization effects in an distributed optical fiber sensor disturbance location system

H. Xu, X. Qian, Fudan Univ. (China)

An analysis based on the Jones matrix theoretical analysis is presented to study the polarization effect of the distributed optical fiber sensor which was based on Sagnac interferometer for disturbance location. A new improved distributed optical fiber location system is designed.By using a Faraday rotation mirror ,the system is insensitive to the change of the polarization in the sensing part of the optic fiber,remove the linear birefringence and the orientation birefringence,the practicability of the system is increased.

8028-27, Poster Session

A novel frequency domain location method in distributed optic-fiber sensor based on PGC

H. Xu, H. Wu, X. Qian, Fudan Univ. (China); Z. Qiao, Zhengben Water Purification Co., Ltd. (China)

A novel frequency-domain location method in distributed Optic-Fiber sensor based on Phase Generated Carrie is presented. The configuration and operating principle of the system is illustrated, the location principle and method for the detection system are analyzed.After spectral transformation of the two optical phase change signals and then divided them,the system can obtain the location information of the disturbance. Theory analysis and experiment result show that the proposed technology can realize the detection and location of the disturb signal rapidly and effectively, this method is simply and can be obtained easily, and it has high measurement sensitivity and location precision.

8028-28, Poster Session

All-fiber multimode interference micro-displacement sensor

J. E. Antonio-López, Instituto Nacional de Astrofisica, Optica y Electronica (Mexico) and CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); J. A. Arredondo-Lucio, Univ. Autónoma de Tamaulipas (Mexico); P. L. Likamwa, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); D. A. May-Arrioja, Univ. Autónoma de Tamaulipas (Mexico)

We report on a novel all-fiber micro-displacement sensor based on multimode interference (MMI) effects. The fabricated Micro-Displacement consists of a segment of No-Core multimode fiber (MMF) with one end spliced with a segment of single mode fiber (SMF) that is our input. The other end of the MMF and another SMF are inserted into a capillary tube filled with index matching liquid. Since the refractive index of the liquid is higher than that of the ferrule, a liquid multimode waveguide (diameter of 125 µm) is formed between the fibers inside the capillary. It is well known that wavelength response of MMI devices is very sensitivity when their length (L) is modified. Therefore when the fibers inside the capillary are moved away from each other, we increase the effective length of the MMF. Using this scheme, micro-displacements are detected through changes of the MMI spectral response. The sensing mechanism starts when the facets of the No-Core MMF and the SMF are placed in contact within the capillary tube ($\Delta L=0$), which corresponds to zero displacement. When we begin to separate the facets of the fibers we start to increase the effective length of the MMF, and thus the MMI peak wavelength shift to shorter wavelengths. In this way we can easily detect a displacement range of 3 mm, corresponding to a wavelength range from 1555.4 to 1480.2 nm, with detectable resolution of 20 µm in each step. This Micro-Displacement sensor is promising and attractive due to its simplicity and low cost.

8028-29, Poster Session

Phase-shifted Bragg gratings generated by CO_2 laser post-fabrication processing

F. Guo, M. Han, Univ. of Nebraska-Lincoln (United States)

An experimental demonstration of a phase shifted Bragg grating is carried out. This phase shifted Bragg grating is obtained by the irradiation of CO2 laser along with a proper stress. Such a post-processing method shows more flexibility than phase-mask method and also has a good reproducibility.

8028-31, Poster Session

Automated testing for the fast and accurate determination of detergent efficiency by optical fibre sensors

M. Patitsa, H. Pfeiffer, M. Wevers, Katholieke Univ. Leuven (Belgium)

This sensor is to be used to study the efficiency of different cleaning products and also indicate how formulation, concentration, stirring velocity and temperature affect the cleaning behaviour of a surfactant.

There are already detergent tests available: a)Visual comparison of samples,b) Chemical analysis of the remaining water after cleaning, c)Radioactive methods and d) Spectrometry . These methods have disadvantages that make them inaccurate, time consuming and limited to small quantities. Thus, there is a need in the art for a method to develop this optical to offer a dedicated and more accurate solution.

Before the experiment, the sensor is coated by a defined stearic acid layer modelling some kind of defined dirtiness. Evanescence wave spectroscopy and surface plasmon resonance was used to sense and transmit information regarding the number of layers that are deposit by using Langmuir-Blodgett technique and then removed by the Sodium Dodecyl Sulfate surfactant solution. Beside the optical sensor the detection of the UV and VIS spectral range requires the presence of three spectrometer components- the light source, the bifurcated cable and the spectrometer. The transmittance spectroscopy light is passed through the sensing and compared with the light that has not. The output depends on the lipid layer thickness the detergent efficiency and the test's parameters. As LB layers are deposit, film thickness increases and the result of this is that less light passes through and hence the transmittance decreases.The opposite effect happens when the stearic acid layers on the fibre are removed by the surfactant solution.

8028-19, Session 5

Optical efficiency in metal-lined capillary waveguide Raman sensors

S. Biedrzycki, M. P. Buric, National Energy Technology Lab. (United States) and Univ. of Pittsburgh (United States); J. Falk, S. D. Woodruff, National Energy Technology Lab. (United States)

Researchers have long sought to improve collection efficiencies in scattered-light sensing applications. In our work, we are interested in the efficient collection of spontaneous Raman photons scattered from gaseous samples so as to enable the accurate, real-time, simultaneous measurement of otherwise difficult to distinguish molecular gasses or hydrocarbons. Hollow capillary waveguides, lined with a metal and dielectric over-coating, have often been used for delivering IR laser light to a target. We demonstrate that these waveguides can be used as both a sample holder which contains Raman gasses and as a laser-pumped optical cell which can collect Raman scattering from gasses inside the waveguide. Here, we show how classical electromagnetic theories with appropriate assumptions for high-order modes can be applied with robust computer simulation to accurately calculate the spontaneous Raman scattering power that can be collected using such a waveguide. We verify our new theoretical models with experimental measurements of Raman signals from a number of gasses. We show that a properly designed hollow-metal/dielectric capillary waveguide can be used to collect scattered visible Raman photons with significantly better efficiency than free-space collection geometries or un-lined silica waveguides. We also demonstrate a cutback experiment which verifies our new theoretical predictions of the variation of scattering collection efficiency with guide dimensions. These simulations allow us to design spectrometers and detectors to maximize Raman-light throughput in a high-sensitivity gas detection system.

8028-20, Session 5

Position Determination and Monitoring of Disturbance along Distributed Fiber Optic Sensors

H. Wu, H. Xu, T. Bu, D. Zhao, Fudan Univ. (China)

Distributed Fiber Optic Sensor for Position Determination is a novel position sensor and can be used as a monitoring system in communication main of long distances. Single fiber is employed as the sensor in the system to pick up the disturbances in the environment. The principle of the system is that for a disturbance signal applied at a particular position along the fiber, the response, in the frequency domain, presents a series of periodic maxima and minima (or nulls). These minima depend on the position of the disturbance along a fiber. An intelligent, reliable and real-time signal processing method is needed in such a system to determine the position of disturbance. It is not enough to process the signal of the system just using FFT (fast Fourier transform) algorithm. By using power spectral estimation and wavelet transforming as the method of signal processing, the position of a random disturbance is successfully determined. With graphic programming language LabVIEW as the software developing platform, the periods for hardware testing and program debugging are largely shortened.

8028-21, Session 5

Lithographic inscription of micro-optical devices on a multi-material optical fiber tip

J. Kaufman, G. Tao, A. F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We present a new approach to the fabrication of micro-optical components on the end facet of a multi-material fiber. The combination of novel fiber designs and optical device fabrication on the fiber tip allow for the implementation of lab-on-a-chip sensing technique without a chip altogether and relying solely on an optical fiber.

In our proposed approach, the tip of an optical fiber itself is used as a lithographic substrate on which optical components are inscribed. We present the fabrication of micro-optical elements on the end facet of optical fibers whose cladding material is a polymer (polyethersulfone, PES) and core material is a chalcogenide glass (As_2Se_3) designed for infrared light transmission. While these two materials are also thermally compatible, allowing them to be pulled together in the fiber drawing process, they are chemically quite distinct, eliminating the possibility of direct implementation of a traditional lithographic process. Instead, a modified UV lithography process to pattern the fiber tip is described. A chemical etch is used to smooth the tip to sub-10-nm roughness. We demonstrate the procedure by fabrication and characterization of Fresnel lenses for near-infrared light on the fiber end facet.

8028-22, Session 5

Test of a novel miniature blood pressure sensor in the coronary arteries of a swine model

N. Wu, K. Sun, X. Zou, Univ. of Massachusetts Lowell (United States); K. Barringhaus, Univ. of Massachusetts Medical School (United States); X. Wang, Univ. of Massachusetts Lowell (United States)

Fractional flow reserve (FFR) has proven to be very useful in diagnosis of narrowed coronary arteries. It is a technique that is used in coronary catheterization to measure blood pressure difference across a coronary artery stenosis in maximal flow. In-vivo blood pressure measurement is critical in FFR diagnosis. This paper presents a novel miniature all-optical fiber blood pressure sensor. It is based on Fabry-Perot (FP) interferometry principle. The FP cavity was fabricated by directly wet etching the fiber tip. Then, a diaphragm with well-controlled thickness was bonded to the end face of the fiber using the thermal bonding technique. Finally, the sensor was packaged with a bio-compatible and flexible coil for animal tests. A 25-50 kg Yorkshire swine model was introduced as the animal test target. The left anterior descending coronary artery (LAD) was exposed, and beyond the takeoff of the largest diagonal branch, a 3.0 mm vascular occluder was secured. Firstly, standard invasive manometry was used to obtain the blood pressure as baseline. Next, a guiding catheter was introduced into the ostium of the left main coronary artery, and the miniature blood pressure sensor was advanced into the LAD at a point beyond the vascular occlude. The blood pressure beyond the vascular occlude was recorded. The sensor successfully recorded the blood pressure at both near-end and far-end of the vascular occluder.

8028-23, Session 5

Optoacoustic fiber optic interferometric sensors for biomedical applications

D. C. Gallego, H. Lamela, Univ. Carlos III de Madrid (Spain)

Optoacoustic tomography (OAT) is a non-invasive and non-ionizing imaging technique to visualize biological soft tissues. It takes the superior contrast based on the optical absorption and the spectroscopy capacity from the optical tomography and its high spatial resolution from the ultrasonic imaging. These features make it suitable in many medical imaging applications.

Optoacoustic signals require broadband detectors to image the different sizes of absorption regions inside the body. The detection technology traditionally used in ultrasonic imaging, based on piezoelectric transducers, is highly sensitive but has narrow bandwidth because of their resonant nature. The detectors based on thin piezoelectric polymer films can be made sensitive within an ultrawideband, but their sensitivity decreases as their size is reduced. Optical detection techniques have some advantages over traditional electrical methods such as, large detection bandwidth and immunity to electrical perturbations. In particular, intrinsic fiber optic interferometric sensors (IFOIS) present some improvements: the fabrication is straightforward and involves the use of low cost materials; they are non-metallic (can be combined with MRI in a multimodal imaging technique); and can be made from biocompatible materials opening the possibility for the fabrication of an optoacoustic endoscope.

The acoustic sensitivity of IFOIS depends strongly of the material which is composed of. It has been demonstrated from the authors that a single-mode polymer optical fibers (SMPOF) have 12 times more sensitivity sensing ultrasonic waves in the 1MHz frequency range than a singlemode silica optical fibers (SMSOF). However, these SMPOF are still under development and present high loss and difficulties to coupling light into. On the other side, the multimode graded-index perfluorinated polymer optical fibers (GIPOF) present lower losses and these are easier to handle, but due to their multimode nature there is degradation in the visibility of the interference reducing the total sensitivity. In this work we compare experimentally two fiber optic sensors based on SMSOF and GIPOF, respectively. Both sensors are designed for detection of optoacoustic wave sources with dimensions between 15mm and 0.3mm what corresponds to ultrasonic frequencies in the range from 100kHz to 5MHz. This will be done based on the comparison of sensitivity, dynamic range, frequency bandwidth, spatial resolution and compactness.

8028-24, Session 5

Continuous monitoring of plant stem diameter growth using fiber-optic interferometric sensing

J. Chatterjee, B. G. Grossman, Florida Institute of Technology (United States)

Dendrometers and dendrographs have been successfully used for point and band measurements of tree stem diameter growth. These sensors have been used with LVDT based data logging systems for continuous monitoring. In this paper a prototype technique is presented for the continuous monitoring of plant stem diameter growth using an approach based on fiber-optic interferrometric sensing. The advantage of this sensing technique over the others would be the ability to measure and analyze with very high sensitivities over short time spans. Sensor construction is described in detail and the influences of environmental growth parameters have been investigated. The sensor is mounted on the plant stem and the change in plant stem diameter and environmental stimuli is found responsible for the output signal display which is in the form of interferrometric fringes. The data acquisition is performed over a long duration using labVIEW based data logging. Filtered and unfiltered output of the data has been presented in the form of graphs where an attempt has been made to relate the fringes to stem diameter changes. The sensing system is non destructive and non invasive and has been targeted to respond to changes in stem diameter due to changes in plant growth parameters. Isolated experimental results have been presented over different time periods including data for environmental growth parameters in erratic and periodic frequencies.

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8029A-01, Session 1

Instrument free nucleic acid amplification assays for global health settings

P. LaBarre, B. H. Weigl, PATH (United States)

As traditional high quality diagnostic laboratories are not widely available or affordable in developing country health care settings, microfluidics-based point-of-care diagnostics may be able to address the need to perform complex assays in under-resourced areas. Many instrument-based as well as non-instrumented microfluidic prototype diagnostics are currently being developed. In addition to various engineering challenges, the greatest remaining issue is the search for truly low-cost disposable manufacturing methods.

Diagnostics for global health, and specifically microfluidics and molecular-based low resource diagnostics, have become a very active research area over the last five years, thanks in part to new funding that became available from the Bill and Melinda Gates Foundation, the National Institutes of Health, and other sources. This has led to a number of interesting prototype devices that are now in advanced development or clinical validation. These devices include disposables and instruments that perform multiplexed PCR-based lab-on-a-chips for enteric, febrile, and vaginal diseases, as well as immunoassays for diseases such as malaria, HIV, and various sexually transmitted diseases. More recently, instrument-free diagnostic disposables based on isothermal nucleic acid amplification have been developed as well. Regardless of platform, however, the search for truly low-cost manufacturing methods that would result in cost of goods per disposable of around US$1/unit at volume remains a big challenge. This talk will give an overview over existing platform development efforts and original research in this area at PATH.

For example, we have demonstrated that Sodium acetate and CaO heat sources thermally linked to a proprietary EPCM can reliably maintain a thermal profile suitable for isotermal diagnostic assay. We have verified the function of this multiple-pathogen-capable platform with quantified fluorescent results using samples spiked with clinically relevant dilutions of malaria DNA. Next steps will focus on the development of a smaller, optimized device and validation with LAMP and other isothermal assays using clinical samples. We are also advancing other kit technologies such as the high containment, multi-chamber tube to enable a non-instrumented, portable disease-specific LAMP kit in a stable format.

8029A-02, Session 1

Novel approaches in diagnosing tuberculosis

A. H. J. Kolk, N. A. Dang, S. Kuijper, Univ. van Amsterdam (Netherlands); T. Gibson, Scensive Technologies, Ltd. (United Kingdom); R. Anthony, Royal Tropical Institute (Netherlands); M. Claassens, Stellenbosch Univ. (South Africa); E. Kaal, DSM Food Specialties (Netherlands); H. Janssen, Unilever N.V. (Netherlands)

The WHO declared tuberculosis (TB) a global emergency. An estimated 8-9 million new cases occur each year with 2-3 million deaths. Currently, TB is diagnosed mostly by chest-X ray and staining of the mycobacteria in sputum with a detection limit of 1x104 bacteria /ml. There is an urgent need for better diagnostic tools for TB especially for developing countries. We have validated the two electronic noses from Scensive Technologies for the detection of Mycobacterium tuberculosis by headspace analysis of 284 sputum samples from TB patients. We used linear discriminant function analysis resulting in a sensitivity of 75% a specificity of 67% and an accuracy of 69%. Further research is still required to improve the results by choosing more selective sensors and sampling techniques.

We used a fast gas chromatography- mass spectrometry method (GC-MS). The automated procedure is based on the injection of sputum samples which are the methylated inside the GC injector using thermally assisted hydrolysis and methylation (THM-GC-MS). Hexacosanoic acid in combination with tuberculostearic acid was found to be specific for the presence of M. tuberculosis. The detection limit was similar to microscopy. We found no false positives, all microscopy and culture positive samples were also found positive with the THM-GC-MS method.

The detection of ribosomal RNA from the infecting organism offers great potential since rRNA molecules outnumber chromosomal DNA by a factor 1000. It thus may possible to detect the organism without amplification of the nucleic acids (NA). We have developed a method to disrupt mycobacteria for the isolation of NA. We used a capture and a tagged detector probe for the direct detection of M. tuberculosis in sputum. So far the detection limit is 1x106 bacteria / ml. Currently we are testing lab on a chip detection systems.

8029A-03, Session 1

Massively multiplexed microbial identification using resequencing DNA microarrays for outbreak investigation

T. A. Leski, U.S. Naval Research Lab. (United States)

Multiplexed microbial diagnostic assays are critical for rapid and accurate detection and identification of pathogens causing nonspecific symptoms (e.g. flu-like) in which traditional symptom-based differential diagnosis is impossible. Resequencing pathogen microarray (RPM) is an emerging technological platform, relying on combination of massively multiplex PCR and high-density DNA microarrays that enabled the development of assays capable of detection and highly accurate identification of hundreds of infectious agents simultaneously. The RPM diagnostic system was deployed to Sierra Leone, West Africa in collaboration with researchers from Njala University. The diagnostic laboratory was set up in Bo, the second largest city located in the middle of the country. Using this resource and RPM-Flu microarray for broad-range detection of respiratory pathogens, including all subtypes of influenza, we analyzed samples collected from a number of poultry farms from chickens during a suspected outbreak of avian influenza. The microarray results were additionally confirmed by influenza specific real-time PCR testing. The results of the study excluded the possibility that the outbreak was caused by influenza, but implicated Klebsiella pneumoniae as a possible pathogen causing chicken mortality. The outcome of this feasibility study confirms that application of broad-spectrum detection platforms for outbreak investigations allows for rapid discovery of the responsible agent, even in cases when a different agent is suspected, thus allowing for quick and cost effective detection of low probability events such as outbreak of a rare disease or unsuspected agent.

8029A-04, Session 1

Label-free methods for detection of viruses by magnetic relaxometry

L. H. Strong, D. B. Hall, G. Derderian, Radiation Monitoring Devices, Inc. (United States); M. A. Whitt, The Univ. of Tennessee Health Science Ctr. (United States); G. Varadi, Radiation

Monitoring Devices, Inc. (United States)

We report the development of nanoparticle (NP)-based immunoassays and follow-on nucleic acid assays for viruses in crudely extracted samples without extensive, time-consuming purification. Superparamagnetic NPs containing surface coated probes for targeted pathogen receptors were equilibrated with the biological collections containing VSV and HIV-1 model viruses. Pathogen load was quantified by measurement of the relaxation dynamics due to NP birefringence and/or light scattering from NP-target complexes when subjected to pulsed magnetic field modulation. Loop assisted isothermal amplification was then used to expand as few as 100 gene templates of HIV-1 into easily detectable optical signatures, employing primers coupled to superparamagnetic NPs.

8029A-05, Session 1

Tunable wavelength interrogated sensor platform (TWIST) for point-of-care diagnostics of infectious diseases

S. Grego, K. H. Gilchrist, B. R. Stoner, RTI International (United States)

The TWIST platform is an optical evanescent wave sensor based on an input grating coupler, the core technology to an immunoassay-based portable instrument for point of care diagnostics. A critical element to achieve low-cost, compact optical sensors for point-of-care diagnostics is a convenient approach for coupling laser light into the thin waveguide device. The advantage of our device design is that the input grating coupler serves as both the light coupler and the sensor and therefore the device has a simple structure and straightforward microfabrication process (for ultimate low cost). The advantage of our system configuration derives from using the wavelength spectral shift of a largely tunable infrared laser source as the transduction mechanism. We have demonstrated that high performance (sensitivity and stability) can be achieved by compact, low-cost lasers developed for tuning on the telecom grid. Detection of the outcoupled light signal is performed with germanium photodiodes and a custom-fabricated data acquisition card. The system footprint including light source, detectors and digitizers is no larger than 12” x 12”. The system is amenable to expansion to multianalyte capability and we have demonstrated two-channel data acquisition from a sensor functionalized with specific receptors and a negative control sensor to enable on-chip correction for non-specific binding. Preliminary virus detection data will be presented. The sensing principle is the same for either virus or protein so the system can detect both antigen and host response antibodies which is highly desirable for rapid infectious disease detection.

8029A-06, Session 1

Constructing paths through social networks for disease surveillance

M. J. Greene, CNA Corp. (United States)

A vast amount of real-time information about infectious disease outbreaks is found in various forms of Internet-based data streams. This paper discusses a research effort to address the flow and growth of disease surveillance using the Internet. It builds on the infrastructure developed by the International Society for Infectious Diseases described at last year’s SPIE and presents an update that shows how paths can be constructed pro-actively in social networks to track the evolution of new diseases. Several authors have commented on the role of social behavior in other fields: Norbert Wiener, who pointed out that intercommunication of ants leads to “emergent behavior”; Vannevar Bush, who stated that tracing paths from one information source to another represents “the way we think”; Jon Kleinberg, who noted that “social networks can spread information from person to person, contagiously, in the style of an epidemic”; Jaron Lanier, who worries that “the social network phenomenon currently underway is leading us to a point where our relationship with technology itself becomes the only measure of our humanity.” However, my approach focuses on a technique that mimics the famous experiments of social psychologist Stanley Milgram, who provided the first empirical evidence of “six degrees of separation” when constructing paths to distant targets. I apply the model to assist epidemiologists in tracking the evolution of disease outbreaks for further analysis. The paper concludes with recommendations for advancing the science of information systems to the art of biosurveillance.

8029A-07, Session 1

Solving stochastic epidemiological models using computer algebra

J. F. Ospina, Univ. EAFIT (Colombia)

Mathematical modeling in Epidemiology is an important tool to understand the ways under which the diseases are transmitted and controlled. The mathematical modeling can be implemented via deterministic or stochastic models. Deterministic models are based on short systems of non-linear ordinary differential equations and the stochastic models are based on very large systems of linear differential equations. Deterministic models admit complete, rigorous and automatic analysis of stability both local and global from which is possible to derive the algebraic expressions for the basic reproductive number and the corresponding epidemic thresholds using computer algebra software. Stochastic models are more difficult to treat and the analysis of their properties requires complicated considerations in statistical mathematics. In this work we propose to use computer algebra software with the aim to solve epidemic stochastic models such as the SIR model and the carrier-borne model. Specifically we use Maple to solve these stochastic models in the case of small groups and we obtain results that do not appear in standard textbooks or in the books updated on stochastic models in epidemiology. From our results we derive expressions which coincide with those obtained in the classical texts using advanced procedures in mathematical statistics. Our algorithms can be extended for other stochastic models in epidemiology and this shows the power of computer algebra software not only for analysis of deterministic models but also for the analysis of stochastic models. We also perform numerical simulations with our algebraic results and we made estimations of basic parameters as the basic reproductive rate and the stochastic threshold theorem. We claim that our algorithms and results are important tools to control the diseases in a globalized world.

8029A-08, Session 1

Molecular and cellular sensing on health diagnostic compact disc in portable computer for global health and telemedicine

L. Liu, Univ. of Illinois at Urbana-Champaign (United States)

Blood check for molecular and cellular disease biomarkers is a regular technique of health diagnosis, but it usually requires expensive bench scale equipments and well trained expertise provided only in resourceful medical facilities. Therefore the molecular and cellular level blood analysis is usually not accessible to many people in developing countries or to ill soldiers in rural fields. We demonstrated a technology to analyze molecular biomarkers and phenotypes of microparticles and cells on a microfluidics integrated digital compact disc, or health diagnostic compact disc (HDCD), operated in the standard optical drive of a portable computer. Special binary data sequence was written on CD-Recordable (CD-R) discs which are engineered with microscale fluidic channel networks above the digital data layer. The surface of the microfluidics is chemically and biologically functionalized to recognize molecular biomarkers. Cells and microparticles introduced in the microfluidics of HDCD are separated, collected and imaged in the optical drive. In the laser scanning and reading process of the optical drive, the cells and molecules is entangled with the original binary digital data bits on CD and the convoluted data acquired by the optical drive is analyzed to extract information about the biomarkers concentration, type, numbers and morphology of microparticles and cells in the biofluidic sample. Abundant molecular and cellular level information is inherently digitalized by web-based application software and the digital health diagnosis information acquired from the portable computer is readily transmitted through internet and wireless networks.

8029A-09, Session 1

Lab-on-a-cellphone as an emerging telemedicine platform

O. Mudanyali, D. Tseng, C. Oztoprak, S. O. Isikman, I. Sencan, O. Yaglidere, A. Ozcan, Univ. of California, Los Angeles (United States)

Today there are more than 4 billion cellphone users in the world, and the majority of these cellphones are being used in the developing parts of the world. This massive volume brings an enormous cost-reduction to cellphones despite their sophisticated hardware/software capabilities. Utilizing this advanced state-of-the-art of the cellphone technology towards point-of-care diagnostics and/or microscopic imaging can offer numerous opportunities to improve health-care 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 cell-phone microscope which achieves a spatial-resolution of <2 µm over an imaging field-of-view that is >10 fold larger than conventional microscopes, providing an alternative telemedicine tool to rapidly monitor 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 or costly optical/mechanical components, i.e., an inexpensive hardware attachment, that is only ~38 grams, is needed to perform lensfree microscopy on a commercially-available cellphone. This cellphone 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 cellphone. Acquired holographic images are then digitally processed using custom-developed reconstruction algorithms to rapidly create microscopic images of the specimen. This lensfree cellphone 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.

8029A-10, Session 1

On-chip blood analysis using lensless microscopy

S. O. Isikman, Univ. of California, Los Angeles (United States); S. Seo, Korea Univ. (Korea, Republic of); I. Sencan, O. Mudanyali, T. Su, W. Bishara, A. Erlinger, A. Ozcan, Univ. of California, Los Angeles (United States)

Although advanced tools are widely available for whole blood analysis such as flow-cytometers and light-microscopes, these instruments, with their large sizes and complexity, are in general designed for use in well-equipped laboratories. However, blood analysis in resource-limited settings requires compact, light-weight and cost-effective devices which can be operated by minimally trained personnel. To address this need, we have recently developed a field-portable on-chip holographic microscopy and cytometry platform achieving sub-cellular resolution over a large field-of-view. Here we demonstrate the application of this lensless imaging modality for automated high-throughput whole blood analysis, which can provide a significant solution for rapid medical diagnosis in resource-limited environments.

In our lensfree imaging approach, a standard coverglass, on which the blood sample is dropped or smeared using conventional techniques, is placed directly onto an optoelectronic sensor-array (e.g., a CMOS chip). A simple LED is utilized to record lensfree holographic images of the blood cells over the entire active area of the sensor-array (i.e., ~24mm2). Through rapid digital processing of these recorded lensfree holograms, we demonstrate accurate automated counting of red-blood-cells (RBCs) at densities reaching ~0.4 Million cells/µL. We also characterize the volume of the RBCs at the single cell level. 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 lensfree on-chip imaging platform can also perform highly accurate hemoglobin concentration measurements by quantifying the photon transmission through blood samples.

8029A-11, Session 2

Digital microbiology: detection and classification of unknown bacterial pathogens using a label-free laser light scatter-sensing system

B. P. Rajwa, Purdue Univ. (United States); M. M. Dundar, F. Akova, Indiana Univ.-Purdue Univ. Indianapolis (United States); V. Patsekin, J. E. Dietz, Purdue Univ. (United States); A. K. Bhunia, Ctr. for Food Safety Engineering (United States); E. D. Hirleman, J. P. Robinson, Purdue Univ. (United States)

The majority of tools for pathogen sensing and recognition are based on physiological or genetic properties of microorganisms. However, there is enormous interest in devising label-free and reagentless biosensors that would operate utilizing the biophysical signatures of samples without the need for labeling and reporting biochemistry. Optical biosensors are closest to realizing this goal and vibrational spectroscopies are examples of well-established optical label-free biosensing techniques. A recently introduced forward-scatter phenotyping (FSP) also belongs to the broad class of optical sensors. However, in contrast to spectroscopies, the remarkable specificity of FSP derives from the morphological information that bacterial material encodes on a coherent optical wavefront passing through the colony. The system collects elastically scattered light patterns that, given a constant environment, are unique to each bacterial species and/or serovar. Both FSP technology and spectroscopies rely on statistical machine learning to perform recognition and classification. However, the commonly used methods utilize either simplistic unsupervised learning or traditional supervised techniques that assume completeness of training libraries. This restrictive assumption is known to be false for real-life conditions, resulting in unsatisfactory levels of accuracy, and consequently limited overall performance for biodetection and classification tasks. The presented work demonstrates application of the FSP system to classify various pathogenic bacteria in a nonexhaustive framework, that is, without full knowledge about all the possible classes that can be encountered. Our study uses a Bayesian approach to learning with a nonexhaustive training dataset to allow for the automated and distributed detection of unknown bacterial classes.

8029A-12, Session 2

Digital pathology: development and validation of feature analysis on consecutive tissue sections

T. D. Johnson, F. Voelker, G. D. Young, S. Potts, Flagship Biosciences, LLC (United States)

Despite remarkable advances in histology pattern recognition recently, automated image analysis is still out of reach for many common pathology applications in the pharmaceutical industry. Frequently there simply is not enough information in the stains utilized in most IHC and H&E studies to provide reliable pattern recognition results without substantial manual curation after analysis. In addition, there remains an unmet need for multiplexing in IHC in brightfield applications beyond one or two proteins.

Return to Contents

We have developed a novel approach to both pattern recognition and multiplexing called Feature Analysis on Consecutive Tissue Sections (FACTS). The process involves utilizing a target tissue with strategically chosen stains for the region of interest. We utilize careful sectioning of thin 4 um sections with one or more target sections on either side of the reference section, that are stained for the biomarker or lesion to be measured. The regions of interest are computed once on the reference section and then transferred to the target sections by one of several methods from the field of image registration. In this presentation we look at a number of computational image registration and region of interest transfer approaches from radiology and other areas and present some validation results for several histology applications. Each registration approach has its advantages in certain biological applications. The FACTS method requires only minimal changes to current histology practice, and the labor costs are less than what is required for running multiple IHC markers in clinical or preclinical laboratories. Validation for both GLP or CLIA can be done without substantial modifications to common histopathology laboratory practices.

8029A-13, Session 2

Concurrent magnetic resonance and diffuse optical imaging for neo-adjuvant therapy assessment

M. Seetamraju, X. Zhang, Radiation Monitoring Devices, Inc. (United States); S. Davis, Dartmouth College (United States); R. Gurjar, R. Myers, Radiation Monitoring Devices, Inc. (United States); B. W. Pogue, Dartmouth College (United States); G. Entine, Radiation Monitoring Devices, Inc. (United States)

Neo-adjuvant therapy involves the administration of tumoricidal therapeutic agents aimed at shrinking the size of large breast tumors prior to breast conserving lumpectomy procedures. During this therapy and in order to improve treatment outcome, it is important to periodically assess the tumor size and changes to its blood supply. One such monitoring method is diffused optical tomography (DOT) using near IR light. Despite its low contrast (1:4) and spatial resolution (2 to 4 mm) this method has been used to obtain spatial and functional images based on the spectral differences between healthy and hypoxic tissue. The DOT images can be improved by incorporating high-resolution anatomical information from concurrently obtained Magnetic Resonance Images (MRI) in to the optical image reconstruction process.

Here we report on the development of the first prototype of a MRI compatible DOT system designed for obtaining tissue chromophore maps of breast tissue. The multi-wavelength imaging module has parallel acquisition across 16 cooled avalanche photodiodes (APD) for high resolution and high throughput imaging. It has low sensitivity to the high magnetic and RF fields associated with MRI units, allowing simultaneous data collection from the two techniques. Using this APD module in a dual-modality imaging setup, phantom and animal models were used to demonstrate functional optical imaging with high resolution and contrast. Optical image reconstruction was aided by spatial and anatomical information obtained from the simultaneous MRI images.

8029A-14, Session 2

Light without substrate amendment: the bacterial luciferase gene cassette as a mammalian bioreporter

D. Close, T. Xu, P. Jegier, A. Smartt, S. A. Ripp, G. Sayler, The Univ. of Tennessee (United States)

Bioluminescent production represents a facile method for bioreporter detection in mammalian tissues. The lack of endogenous bioluminescent reactions in these tissues allows for high signal to noise ratios even at low signal strength compared to fluorescent signal detection. While the luciferase enzymes commonly employed for bioluminescent detection are those from class Insecta (firefly and click beetle luciferases), these are handicapped in that they require concurrent administration of a luciferin compound to elicit a bioluminescent signal. The bacterial luciferase (lux) gene cassette offers the advantages common to other bioluminescent enzymes, but is simultaneously capable of synthesizing its own luciferin substrates using endogenously available cellular compounds. By using bacterial luciferase genes codon-optimized for human expression, it is possible to autonomously express a bioluminescent signal from a human cell line. The bioluminescent signal from human codon-optimized bacterial luciferase is strong enough for detection through tissue, and thus can be used for non-invasive, near surface, in vivo detection in small animal models. However, unlike alternate luciferase systems, the lux bioluminescent signal is stable over relatively prolonged time periods and can be detected using field-deployable equipment without cell lysis or luciferin addition. By regulating the production of the luxC and luxE genes, the cassette can be tailored for development into a real-time, autonomous bioreporter system that is the first of its kind capable of directly representing human cell bioavailability of target compounds.

8029A-15, Session 2

Characterization of a chromosomally integrated luxCDABE marker for investigation of STEC shedding in cattle

Y. Hong, The Univ. of Tennessee (United States)

Shiga toxin-producing Escherichia coli (STEC) O91:H21 has been recognized as a potential life-threatening foodborne pathogen, and is commonly isolated from adult patients in some European countries. Cattle are the principle reservoir. Studies examining STEC shedding in cattle often include inoculation of strains carrying antibiotic resistance makers for identifiable recovery. However, co-habitating intestinal microbes exhibiting like antibiotic resistance patterns can confound such studies. Such was the case in a study by our group when attempting to characterize shedding patterns of O91:H21 in calves, leading us to seek other, more definitive, markers. Among our strategies was the development of a chromosomally integrated bioluminescent marker via transposon mutagenesis using a luxCDABE cassette from Photorhabdus luminescens. Validations, including API 20E for identification of biochemical products, PCR for confirmation of serotype and virulence genes, growth curve analysis for determination of vigor, and in vitro stability assay, indicated no impact on metabolic products, identical virulence gene pattern, no significant cost to growth, and high in vitro stability. Animal experiments revealed that calves were colonized within 1-2 days post-inoculation with concentrations reaching 104-105 CFU/gram feces and the strain remained detectable until 10-14 days post-challenge; similar to that of an earlier study using a nalidixic acid resistance marker. Analyses of fecal samples indicated the luxCDABE was stable in vivo and no excision of luxCDABE cassette or reacquisition of the cassette by co-habitating bacteria was observed. Our results indicate that a luxCDABE based marker may be a superior model for the study of STEC colonization and shedding in cattle.

8029A-16, Session 3

Measuring from source to tap: ensuring water supply safety and security

D. J. Kroll, Hach Co., Inc. (United States)

The threat of terrorist action targeting water supplies is often overlooked for the more historically obvious threats of an air attack or a dirty bomb. Studies have shown that an attack on water is simple to orchestrate, inexpensive and can result in mass casualties. The twin motivators of the terrorist threat to water along with consumer demands for safe and potable supplies has lead to a sea change in the drinking water industry. From a historical perspective, most monitoring in the distribution system as well as source water has been relegated to the occasional snapshot provided by grab sampling for a few limited parameters or the infrequent regulatory testing required by mandates such as the Total Coliform Rule.

New technologies are being deployed to ameliorate the threat form both intentional and accidental water contamination. The threat to water and these new technologies are described as well as needs and requirements for new sensors to improve the monitoring structure.

8029A-18, Session 3

On-the-flow pathogen detection in water

P. Kiesel, J. Martini, M. F. Huck, N. M. Johnson, M. Bern, Palo Alto Research Center, Inc. (United States)

Water-quality monitoring is an essential priority for global health. It is estimated that worldwide more than 5000 people die daily from drinking contaminated water. With microorganisms a primary cause for the occurrence of infectious diseases, the concentrations of harmful bacterial cells should be routinely monitored to maintain microbiological quality control of drinking water. Because of the difficulty and cost of directly measuring all microbial pathogens in water samples, organisms like E.coli, Giardia and Cryptosporiduim that indicate the presence of sewage and fecal contamination have been targeted for measurement. Bacterial quantitation is currently performed by labs that primarily use plate-culture assay techniques which can take up to 24 hours to produce test result. In order to achieve more timely assessment of water quality, PARC is developing a compact and robust platform for rapid pathogen identification and quantitation in water. The anticipated microfluidic system should provide sample concentration, on-chip sample preparation, and uses a micro-fluidic based flow cytometer for detection. The suggested approach is suitable for point-of-need testing and in-line water monitoring. The technique enabling the on-the-flow detection of the pathogens is termed “spatially modulated fluorescence detection” and delivers high signal-to-noise discrimination without precision optics. Relative movement between analyte and a predefined patterned environment generates a time-dependent signal, and correlating the detected signal with the known pattern achieves high discrimination of the particle signal from background noise. The detection technique has been evaluated with measurements of absolute CD4+ and percentage CD4 counts in human blood. Our results are in excellent agreement with cell counts of the same samples performed with a commercial instrument (BD FACSCount).

We have assembled and tested a working prototype of a micro-fluidic based flow cytometer. The detection subsystem includes a basic pin photodiode rather than a PMT or APD. The prototype was assembled with off-the-shelf components (total cost of all active parts <$350). Measurements of the sensitivity and dynamic range were conducted with calibration particles and yielded a detection limit of ~200 MEPE, which meets the needs for a wide range of bio-particle-detection applications. By using an avalanche rather than a pin photodiode the sensitivity has been further improved to ~50-100 MEPE which is promising for detection of very dim objects, e.g., specifically tagged E-coli. First measurements with water-borne pathogens clearly show that this instrument can be used to reliably identify and count specifically-tagged pathogens in water.

Acknowledgment: This project is partly funded by ARO.

8029A-19, Session 3

Large area radiation source for water and wastewater treatment

M. T. Mueller, S. Lee, A. Kloba, R. Hellmer, N. Kumar, M. Eaton, Stellarray (United States); C. Rambo, S. Pillai, Texas A&M Univ. (United States)

There is a strong desire for processes that improve the safety of water supplies and that minimize disinfection byproducts. Stellarray is developing mercury-free next-generation x-ray and UV-C radiation sources in flat-panel and pipe form factors for water and wastewater treatment applications. These new radiation sources are designed to sterilize sludge and effluent, and to enable new treatment approaches to emerging environmental concerns such as the accumulation of estrogenic compounds in water. Our UV-C source, based on cathode technology, differs significantly from traditional disinfection approaches using mercury arc lamps or UV LEDs. Our sources accelerate electrons across a vacuum gap, converting their energy into x-rays when an anode target or UV-C when striking a phosphor. Stellarray is the first to develop a flat panel x-ray source for wastewater treatment, which matches the radiation source to the target area for maximum coverage.

8029A-20, Session 3

Early warning system for detection of microbial contamination of source waters

C. T. Mogensen, A. Bentien, M. Lau, B. Højris, K. Iversen, Grundfos AS (Denmark)

Ensuring chemical and microbial water quality is an ever increasing important issue world-wide. Currently, determination of microbial water quality is a time (and money) consuming manual laboratory process. We have developed and field tested an online and real time sensor for measuring the microbial water quality of a wide range of source waters.

We’ve designed a novel optical technique in combination with advanced data analysis to arrive at a measure for the microbial content present in the sample. This gives a fast and reliable detection capability of microbial contamination of the source. Sample acquisition and analysis is performed in real-time where objects in suspension are differentiated into e.g. organic/inorganic subgroups.

The detection system is a compact, low power, reagentless device and thus ideal for applications where long service intervals and remote operations are desired. Due to the very large dynamic range in measured parameters the system is able to monitor process water in industry and food production as well as monitor waste water, source water and water distribution systems.

The applications envisioned for this system includes early warning of source water contamination and/or variation. This includes: water plants/water distribution networks, filtration systems (water purification), commercial buildings, swimming pools/public baths, waste water effluent, and industry in general.

8029A-74, Session 3

A new demulsifier device for oil-water separation in oil tanks

M. Meribout, The Petroleum Institute (United Arab Emirates)

In addition to its sensing part to measure the emulsion layer, the device also comprises a microwave generator which moves vertically inside a void tube covering the whole vertical area of the tank under inspection. This tube is made of plastic to allow microwaves to reach the emulsion layer and therefore increases its temperature which would lead to an oil-water separation. Experimental results indicate that the efficiency of separation, in terms of separation time and energy consumption, occurs when the microwave generator targets the emulsion area where the water content is 10 to 30%. This requires a continuous control of the position of the emulsion layer inside the tank while the heating occurs. An actuator will move the microwave generator according to this new position.

8029A-21, Session 4

Traumatic brain injury produced by exposure to blasts-a critical problem in current wars: biomarkers, clinical studies, and animal models

C. E. Dixon, Univ. of Pittsburgh (United States)

Traumatic brain injury (TBI) resulting from exposure to blast energy released by Improvised Explosive Devices (IEDs) has been recognized as the "signature injury" of Operation Iraqi Freedom and Operation Enduring Freedom. Repeated exposure to mild blasts may produce subtle deficits that are difficult to detect and quantify. Several techniques have been used to detect subtle brain dysfunction including neuropsychological assessments, computerized function testing and neuroimaging. Another approach is based on measurement of biologic substances (e.g. proteins) that are released into the body after a TBI. Recent studies measuring biomarkers in CSF and serum from patients with severe TBI have demonstrated the diagnostic, prognostic, and monitoring potential. Advancement of the field will require 1) biochemical mining for new biomarker candidates, 2) clinical validation of utility, 3) technical advances for more sensitive, portable detectors, 4) novel statistical approach to evaluate multiple biomarkers, and 5) commercialization. Animal models have been developed to simulate elements of blast-relevant TBI including gas-driven shock tubes to generate pressure waves similar to those produced by explosives. These models can reproduce hallmark clinical neuropathological responses such as neuronal degeneration and inflammation, as well as behavioral impairments. An important application of these models is to screen novel therapies and conduct proteomic, genomic, and lipodomic studies to mine for new biomarker candidates specific to blast relevant TBI.

8029A-22, Session 4

Biomarkers for severe, moderate and mild traumatic brain injury

K. Wang, Banyan Biomarkers, Inc. (United States)

Traumatic Brain Injury (TBI) is a major problem military and civilian medicine. Yet, there are no simple non-invasive diagnostics for TBI. Our goal is to develop and clinically validate blood-based biomarker assays for the diagnosis, prognosis and management of mild, moderate and severe TBI patients. These assays will ultimately be suitable for deployment to far-forward combat environments. Using proteomic and systems biology approach, we identified over 20 candidate biomarkers for TBI and developed robust ELISA for at least 6 candidate biomarkers. including Ubiquitin C-terminal hydrolase-L1 (UCH-L1), Glial Fibrillary Acidic Protein (GFAP) and a 145 kDa breakdown product of αII-spectrin (SBDP 145) generated by calpain proteolysis.

In a multi-center feasibility study (Biomarker Assessment For Neurotrauma Diagnosis And Improved Triage System (BANDITS), we analyzed CSF and blood samples from 101 adult patients with severe TBI [Glasgow Coma Scale (GCS) $\leq$ 8] at 6 sites and analyzed 27 mild TBI patients and 5 moderate TBI patients [GCS 9-15] from 2 sites in a pilot study. We identified that serum levels of UCH-L1, GFAP and SBDP145 have strong diagnostic and prognostic properties for severe TBI over controls. Similarly initial post-TBI serum levels (< 6 h) of UCH-L1 and GFAP have diagnostic characteristics for moderate and mild TBI. We are now furthering assay production and planning pivotal clinical study to seek FDA approval of these diagnostic assays.

8029A-23, Session 4

Saliva-based biomarkers for noninvasive diagnostics: applications for mTBI, PTSD and HIV/AIDS

S. O. Southern, Gaia Medical Institute (United States)

We have developed a large panel of biomarkers (n=100) for molecular disease diagnostics. The biomarkers can be measured noninvasively in saliva or the skin using a simple rapid immunoassay. Current applications of the technology include monitoring the efficacy of antiretroviral drugs in HIV/AIDS patients, prognostics of mild traumatic brain injury (mTBI) and post-traumatic stress disorder (PTSD), diagnostics of different types of dehydration, and screening for environmental stress in wild animals. To commercialize the technology, selected validated biomarkers will be integrated into a digital immunodiagnostic test that will indicate actionable levels of the specific medical risk. The commercial test will be a low-cost hand-held device easy to use in point-of-care or field settings.

8029A-24, Session 4

Field-based multiplexed and quantitative assay platforms for diagnostics of TBI and wound infections

S. Venkatasubbarao, Intelligent Optical Systems, Inc. (United States)

Military has continued interest in handheld, field-usable sensors and test kits in a variety of diagnostic applications such as traumatic brain injury (TBI), wound infection and infectious disease. Field-use presents unique challenges for biosensor design, both for the readout unit and for the biological assay platform. We have developed robust biosensor devices that offer ultra-high sensitivity and also meet field-use needs. The systems under development include a multiplexed quantitative lateral flow test-strip for TBI diagnostics, a field test kit for diagnostics of pathogens endemic to the Middle East, and a microfluidic assay platform with a label-free reader for performing complex biological automated assays in the field. We will discuss unique challenges of adapting a lateral flow test-strip assay for epidemiological studies in low resource environments.

8029A-25, Session 4

Virtual reality exposure therapy for combat related PTSD

A. S. Rizzo III, The Univ. of Southern California (United States)

War is perhaps one of the most challenging situations that a human being can experience. The physical, emotional, cognitive and psychological demands of a combat environment place enormous stress on even the best-prepared military personnel. Such stressful experiences have a considerable likelihood for producing significant numbers of returning military personnel at risk for developing PTSD and other psychosocial disorders. Research in this area has documented the significance of this problem and a recent RAND report has underscored its magnitude. This presentation will detail the development and current results from use of the Virtual Iraq/Afghanistan exposure therapy system--a series of customizable virtual scenarios designed to represent relevant Middle Eastern contexts for use as a tool for conducting exposure therapy. We will summarize the results from an open clinical trial using Virtual Iraq with 20 treatment completers which indicated that 16 no longer met PTSD Checklist-Military criteria for PTSD at post-treatment.

8029A-27, Session 4

Accelerating the commercialization of university technologies for military healthcare applications: the role of the proof of concept process

R. Ochoa, L. Rasochova, Univ. of California, San Diego (United States)

The von Liebig Center for Entrepreneurism and Technology Advancement at UC San Diego was created in 2002 with the mission to accelerate the translation and commercialization of university research, and to prepare engineering students for entrepreneurial workplace. Since inception, the Center has advised close to 290 technologies, funded 70 projects and provided entrepreneurial education to over 500 graduate students in engineering and science. In 2010, the Center launched Wireless Health Innovation Challenge sponsored by TATRC and Qualcomm Health & Life Sciences. This initiative is intended to nurture and accelerate the commercialization of novel wireless healthcare technologies developed within research institutes and universities in Southern California. The Department of Defense is seeking wireless health technologies to address needs in both deployed and non-deployed environments. Examples of work include personal wireless networks and wearable, flexible-display cell phones. These and other wireless health technologies can aid in operational environments, including disaster relief and humanitarian efforts. For veterans returning from deployment, the Army has also established a program that utilizes veterans' own cell phones to help them continue treatment in cases of post-traumatic stress disorder (PTSD) and traumatic brain injury (TBI). Areas of interest include: Tools for behavioral health management; Tools for the management of chronic diseases, smoking cessation, etc.; Tools to aid rehabilitation of motor skills and balance; Technologies to enable remote clinical consultation; Physiological sensing (e.g., for home monitoring applications, or the integration of body-worn sensors that use Bluetooth in civilian environments, but ultra-wideband (UWB) for short-range communications between "mobile device" and sensors in deployed environments); Patient education (e.g., health and wellness information).

8029A-28, Session 5

Detecting gait alterations due to concussion impairment with radar using information-theoretic techniques

J. Palmer, K. Bing, A. Sharma, E. Greneker, Georgia Tech Research Institute (United States)

Previous studies have demonstrated that measuring changes in gait could provide an easier method of diagnosing and monitoring concussion or mild traumatic brain injury (MTBI) resulting from a car accident, improvised explosive device (IED) blast, sports injury, or other source. GTRI measured radar signal returns generated from walking individuals to explore if differences in gait patterns between normal and "concussed" individuals could be identified. Access to concussed individuals was not available during the preliminary research stage. Instead, based on research that demonstrated a blood alcohol content, BAC, of 0.05% was equivalent to concussion impairment, BAC impairment goggles were used to simulate a concussion. Eight individuals were asked to walk normally, walk while completing a cognitive task, walk while wearing the goggles (impairment), and walk while wearing the goggles and completing a cognitive task. The results were analyzed using information-theoretic (IT) techniques to compare information entropy levels in the radar spectrograms of undiagnosed individuals with normal and "concussed" datasets. These algorithms were chosen because of their potential to identify similarities and differences without requiring baseline data for a specific individual. One-tailed, two-sample, unequal variance t-tests were performed on the output data of the IT techniques. The preliminary results show that the two sets are statistically different from one another ($p< 0.05$). From the results of the IT techniques, decision index (D(Q)) thresholds were chosen for acceptable true positive and false positive percentages or for receiver operator characteristics.

8029A-29, Session 5

A miniature pressure sensor for blast event evaluation

N. Wu, W. Wang, Y. Tian, C. Niezrecki, X. Wang, Univ. of Massachusetts Lowell (United States)

Traumatic brain injury (TBI) is a great potential threat to people who deal with explosive devices. Protection from TBI has attracted more and more interest. Great efforts have been taken to the studies on the understanding of the propagation of the blast events and its effect on TBI. However, one of the biggest challenges is that the current available pressure sensors are not fast enough to capture the blast wave especially the transient period. This paper reports an ultrafast pressure sensor that could be very useful for analysis of the fast changing blast signal. The sensor is based on Fabry-Perot (FP) principle. It uses a 45° angle polished fiber sitting in a V-groove on a silicon chip. The endface of the angle polished fiber and the diaphragm which is lifted off on the side wall of the V-groove form the FP cavity. The sensor is very small and can be mounted on different locations of a helmet to measure blast pressure simultaneously. The tests were conducted at Natick Soldier Systems Center in Natick, Massachusetts. The sensors were mounted in a shock tube, side by side with the reference sensors, to measure a rapidly increased pressure. The results demonstrated that our sensors' responses agreed well with those from the electrical reference sensors and their response time is comparable.

8029A-30, Session 5

Point-of-care instrument for monitoring tissue health during skin graft repair

R. Gurjar, M. Seetamraju, D. E. Wolf, Radiation Monitoring Devices, Inc. (United States)

We present research performed towards the realization of a point-of-care hypoxia instrument that can map out tissue oxygenation and blood flow in subsurface tissues. One particular application of this work is to monitor the viability of skin grafts in skin burn injuries over time.

Here, we provide a detailed analysis of return signals from subsurface and deep tissues (~1 cm). We provide experimental conditions and optical layout that enables tissue characterization and measurement of blood flow as a function of depth. Tissue characteristics are parametrized by oxyhemoglobin and deoxyhemoglobin concentration, based on optical absorption measurements at three different wavelengths. The surface measurements are carried out by photon counting sensors, enabling diffuse correlation measurements for blood dynamics and at the same time by another complimentary set of detectors for blood and tissue oxygenation determination. We identify instrumental parameters, which will enable us to develop a simple patch geometry holding multiple wavelength light sources and sensitive detectors. This can then be used to map blood flow velocity and tissue oxygenation as a function of depth in subsurface tissue after skin graft surgery.

8029A-31, Session 5

Towards trustworthy medical device systems

N. Paul, Oak Ridge National Lab. (United States); D. C. Klonoff, Mills-Peninsula Diabetes Research Institute (United States)

Medical devices benefit patients and address chronic health conditions (e.g., heart disease). Physicians use these devices to monitor and control patient treatment. Unfortunately, these monitoring and control features present vulnerabilities to malicious attack. We have identified potential threats and attacks that can adversely affect patients, and, in some instances, wide-scale attack may be possible.

Current medical device system vulnerabilities represent a direct threat to patient lives, and novel research is needed to build trustworthy medical systems.

We intend to identify medical device threats and vulnerabilities, show that these vulnerabilities can be exploited, design mitigating solutions, and prototype defensive solutions. Our constraints are (1) patient acceptability, (2) resource constraints (through device miniaturization), and (3) the patient's environment. This research will address basic scientific questions in medical device therapy and embedded systems, fundamentally change the design of medical device systems now and in the future, and will impact global and military healthcare.

In 2008, Halperin et al. showed that an Internal Cardiac Defibrillator (ICD) was susceptible to attack. In 2010, our laboratory discovered an insulin pump system attack where we remotely programmed an individual's insulin pump from a distance of 100 ft. William Maisel, the FDA's advisor to the Center Science Council, has stated that "the security of medical devices is not a luxury." Fred Pearce, the Assistant Director of Medical Research and Engineering at the Office of the Director Defense Research and Engineering, said that this research directly addresses threats to the military's Echelon 2 support units and medical Blackhawk helicopters.

8029A-32, Session 6

Beyond command and control

R. Arias, U.S. Dept. of Defense (United States)

The January 2010 earthquake that devastated Haiti shocked the world and prompted a global response. Over 800 organizations representing the whole of society mobilized to provide aid and relief. But how could a global response achieve "unity of effort" when "unity of command" was not feasible? For its part, U.S. Southern Command looked beyond conventional "Command and Control" systems and decided to use a web based, social networking platform to "Connect and Collaborate" with non-traditional partners. After all, that platform, the All Partners Access Network (APAN), had been developed under the Transnational Information Sharing Cooperation (TISC) Joint Capability Technology Demonstration (JCTD) for exactly that purpose: to provide the Department of Defense (DoD) with information sharing capabilities and concepts that address the challenges associated with collaboration among diverse groups of actors operating in complex environments. APAN allows users to join groups or shared knowledge communities (communities of interest and communities of practice) in order to increase situational awareness, share information, participate in discussions, collaborate, and coordinate activities. Immediately following the earthquake, U.S. Southern Command established the Haiti HA/DR Community of Interest (COI). In the first 14 days, the COI grew to over 1,900 users, helping responders to "connect and collaborate" with other responding organizations, improving situational awareness and facilitating information sharing on a wide range of areas: hospital status and availability; medical and food distribution locations; status and location of seaports and airports; imagery/maps; cell phone coverage; volunteer methods.

8029A-34, Session 6

Paradigms for integration and data synthesis of military, civilian and infrastructure health through adaptive software defined radio and antennas (SDR-A)

G. Lilienthal, Argon ST (United States)

Demand for remote health sensing is driving technological advances in sensing platforms, bioinformatics, multi-parametric synthesis and in communications bandwidth. Data streams originate in small, hand-held devices, fixed and mobile sensors both in the field, point-of-care and hospitals. Knowledge of warfighter's health is a strategic parameter in decision making in-theatre. Effective responses to natural disasters depends on timely data flow over a variety of communications channels with incompatible bandwidths and spectrums. Software Defined Radio offers solutions to collection of the ultra-wide spectrum data over which these information channels communicate, making possible the synthesis of real-time assessments of human and infrastructure health.

8029A-35, Session 6

Communication architectures for remote environmental monitoring

T. Soni, Argon ST, Inc. (United States)

Remote environmental monitoring has been a major challenge for two primary reasons - energy availability and data access. In this paper we present architectures for energy efficient communication networks planned specifically for remote environmental monitoring applications. This includes satellite based communications for global applications as well as pure terrestrial ad-hoc mesh type communications for smaller theaters. All of these include communication protocols that minimize the energy required and permit long battery life. Specific real-world deployment examples include a low-earth-orbit satellite approach to remote environmental monitoring and a ad-hoc mesh based approach used to monitor water quality in army training ranges.

8029A-36, Session 6

Using social media to communicate during crises: an analytic methodology

M. J. Greene, CNA (United States)

The Department of the Navy Office of Information has recently released its Social Media Handbook designed to provide information needed to safely and effectively use social media. This paper discusses the use of the Handbook for crisis communication and points out the need for a methodology that will help to find appropriate people with whom to share information for particular aspects of a crisis during Humanitarian Assistance missions.

8029A-38, Session 6

Mobile sensors for environmental chemical awareness

E. Forzani, C. Chen, A. Prabhakar, R. Wang, F. Tsow, N. Tao, Arizona State Univ. (United States)

The widespread use of cellular phones has enabled our laboratory with unprecedented development of mobile chemical sensors. Cell phones have offered us not only powerful computing capabilities for sensor signal processing but also friendly environments for non expert users to access chemical information, and intrinsic global positioning system (GPS) to correlate environmental chemical information and location.

However, the challenges to design environmental chemical sensors have been significant. The interest of accurately and precisely detecting analytes molecules at much lower concentration than other interference molecules in environments with changing temperature and humidity conditions have brought interesting problems to solve.

Our team has overcome the problems by implementing integrative sensing approaches based on sensing platforms, transduction mechanisms and sample collection and conditioning sub-systems that work cooperatively assembled in a single sensing unit to meet the needs.

We have created mobile environmental sensors that has been validated and tested in the field, providing important environmental chemical awareness information. This presentation summarizes major results on how integrated sensing approaches can be applied to develop and produce the described mobile environmental sensors devices as well as examples of the benefits of the developed technologies.

8029A-39, Session 6

The development of a multiband system for early detection of wildlife fires and indoor search and rescue operations

B. Gouverneur, G. Gielis, J. Cloots, S. Nemeth, J. P. Vermeiren, Xenics NV (Belgium)

Xenics is involved in the the European Union Framework 7 project "Firesense" about the protection of archeological treasures around the Mediterenean against wildfires.

Alllthough visible cameras are low-cost and give good performance during daytime for smoke detection; they fall short when wildfires are grown and spreading under the influence of wind during night time or bad visibility conditions.

In order to ameliorate the detection probability several infrared bands are tested ranging from the NIR till the LWIR range. Certainly the SWIR and the LWIR band are helpfull in looking through haze or to penetrate in dust clouds. Also narrow band detection of the Potassium emission and the absorption of radiation by the MWIR CO2 bands will be discussed.

The fusion of multiple detection bands will be discussed; the use of the visible is very interesting to increase situational awarness and to make reliable smoke detections during daytime operation. The fusion of the SWIR and LWIR yields excellent results to detect fire sources in a very early stage. The overlaying of images and the fusion of images coming from multiple cameras will be discussed; as well as the segmentation algorithm and the methods used to make the fire and smoke detection.

Excellent results are also obtained when fire fighting in underground parking lots, where a simultaneous observation of the fire source and the detection of victims can be demonstrated.

8029A-49, Session 6

Classification of airborne particles from two-dimension, angle-resolved optical scattering (TAOS) patterns by a new feature extraction method

G. F. Crosta, Univ. degli Studi di Milano-Bicocca (Italy); Y. Pan, U.S. Army Research Lab. (United States); R. K. Chang, Yale Univ. (United States)

The real-time characterization of airborne particles is relevant to environmental monitoring and to the early detection of biological threat.

An experimental technique has been developed to record Two-dimension, Angle-resolved Optical Scattering (TAOS) patterns.

Patterns consist of scattered light intensity and are formed when a LASER pulse illuminates single (micrometer or sub-micrometer sized) moving airborne particles.

TAOS instrumentation has made impressive progress in the past 10 years; patterns are collected by the hundreds in short sampling times.

Nonetheless, there is no satisfactory inversion method capable of estimating the particle size and shape from its TAOS pattern.

Herewith, progress is reported about a method which is based on the extraction of morphological features followed by multivariate statistics and is aimed at classifying patterns (rather than identifying original particles).

Classifier training is supervised i.e., relies on patterns from known materials.

After training and validation, the classifier is applied to the recognition of patterns of unknown origin.

TAOS patterns collected in the backward scattering hemisphere are processed.

The classifier is trained by patterns from NaCl crystals and dioctyl-phthalate droplets.

After feature extraction and multivariate statistical analysis, each pattern is mapped to a point in the principal components space.

After training, TAOS patterns from other materials such as “ambient” particles, Diesel exhaust, bacterial spores etc., are submitted to the classifier for recognition.

Confidence bounds and reliability of the classifier are assessed.

The feasibility of real-time particle class recognition is discussed.

8029A-53, Session 6

Evaluating the capability of SPOT5 data in monitoring pollarding forest areas of Northern Zagros: case study--Kurdistan, pollarded forests of Baneh

D. Oladi, A. Moradi, Univ. of Mazandaran (Iran, Islamic Republic of)

To evaluate the capability of SPOT5 HRG data for monitoring the pollarding forest areas in northern Zagros, some parts of pollarded forests located at Baneh city were selected. The Pollarding area was determined as ground truth in a 3-year alternation period using a global positioning system (GPS). Radiometric and geometric correction, were applied to the image and then the data was pre-processed, using 2 methods of spectral rationing and Principal Component Analysis (PCA). Likewise, multi-spectral bands were fused with IRS-1C PAN image, using a Principal Component transformation (PCT). The obtained results were combined with original bands. The separability of classes was studied using Bhuttacharrya Distance Criteria. The resulting data was classified using a maximum likelihood algorithm. Then the classified image was compared with ground truth on a pixel by pixel base. In order to the determine classification accuracy, four parameters encompassing Overall Accuracy, Kappa Coefficient, Producer Accuracy and User Accuracy were used. The results showed that most of the classes were completely separatable from northern Koor class. The highest overall accuracy was 65.3% and Kappa Coefficient equal to 63% was obtained through a four-class classification of the fused image. Northern Shan class showed the highest user accuracy (71%) and producer accuracy (78%). Likewise, southern Koor class showed the lowest user accuracy in all methods. Results of this study showed the high capability of abovementioned image and methods to separate the pollarding areas and to prepare the map of the area.

8029A-46, Poster Session

Field-portable semen analysis using lensless microscopy on a chip

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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 powerful toolset to this challenging task, here we demonstrate an automated semen analysis platform using a lensfree on-chip microscope that can automatically investigate both sperm concentration and motility. This compact holographic microscope weighs only ~46 grams (~1.6 ounces) and does not utilize any lenses, lasers or other bulky optical components to acquire the phase and amplitude images of sperms over ~24mm2 field-of-view with a numerical aperture of ~0.2. With this wide-field lensfree on-chip microscope, ~20 consecutive holographic frames are captured for each semen sample within ~10 seconds. Automated quantification of the count, speed distribution and trajectories of the moving sperms are done through digital subtraction of these consecutive holographic frames, while summation of the same frames enables counting of the immobile sperms. By analyzing human semen specimens, we verify the accuracy of this automated platform with manual counts made with a traditional microscope, where the results closely agree. Such a compact and light-weight automated semen analysis tool based on a wide-field lensfree on-chip microscope is especially important for various point-of-care applications, such as fertility clinics, personal male fertility tests, and also the evaluation of the influence of long-term radiation or chemical exposure on male fertility.

8029A-47, Poster Session

Amplification-free point of care immunosensor for high sensitivity monitoring of lung transplant rejection

P. Chung, E. R. Bracho-Sanchez, P. Jiang, G. Schultz, C. D. Batich, Univ. of Florida (United States)

Point-of-care testing (POCT) is applicable at the near patient, where timely diagnosis or prognostic information could help doctors decide the following treatment. Among types of developed POCT, gold nanoparticle based lateral flow strip even provides advantages such as simple operation, cost-effective systems, and user-friendly platform. Therefore, this type of POCT is most likely to be used in battlefields and developing countries. However, the conventional lateral flow strip suffers from a high detection limit. Although enzyme-linked amplification was demonstrated to improve the detection limit and sensitivity by stronger visible lines or by using an electrochemical analytical intrumentation, the enzyme labels have potential to cause interference with other enzymes in our body fluids. To eliminate this limitation, we developed an amplication-free gold nanoparticle based immunosensor applied for detecting collagen type five, which is produced abnormally when lung transplant patients have transplant rejections. By using suitable blocking protein to stabilize gold nanoparticles, a low detection limit of ng/ml was achieved in human plasma samples. This strategy is a promising platform for clinical POCT.

8029A-48, Poster Session

A non-contact ECG sensing platform

X. Yu, Case Western Reserve Univ. (United States)

This paper describes the development of a non-contact sensing platform to monitor the ECG signals. The non-contact sensing will be based on capacitive coupling the bioelectricity produced by cardiovascular activities around the heart. High sensitivity sensor and electronics are designed to amplify the signals. Our preliminary study has pointed to the promise of this sensing concept. A sensor prototype was able to clearly detect the ECG signals from 10 cm away from the body. Research tasks continue improving the sensor design to detect the polarization in the ECG signals. The final goal is a non-contact sensing platform for ECG signals and for real time diagnostics of the mental distress and cardiovascular diseases.

8029A-40, Poster Session

Research of soil moisture retrieval in arid region on the moistureshed scale

Q. Zhang, National Astronomical Observatories (China); K. Zhou, Xinjiang Institute of Ecology and Geography (China)

This study tries to optimize and adjust the existing reversion models available for different land cover types. A co-reversion model will be established and used for retrieving soil moisture of different vegetation types of the arid area by using MODIS and AMSR-E remote sensing data. The downscaling strategy and field verification will be used to analyze the accuracy, uncertainty and sensitivity of the reversion model. The popularity and regionality of the model will be also examined to explore the possibility of the model used for large-scale and dynamic monitoring of soil moisture using remote sensing technology.

8029A-51, Poster Session

Aerosol sensing technologies in the mining industry

S. Janisko, National Institute for Occupational Safety and Health (United States)

Recent health, safety and environmental regulations are causing an increased demand for monitoring of aerosols in the mining industry. Of particular concern are airborne concentrations of combustible and toxic rock dusts as well as particulate matter generated from diesel engines in underground mines. In response, the National Institute for Occupational Safety and Health (NIOSH) has been evaluating a number of real-time sensing technologies in terms of precision and accuracy against standard measurement methods, selectivity to appropriate mine aerosol, response to known interferences and suitability for anticipated applications.
In particular, filter-based light absorption using elemental carbon as a surrogate measurement of total diesel particulate matter (DPM) mass concentration as well as mechanical tapered element oscillating microbalance (TEOM) technology for measurement of both DPM and rock dust mass concentrations have been extensively evaluated. Although these technologies are promising in their ability to accurately measure mine aerosols for their respective applications, there are opportunities for design improvements or alternative technologies which may significantly enhance the monitoring of mine aerosols. Reductions in measurement response time, increased volumetric distribution of sampling area, decreased maintenance of sensing instrumentation and the delivery of information across the mine communication network are all areas where current technologies can be improved. The following paper outlines the results of NIOSH research in this area and also provides an overview of current practices and future directions in mine aerosol monitoring.

8029A-52, Poster Session

A statistical method to correct radiometric data measured by AVHRR onboard the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites (POES)

M. Z. Rahman, LaGuardia Community College (United States); L. Roytman, The City College of New York (United States); A. H. Kadik, LaGuardia Community College (United States)

This paper apply an statistical technique to correct radiometric data measured by Advanced Very High Resolution Radiometers(AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites(POES). This paper study Normalized Difference Vegetation Index (NDVI) stability in the NOAA/NESDIS Global Vegetation Index (GVI) data for the period 1982-2003. AVHRR weekly data for the five NOAA afternoon satellites NOAA-7, NOAA-9, NOAA-11, NOAA-14, and NOAA-16 are used for the China dataset, for it includes a wide variety or different ecosystems represented globally. GVI has found wide use for studying and monitoring land surface, atmosphere, and recently for analyzing climate and environmental changes. Unfortunately the POES AVHRR data, though informative, can not be directly used in climate change studies because of the orbital drift in the NOAA satellites over these satellites' life time. This orbital drift introduces errors in AVHRR data sets for some satellites. To correct this error of satellite data, this paper implements Empirical Distribution Function (EDF) which is a statistical technique to generate error free long-term time-series for GVI data sets. It allows one to represent any global ecosystem from desert to tropical forest and to correct deviations in satellite data due to orbit degradation. The corrected datasets can be used as proxy to study climate change, epidemic analysis, and drought prediction etc.

8029A-54, Poster Session

Low-power wireless trace gas sensing network

C. J. Smith, S. So, A. Khan, M. A. Zondlo, G. Wysocki, Princeton Univ. (United States)

A low-power wireless spectroscopic sensor network for monitoring of trace-gases will be presented. The prototype sensor-nodes for carbon dioxide (CO_2) monitoring are based on tunable diode laser absorption spectroscopy and operate using a 2 um VCSEL and a 3.5 m Herriott multi-pass cell. The sensor system, which employs real-time wireless communications, is controlled by custom on-board electronics based on the openPHOTONS platform and can be operated autonomously or remotely. The control board implements wavelength modulation spectroscopy (WMS) of the target absorption line. An integrated lock-in amplifier demodulates the first three WMS signal harmonics for control and sensing. The peak of the 2nd harmonic is used to measure CO_2 concentration. For increased stability, an active feedback loop uses the zero-crossing of the 3rd harmonic WMS signal to lock the laser emission wavelength to the peak of the absorption line. The operating sensor-node consumes approximately 300 mW power and can work autonomously for up to 100 hours when powered by a Lithium-ion polymer battery. Environmentally controlled long term stability measurements over 12 hours show sensor-node minimum detection limit of ~0.138 ppm with 1 sec averaging and ultimate minimum detectable fractional absorption of 1.5E-6 with 3,500 seconds averaging. Lab and field tests of the CO_2 sensor-node have shown precision comparable to that of commercial sensors with R^2 from 0.89 to 0.99 while consuming less than a tenth of the power. These results and preliminary data for testing of long-term, real-time monitoring in a multi-node sensor network will be presented.

8029A-55, Poster Session

Simultaneous detection of atmospheric nitrous oxide and carbon monoxide using a quantum cascade laser

A. Khan, K. Sun, M. A. Zondlo, Princeton Univ. (United States)

We describe a non-intrusive, open-path, fast-response compact sensor for simultaneous measurements of carbon monoxide (CO) and nitrous oxide (N_2O) primarily designed for UAV applications. N_2O is the third most important greenhouse gas, but its spatial and temporal emissions are poorly quantified. On the other hand, CO is an important tracer to distinguish between fossil fuel and biogenic sources. We use a 4.5 micron thermoelectrically-cooled, distributed feedback, continuous wave quantum cascade laser (QCL) as a mid-infrared radiation source to scan CO and N_2O transitions centered at 4538.9 nm and 4539.8 nm respectively. Detection was achieved by a thermoelectrically cooled 5 micron InSb infrared detector.

For the first time in this application, a compact cylindrical cell with N/2 pattern configuration was used to minimize the sensor with a pathlength of 15 meters (2.54 cm radius mirrors, 25 cm basepath). Wavelength modulation spectroscopy (WMS) was employed to achieve high sensitivity detection. The system was calibrated with NOAA concentration standard for N_2O and CO, and a temperature-regulated bath (with accuracy and stability of 0.05 K) was used to examine long-term drift of the sensor. The detection limit of 10-5 fractional absorbance was achieved at 1 Hz. This is equivalent to 0.3 ppbv of N_2O and 2 ppbv of CO out of 320 ppbv and 100 ppbv ambient levels. To demonstrate field applicability we present results of air quality measurements where the sensor was deployed in the field. In summary we report first cryogen-free, consumable-free sensor that can operate with 10 W of power and packaged in a small shoe-box size which is ideal for UAV or airborne applications.

8029A-56, Poster Session

Novel handheld x-ray fluorescence spectrometer for routine testing for the presence of lead

N. M. Rensing, T. C. Tiernan, M. R. Squillante, Radiation Monitoring Devices, Inc. (United States)

RMD is developing a safe, inexpensive, and easy to operate lead detector for consumers that can reliably detect dangerous levels of lead in toys and other products. Lead and its compounds have been rated as top chemicals that pose a great threat to human health. However, widespread testing is rarely undertaken until lead poisoning is detected. The problem is not due to the accuracy or sensitivity of existing lead detection technology, but rather to the high expense, safety and licensing barriers of available test equipment. An inexpensive and easy to use lead detector would enable the identification of highly contaminated objects and areas and allow for timely and cost effective remediation. The military has similar needs for testing for lead and other heavy elements such as mercury, primarily in the decontamination of former military properties prior to their return to civilian use.

RMD's research and development efforts are based on advanced solid-state detectors combined with recently patented lead detection techniques to develop a consumer oriented lead detector that will be widely available and easy and inexpensive to use. These efforts will result in an instrument that offers: (1) high sensitivity, to identify objects containing dangerous amounts of lead, (2) low cost to encourage widespread testing by consumers and other end users and (3) convenient operation requiring no training or licensing. In contrast, current handheld x-ray fluorescence spectrometers either use a radioactive source requiring licensing and operating training, or use an electronic x-ray source that limits their sensitivity to surface lead.

8029A-57, Poster Session

Environmental monitoring of brominated flame retardants

M. C. Vagula, N. Kubeldis, Gannon Univ. (United States); C. F. Nelatury, Univ. of Pennsylvania (United States)

Polybrominated diphenyl ethers (PBDEs), a class of liposoluble persistent organic compounds are commercially produced fire-retardants used in many household products such as TVs, computers, electronic gadgets, carpets, upholstery, etc. They have become a serious environmental concern due to their high molecular stability and inability to bond with the chemicals in which they are combined. It has been reported that their congeners, hydroxylated and methoxylated metabolites cause changes in neurological, reproductive, and endocrine functioning in animals. Unfortunately, the toxicity profile of PBDEs is not yet fully understood. Studies on their effects are somewhat limited, but demonstrate that PBDEs act as potential endocrine disrupters, neurotoxins, and lead to developmental and behavioral problems in laboratory animals. Environmental protection agency (EPA) is interested in establishing a trade-off between fire safety and environmental/ public health. Recently EPA has encouraged research efforts for assessing the toxic effects of PBDEs and keen bio-monitoring in the great lake sediments. This paper reports its effects on nerve conduction velocities, oxidative stress and absorption of nutrients based on our experimental work performed on laboratory animals. This study helps EPA lay down tighter regulations in the industrial use of these compounds.

8029A-18, Session 7

Measurement techniques for the Deepwater Horizon (MC-252) oil spill response

R. Crout, National Oceanic and Atmospheric Administration (United States)

The explosion of the Deepwater Horizon (MC-252) drilling platform on 20 April 2010 began a long, unprecedented response from BP and the federal government. Previous responses to oil spills were limited in time due to the amount of oil spilled and were generally confined to the surface. Some of the oil from the Deepwater Horizon wellhead in 1500 meters of water broke into smaller droplets, whose density caused much of the oil to stay within a zone from 1000 to 1300 meters depth. The remainder of the oil rose to the surface. The two primary locations of oil required a broad collection of remote sensing techniques to locate and

Return to Contents

monitor the oil spill.

Surface oil was monitored primarily from the air using aircraft and satellite assets. Satellite visible, infra-red, and radar satellite imagery helped to locate the position of oil in the northern Gulf of Mexico and its potential movement away from the spill site. Daily over-flights by NOAA and other aircraft provided higher spatial and temporal resolution data that were assimilated into daily products.

These remote sensing assets were able to track the surface oil, but the subsurface oil required different techniques. In addition to salinity and temperature profiles to determine the subsurface structure, fluorometry and dissolved oxygen measurements provided information related to oil and its consumption by microorganisms. Water samples collected from CTD casts were analyzed on-board for particle size distribution using a Laser In-situ Scattering Transmissometry (LISST) sensor. Water samples were also returned to on-shore laboratories, where they were subjected to Gas Chromatography and Mass Spectrometry to determine the chemical constituents in the seawater.

8029A-19, Session 7

Combining numerical ocean circulation models with satellite observations in a trajectory forecast system: a rapid response to the Deepwater Horizon oil spill

Y. Liu, R. H. Weisberg, C. Hu, Univ. of South Florida (United States)

The Deepwater Horizon oil spill presented an unprecedented threat to the Gulf of Mexico (GOM) marine resources. Needed for mitigation efforts and ship survey guidance was a system for tracking the oil in a timely fashion. We report on such system, implemented immediately upon spill onset, by marshaling numerical model and satellite remote sensing resources available from existing coastal ocean observing activities. Surface oil locations inferred from satellite imagery were used to initialize the positions of the virtual particles in an ensemble of trajectory models, and the particles were tracked using forecast surface currents, with new particles added to simulate the continual release of oil from the well. Timely trajectory forecasts were used to plan scientific surveys and other spill response activities.

In addition to the existing moored ADCP and shoreline-based HF radar arrays for ocean circulation monitoring on the West Florida Shelf (WFS), satellite-tracked drifters were deployed in both the GOM Loop Current and the shelf regions, and subsurface gliders and bottom-stationed ocean profilers were manipulated to observe the ocean circulation and to sample the ocean water properties on the WFS. A new ocean optics product was also used to identify the Loop Current and eddies in the GOM. The integrated ocean observing and modeling systems were demonstrated to be very useful in the rapid response.

8029A-20, Session 7

Automated oil spill detection with multispectral imagery

B. Bradford, P. J. Sanchez-Reyes, ITT Corp. Geospatial Systems (United States)

In this publication we present an automated detection method for ocean surface oil, like that which existed in the Gulf of Mexico as a result of the April 20, 2010 Deepwater Horizon drilling rig explosion. Regions of surface oil in airborne imagery are isolated using red, green, and blue bands from multispectral data sets.

The oil shape isolation procedure involves a series of image processing functions to draw out the visual phenomenological features of the surface oil. These functions include selective color band combinations, contrast enhancement and histogram warping. An image segmentation process then separates out contiguous regions of oil to provide a raster mask to an analyst.

We automate the detection algorithm to allow large volumes of data to be processed in a short time period, which can provide timely oil coverage statistics to response crews. Geo-referenced and mosaicked data sets enable the largest identified oil regions to be mapped to exact geographic coordinates.

In our simulation, multispectral imagery came from multiple sources including first-hand data collected from the Gulf. Results of the simulation show the oil spill coverage area as a raster mask, along with histogram statistics of the oil pixels. A rough square footage estimate of the coverage is reported if the image ground sample distance is available.

8029A-41, Session 7

Operational mapping of the DWH deep subsurface dispersed oil

H. Seim, The Univ. of North Carolina at Chapel Hill (United States); R. Crout, G. Rice, National Oceanic and Atmospheric Administration (United States)

A mapping of the deep (approximately 1000-1300 m) dispersed oil feature associated with the blowout of the MC252 wellhead was organized by the subsurface mapping unit within the Unified Area Command starting in early August. Colored dissolved organic matter fluorescence, which had been used to establish existence of the subsurface oil prior to this time, had largely fallen below background levels for the sensors by this time. Dissolved oxygen (DO), deficits in which are assumed to be related to the consumption of the oil by microbes, was the only routinely observed variable in vertical profiles that displayed a persistent and obvious anomaly. The presence and magnitude of the DO anomaly was therefore used to identify the presence and magnitude of the dispersed oil impact. A more sensitive hydrocarbon fluorometer used later in the effort justified the use of the dissolved oxygen signal as a proxy for the feature. An adaptive sampling plan employing daily review of DO profiles to provide vessel guidance to a number of participating vessels was established and permitted a coarse mapping of the feature within 4 weeks. The DO anomaly was found to extend from the wellhead to the WSW for more than 350 km, bounded to the north by the upper slope (approximately 1000 m isobath), with a cross-slope extent of 60-100 km. A weak DO anomaly was also present to the ENE of the wellhead out to 60 km. The operational process employed and the challenge presented by the response situation will be reviewed.

8029A-42, Session 7

In situ characterization of distributions of dissolved contaminants using underwater mass spectrometry

R. T. Short, R. J. Bell, A. Chaudhary, S. K. Toler, F. H. W. van Amerom, SRI St. Petersburg (United States)

The need for chemical monitoring and profiling in our oceans is driven by basic scientific questions as well as more pressing considerations such as the recent Deepwater Horizon oil spill. Such an episode has accelerated the need for real-time environmental observations. Versatile in situ analyzers are needed to locate, map, and monitor the long-term fate of chemical compounds that create environmental and economic damage and endanger public health. A mass spectrometer is a versatile analyzer with capabilities that far exceed traditional in situ underwater chemical sensing techniques with respect to dynamic range, and to sensitivity, and selectively to a broad range of analytes. The ability to perform in situ mass spectrometry greatly enhances both spatial and temporal densities for environmental chemical analysis. Real-time chemical measurements also allow rapid decision making and lead to the possibility of adaptive sampling strategies. SRI International's in situ membrane introduction mass spectrometry (MIMS) instruments can quantitatively detect volatile organic compounds in water at trace

levels, while simultaneously monitoring the concentrations of all light stable dissolved gases to a depth of 1500 meters. The instruments are based on a 200 amu (atomic mass unit) linear quadrupole mass analyzer. Introduction of analytes into the mass spectrometer occurs through a high-pressure PDMS (polydimethyl siloxane) membrane introduction system. Examples of deployments of SRI in situ membrane introduction mass spectrometers will be discussed, as well as progress in the development of alternative underwater sampling interfaces and micro-fabricated mass spectrometers.

8029A-21, Session 8

An empirical approach to derive MODIS ocean color patterns under severe sun glint

C. Hu, Univ. of South Florida (United States)

Oil tracking in the Gulf of Mexico in response to the Deepwater Horizon accident requires timely and accurate observations of major circulation patterns such as the Loop Current and LC eddies. When the eastern GOM becomes nearly isothermal at the surface and the use of sea surface temperature imagery is limited, MODIS ocean color data can be used instead. However, frequent and extensive sun glint prevents such an application when glint reflectance, L¬g, is > 0.01 sr-1. Here, an empirical approach is developed to remove sun glint and clouds based on band ratios between the Rayleigh-corrected reflectance (Rrc) at 469, 555, 645, 859, and 1240-nm. To minimize the effect of residual errors due to variable aerosols and imperfect glint correction, a color index (CI) is derived from to represent the color patterns. Comparison between results from adjacent days with different glint and aerosol patterns suggests that the approach is able to derive consistent color patterns under severe sun glint (L¬g < 0.15 sr-1). Tests of the approach over the Tropical Atlantic, East China Sea, and ocean waters off South Africa further validate the approach's general applicability. The color index (CI) also shows significant correlation with MODIS band-ratio Chl (< 1 mg m-3) for each case examined. The simple design of the approach makes it straightforward to implement for other subtropical and tropical regions when a qualitative MODIS CI is desired to infer circulation patterns and to detect eddies under severe sun glint.

8029A-22, Session 8

Texas coastal ocean observation network: data access and archive software

G. A. Jeffress, S. Duff, Texas A&M Univ. Corpus Christi (United States)

Abstract: The Conrad Blucher Institute (CBI) at Texas A&M University-Corpus Christi operates the Texas Coastal Ocean Observation Network (TCOON.) TCOON collects near real-time physical oceanographic data at 28 coastal stations along the Texas coast. The data include water level, wind speed & direction, barometric pressure, water temperature, and air temperature from stations placed in bays and estuaries along the Texas coast. TCOON provides this critical data to many users, including those in the commercial shipping industry, marine construction, legal water-land boundaries, recreational boaters, and those responsible for marine safety and emergency evacuation in the event of a hurricane. Data sets are available in near real time via the Internet at CBI's web site, via social networking sites such as Facebook and Twitter and some data sets are accessible via voice over the telephone. All data collected since 1991 is available online along with data search tools. TCOON sponsors and developers believe that the more users and uses the system supports, the more valuable the data becomes. The highest scientific standards are used in data collection as these data often end up in litigation in the courts. Database software and the online tools used for data downloads are also open source.

8029A-23, Session 8

Applications of high frequency radar for emergency response in the coastal ocean: utilization of the Central Gulf of Mexico Ocean Observing System during the Deepwater Horizon oil spill and vessel tracking

S. Howden, The Univ. of Southern Mississippi (United States); D. Barrick, H. Aguilar, CODAR Ocean Sensors (United States)

Along much of the U.S. coast, surface currents are being measured in real-time using High Frequency Radar (HFR). Where coverage is adequate, these currents are being utilized in emergency response efforts in tasks such as producing trajectory forecasts for spills of hazardous substances and for search and rescue operations. Although the HFR coverage in the Gulf of Mexico is sparse, the Deepwater Horizon (DwH) oil spill occurred just south of the coverage area of the Central Gulf of Mexico Ocean Observing System (CenGOOS), which operates three long-range CODAR SeaSonde HFRs. NOAA was able to take advantage of the national integration of HFR data, sponsored by NOAA under the Integrated Ocean Observing System, to seamlessly utilize the CenGOOS data in producing the trajectory forecasts for the DwH oil spill event. The value of these surface current data to the emergency response effort will be demonstrated and the importance of extending the HFR coverage in the Gulf will be discussed.

In addition to surface-current maps, the SeaSondes see vessels within their coverage area. At lower HF, this enables beyond-the-horizon, all-weather detection and tracking, overcoming the line-of-sight limitations of conventional microwave radars and VHF AIS ship/shore transponder systems. Programs to develop this dual-use capability have been underway since 2001, funded by DoD and DHS. Offline capability to detect and track vessels has been successfully demonstrated, and examples will be shown. Efforts are underway to upgrade this to a real-time capability. This will be ready for demonstration on coastal SeaSonde systems in early 2011

8029A-43, Session 8

Making sense of ocean sensing: the Gulf of Mexico Coastal Ocean Observing System links observations to applications

C. Simoniello, Gulf of Mexico Coastal Ocean Observing System Regional Association (United States) and Univ. of South Florida (United States); A. E. Jochens, M. K. Howard, Texas A&M Univ. (United States); J. Swaykos, The Univ. of Southern Mississippi (United States); D. R. Levin, National Oceanic and Atmospheric Administration (United States); D. Stone, The Florida Aquarium, Inc. (United States); B. Kirkpatrick, Mote Marine Lab. and Aquarium (United States)

The Gulf of Mexico Coastal Ocean Observing System Regional Association (GCOOS-RA) is one of eleven regional partners of the U.S. Integrated Ocean Observing System that work to enhance our ability to collect, deliver and use ocean information through the development of sustained, routine, regional observing systems. The GCOOS-RA Education and Outreach Council works to bring together industry, governments, academia, formal and informal educators, and the public to assess regional needs for coastal ocean information, foster cooperation, and increase the utility of the information. Whether targeting a specific subset of the population (e.g., public health officials) or the community at large, the ultimate goal is to link observations to applications for the direct benefit of human enlightenment.

Knowledge transfer requires two-way communication; clientele need to be aware of observational capabilities, and regional associations must understand and manage client expectations if useful products are to be developed. If done effectively, the observing system generates

tools that enhance public safety through increased ocean and climate literacy and promote community-level economic stability (e.g., avoiding unnecessary evacuations or beach closures). Examples of data products in various stages of development will be presented. These include novel visualizations of storm surge, public exhibits focused on water quality data, a Harmful Algal Bloom warning system, and a description of the Basic Observational Buoy project designed to engage citizen scientists in Deepwater Horizon Oil Spill monitoring efforts.

8029A-44, Session 8

Building interoperable data systems in the Gulf of Mexico: a case study

M. K. Howard, Texas A&M Univ. (United States)

Data collection in oceanography is undergoing a paradigm shift. We are moving from month-long shipboard campaigns and mooring deployments with annual data recoveries to persistent adaptive presences using networked distributed and sometimes autonomous sensor systems returning data in near real-time. Real-time data have value delayed-mode data does not (e.g., oil spills). The challenge is automating conversion and integration of sensor data to an analysis-ready state. The Integrated Ocean Observing System (IOOS) data management group identified the core elements (data discovery, access, transport, etc.) required to build interoperable systems. In practice, these require standards adoption in vocabularies, data models, and web services. The Gulf of Mexico Coastal Ocean Observation System (GCOOS) began as a regional collaboration of eleven non-federal sub-regional observatories whose data systems evolved independently and were not interoperable. Grants allow us to deploy a service oriented architecture consisting of OPeNDAP transports and standards-based Open Geospatial Consortium Sensor Observation Service web interfaces with Observation and Measurement encodings in each of the observatories. We constructed and deployed a common vocabulary based on the NetCDF Climate and Forecast Metadata Conventions and standard names. The observatories host XML files listing their active sensors which are compiled into catalogs of available assets. Our regional data portal aggregates data from the observatories and constructs data products for stakeholder groups. These capabilities were available during and following the Deepwater Horizon oil spill. Interoperability made the data and products readily available to the incident command centers in hours instead of months.

8029A-45, Session 8

Developing technologies for regional ocean observing systems

J. R. van Smirren, R. I. Smith, Gulf of Mexico Coastal Ocean Observing System Regional Association (United States); X. Guan, Fugro GEOS, Inc. (United States)

The Gulf of Mexico Coastal Ocean Observing System Regional Association(GCOOS-RA) takes a continuing and proactive role in in-situ monitoring and characterization of the marine environment. This includes the use of near real-time data in the description and prediction of conditions in the Gulf of Mexico (GOM) for multiple user groups. In many ways the GOM is also the epitome of what can be considered a “battle space environment”. Its complex and extreme meteorological and oceanic conditions make it an ideal test bed for characterization of such technologies. Many candidate technologies have been tested and used on an ongoing basis for the support of the offshore oil and gas, fisheries, and other industries in the region. In addition, considerable research on the GOM has been undertaken by academic, industrial and government groups. The recent Gulf Of Mexico Oil Spill brought to bear intense monitoring and the introduction of innovative technologies to monitor the environment. However, many methods remain untried.

This paper identifies some of the more useful techniques that have been adopted in understanding the Gulf. We also identify approaches, as yet untried, that could provide vital data for operational support and the provision of data for initialization, assimilation, and verification of ocean forecast models.

8029B-58, Session 8

Superresolution benefit for face recognition

S. Hu, R. A. Maschal, Jr., S. S. Young, S. M. Won, U.S. Army Research Lab. (United States); T. Hong, J. Phillips, National Institute of Standards and Technology (United States)

The availability of inexpensive cameras and storage devices has generated vast quantities of video footage acquired from surveillance systems, necessitating the need for facial recognition systems to automate the identification of suspected individuals. Yet the coarse resolution and distance of recorded individuals from the cameras present significant challenges to face recognition algorithms. Super-resolution image reconstruction is a technique that uses a sequence of low-resolution frames containing subpixel shifts to generate a higher resolution image. Using a database of moving faces and people that closely emulates real world surveillance footage, the benefits of super-resolution image reconstruction are evaluated for the local region principle component analysis (LRPCA) face recognition algorithm. The experiment assessed face recognition performance as a function of subject range in terms of eye-to-eye pixel distance (5-10, 15-20, and 25-30 pixels) at three resolutions (original low-resolution, super-resolved with four frames, and super-resolved with eight frames). Initial results with a sample size of 80 subjects show that super-resolution image reconstruction using eight frames at the mid-range increased the verification rate from 20.0% (using low-resolution imagery) to 41.4% at a false alarm rate of 0.05, representing an improvement by 107%. At the far range of 5-10 pixels eye-to-eye distance, the imagery contained too few details for enhancement, resulting in similar performance. At the close range, super-resolution improved the verification rate from 26.7% to 34.8%. These initial results show the promising potential of super-resolution image reconstruction in aiding facial recognition systems in real world scenarios.

8029B-59, Session 8

A quantitative comparison of 3D face databases for 3D face recognition

D. Smeets, J. Hermans, D. Vandermeulen, P. Suetens, Katholieke Univ. Leuven (Belgium)

During the last decade research in face recognition has shifted from 2D to 3D face representations. The need for 3D face data has resulted in the advent of 3D databases.

In this paper, we first give an overview of publicly available 3D face databases containing expression variations, since these variations are an important challenge in today's research. The existence of many databases demands a quantitative comparison of these databases in order to compare more objectively the performances of the various methods available in literature.

The ICP algorithm is used as baseline algorithm for this quantitative comparison for the identification and verification scenario, allowing to order the databases according to their inherent difficulty.

Performance analysis using the rank 1 recognition rate for identification and the equal error rate for verification reveals that the FRGC v2 database can be considered as the most challenging. Therefore, we recommend to use this database further as reference database to evaluate (expression-invariant) 3D face recognition algorithms.

As second contribution, the main factors that influence the performance of the baseline technique are determined and attempted to be quantified. It appears that large pose variations, an increasing number of expressions and an increasing expression level decreases the recognition results.

8029B-60, Session 8

QUEST hierarchy for hyperspectral face recognition

D. Ryer, U.S. Air Force (United States); T. J. Bihl, K. W. Bauer, Air Force Institute of Technology (United States); S. K. Rogers, Air Force Research Lab. (United States)

A face recognition methodology employing an efficient fusion hierarchy for hyperspectral imagery (HSI) is presented. A Matlab-based graphical user interface (GUI) has been developed to aid processing and to display results. Adaptive feedback loops are incorporated to improve performance thru the reduction of candidate subjects in the gallery as well as the injection of additional probe image samples. Algorithmic results and performance improvements are presented as spatial, spectral, and temporal effects are considered in this Qualia Exploitation of Sensor Technology (QUEST) motivated methodology. The QUEST methodology attempts to develop a general-purpose computational intelligence system that captures the advantages of qualia-like representations. The links in our fusion hierarchy provides the context of the face. There are many links that can connect the internal and external facial features that have proved so important in human recognition research. The links chosen can help incorporate higher levels of abstraction such as important soft biometric cues or the connection between spatial and spectral information. Face recognition by humans utilizes not only spatial information but also spectral and temporal aspects as well. This research addresses the automatic handling of these features and the incorporation of contextual or complimentary information in an efficient architecture that enhances effectiveness and efficiency. The use of hyperspectral imagery and a fusion hierarchy similar to the one presented in this paper offers opportunities for the improvement of current face recognition systems and can be applied to a wider array of object recognition problems.

8029B-61, Session 9

Video analytics and activity recognition

M. A. Shah, Univ. of Central Florida (United States)

No abstract available

8029B-62, Session 10

Adding localization information in a fingerprint binary feature vector representation

J. Bringer, V. Despiegel, M. Favre, Morpho (France)

At BTAS'10, a new framework to transform a fingerprint minutiae template into a binary feature vector of fixed length is described. The algorithm compares all the minutiae vicinities of the fingerprint with a fixed number of representative vicinities. The cell of a given index of the feature vector contains a 1 if and only if at least one vicinity of the fingerprint is close to the representative related to this index. Such a local encoding technique enables to deal with local distortions that may occur between two acquisitions.

We extend this notion to incorporate additional information in the binary vector, in particular on localization of the vicinities. We explore the use of position and orientation information. The performance improvement is promising for utilization into fast identification algorithms or into privacy protection algorithms.

8029B-63, Session 10

Speech biometric mapping for key binding cryptosystem

K. Inthavisas, D. P. Lopresti, Lehigh Univ. (United States)

We propose a new scheme to transform speech biometric measurements (feature vector) to a binary string which can be combined with a pseudo-random key for a cryptographic purpose. We utilize Dynamic Time Warping (DTW) in our scheme. The challenge of using DTW in a cryptosystem is that a template must be useful to create a warping function, while it must not be usable for an attacker to derive the cryptographic key. In this work, we propose a hardened template to address these problems. We evaluate our scheme with two speech datasets and compare with DTW, VQ, and GMM speaker verifications. The experimental results show that the performance of the proposed scheme outperforms VQ and GMM. It is slightly degraded when compared to the DTW speaker verification. The EERs against attackers utilizing the hardened template are 0% both datasets.

8029B-64, Session 10

C-BET evaluation of voice biometrics

D. O. Gorodnichy, Canada Border Services Agency (Canada); M. Thiemi, International Biometric Group (Canada); E. Dubrofsky, Canada Border Services Agency (Canada)

C-BET is the Comprehensive Biometrics Evaluation Toolkit developed by CBSA in order to analyze the risks of using a biometric system for automated border/access control applications. Following the multi-order score analysis and the threshold validated analysis defined within the C-BET framework, the paper presents the results of the C-BET evaluation of a commercial voice biometric product. In addition to error tradeoff and ranking curves traditionally reported elsewhere, the paper presents the results on the newly introduced performance metrics: threshold-validated recognition ranking and non-confident decisions due to multiple threshold-validated scores. The results are obtained on over a million voice audio clip comparisons.

8029B-65, Session 11

Recent advances in face and iris biometrics

A. A. Ross, West Virginia Univ. (United States)

No abstract available

8029B-66, Session 12

Impact of out-of-focus blur on iris recognition

N. A. Sazonova, The Univ. of Alabama at Tuscaloosa (United States); S. C. Schuckers, P. Johnson, Clarkson Univ. (United States); P. Lopez-Meyer, E. S. Sazonov, The Univ. of Alabama at Tuscaloosa (United States); L. Hornak, West Virginia Univ. (United States)

Iris recognition has expanded from controlled settings to uncontrolled settings (on the move, from a distance) where blur is more likely to be present in the images. More research is needed to quantify the impact of blur on iris recognition. In this paper we study the effect of out-of-focus blur on iris recognition performance from images captured with out-of-focus blur produced at acquisition. A key aspect to this study is that we are able to create a range of blur based on changing focus of the camera during acquisition. We quantify the produced out-of-focus blur based on the Laplacian of Gaussian operator and compare it to the gold standard of the modulation transfer function (MTF) of a calibrated black/white chart. The sharpness measure uses an unsegmented iris images from a video sequence with changing focus and offers a good approximation of the standard MTF. We examined the effect of the 9 blur levels on iris recognition performance. Our results have shown that for moderately blurry images (sharpness at least 50%) the drop in performance does not exceed 5% from the baseline (100% sharpness).

8029B-67, Session 12

A simple shape prior model for iris image segmentation

D. Bishop, A. J. Yezzi, Jr., Georgia Institute of Technology (United States)

In order to make biometric systems faster and more user-friendly, lower-quality imagest must be accepted. A major hurdle in this task is accurate segmentation of the boundaries of the iris in these images. Quite commonly, circle-fitting is used to approximate the boundaries of the inner (pupil) and outer (limbic) boundaries of the iris, but this assumption does not hold for off-axis or otherwise non-circular boundaries. In this paper we present a novel, foundational method for elliptical segmentation of off-axis iris images. This method uses active contours with constrained flow to achieve a simplified form of shape prior active contours. This is done by calculating a region-based active contour evolution and projecting it upon a properly chosen set of vectors to confine it to a class of shapes. In this case, that class of shapes is ellipses. This serves to regularize the contour, simplifying the curve evolution and preventing the development of irregularities which present challenges in iris segmentation. The proposed method is tested using images from the UBIRIS v.1 and CASIA-IrisV3 image data sets, with both near-ideal and off-axis images. By avoiding many of the assumptions commonly used in iris segmentation methods, the proposed method is able to accurately fit elliptical boundaries to off-axis images.

8029B-68, Session 12

Security enhanced BioEncoding for protecting iris codes

O. M. Ouda, Chiba Univ. (Japan) and Mansoura Univ. (Egypt); N. Tsumura, T. Nakaguchi, Chiba Univ. (Japan)

Improving the security of biometric template protection techniques is a key prerequisite for the widespread deployment of biometric technologies. BioEncoding is a recently proposed template protection scheme, based on the concept of cancelable biometrics, for protecting biometric templates represented as binary strings such as iris codes. The main advantage of BioEncoding over other template protection schemes is that it does not require user-specific keys and/or tokens during verification. Besides, it satisfies all the requirements of the cancelable biometrics construct without deteriorating the matching accuracy. However, although it has been shown that BioEncoding is secure enough against simple brute-force search attacks, the security of BioEncoded templates against more smart attacks, such as record multiplicity attacks, has not been investigated. In this paper, a rigorous security analysis of BioEncoding is presented. Firstly, resistance of BioEncoded templates against brute-force attacks is revisited thoroughly. Secondly, we show that although the cancelable transformation employed in BioEncoding might be non-invertible for a single protected template, the original iris code could be inverted by correlating several templates used in different applications but created from the same iris. Accordingly, we propose an important modification to the BioEncoding transformation process in order to hinder attackers from exploiting this type of attacks. The effectiveness of adopting the suggested modification is validated and its impact on the matching accuracy is investigated empirically using CASIA-IrisV3-Interval dataset. Experimental results confirm the efficacy of the proposed approach and show that it preserves the matching accuracy of the unprotected iris recognition system.

8029B-69, Session 13

Challenging ocular image recognition

V. P. Pauca, M. Forkin, X. Xu, R. J. Plemmons, Wake Forest Univ. (United States); A. A. Ross, West Virginia Univ. (United States)

Ocular recognition is a new area of investigation targeted at overcoming the limitations of iris recognition performance in the presence of non-ideal data. There are several advantages for increasing the area beyond the iris, yet there are also key issues that must be addressed such as, size of the ocular region, factors affecting performance, and appropriate corpora to study these factors in isolation. In this paper, we explore and identify some of these issues with the goal of better defining parameters for ocular recognition. An empirical study is performed where iris recognition methods are contrasted with texture and point operators on existing iris and face datasets. The experimental results show a dramatic recognition performance gain when additional features are considered in the presence of poor quality iris data, offering strong evidence for extending interest beyond the iris. The experiments also highlight the need for the direct collection of ocular imagery.

8029B-70, Session 13

Segmentation-free ocular detection and recognition

A. F. Rodriguez, B. V. K. Vijaya Kumar, Carnegie Mellon Univ. (United States)

Iris recognition is a well-known technique used to identify persons. In general, iris recognition requires the detection of the eye region in an image, then the segmentation of the iris and conversion of the segmented region from Cartesian coordinates to polar coordinates. This is followed by the extraction of features, and then the application of a classifier. Low resolution images challenge iris recognition techniques, particularly because segmenting the iris becomes nearly impossible. In contrast, recognition using correlation filters (CFs) does not require any segmentation. In this work we assume that in scenarios where the iris can be captured then the whole ocular region is also captured.

In this work we design two types of CFs: The first type for experiments with multiple-classes of targets (multiple individuals) we designed a CF to yield sharp peaks for the ocular region of a particular individual while exhibiting low response to non-ocular regions and ocular regions of other (i.e., impostor) subjects. The second type for experiments with only two-classes of targets (two individuals) we designed a CF to yield sharp positive peaks for one class and sharp negative peaks for the other class while exhibiting low response to non-ocular regions.

The results show that using the CFs we are able to detect and recognize multiple classes of subjects using low resolution irises. We also show that for these low resolution images conventional iris recognition does not work as iris segmentation fails while segmentation-free ocular recognition performs better.

8029B-71, Session 13

Eye safety considerations in the design of an iris capture system

G. Abramovich, F. W. Wheeler, GE Global Research (United States)

We have developed a standoff iris biometrics system for improved usability in access-control applications. The system employs an eye illuminator, which is composed of an array of encapsulated near-infrared light emitting diodes (NIR-LEDs), which are triggered at the camera frame rate for reduced motion blur and ambient light effects. Neither the standards / recommendations for NIR laser and lamp safety, nor the LED-specific literature address all the specific aspects of LED eye-safety measurement. Therefore, we established exposure limit criteria based on a worst-case scenario combining the following: the CIE/ANSI standard/recommendations for exposure limits; concepts for maximum irradiance level and for strobing from the laser safety standards; and ad-hoc rules minimizing irradiance on the fovea, for handling LED arrays, and for LED mounting density. Although our system was determined as eye safe, future variants may require higher exposure levels and lower safety margins. We therefore discuss system configuration for LED radiometric measurement that will ensure reliable eye-safety evaluation. The considerations and ad hoc rules described in this paper are not, and should not be treated as safety recommendations.

Return to Contents

Conference 8030: Ocean Sensing and Monitoring III

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8030-01, Session 1

Hyperspectral and multispectral above-water radiometric measurements to monitor satellite data quality over coastal area

S. Ahmed, The City College of New York (United States); R. Arnone, U.S. Naval Research Lab. (United States); C. O. Davis, Oregon State Univ. (United States); A. Gilerson, T. Harmel, S. M. Hlaing, A. Tonizzo, The City College of New York (United States); A. Weidemann, U.S. Naval Research Lab. (United States)

The Long Island Sound Coastal Observational platform (LISCO) near Northport, New York, has been recently established to support satellite data validation. LISCO is equipped with both multispectral SeaPRISM and hyperspectral HyperSAS radiometers for ocean color measurements from above water. LISCO site offers the potential for improving the calibration and validation activities of current and future Ocean Color satellite missions, as well as for satellite intercomparisons and spectral characterization of coastal waters. Results of measurements made by both the multi- and hyper-spectral instruments, in operation since October 2009, are presented, evaluated and compared with ocean color satellite data. The normalized water-leaving radiance derived from SeaPRISM and HyperSAS data are compared, on the one hand, with the retrieved data of the main multispectral satellite sensors (e.g. MERIS, MODIS and SeaWiFS) and, on the other hand, with the hyperspectral imagery provided by the HICO satellite mission. The advantages of both instrumentations as well as the uncertainties of the retrieved radiances are discussed. The results confirm that the LISCO site is appropriate for use in calibration/validation of ocean color satellites in coastal waters, and as a key element of the AERONET-OC network. Applications to the future ocean color mission VIIRS are also addressed.

8030-02, Session 1

Estimation of the attenuation coefficient of the water body using polarimetric observations

A. Tonizzo, T. Harmel, A. Ibrahim, A. Gilerson, S. Ahmed, The City College of New York (United States)

The degree of polarization (DOP) of the underwater light field in oceanic waters is, as has been known for a long time (Timofeeva, 1970), related to the single scattering albedo of suspended particles. The single scattering albedo in turn is given by the ratio of the scattering coefficient to the attenuation coefficient. Knowledge of the single scattering albedo and of the particulate scattering matrix permits solution of the radiative transfer equation for the ocean body. The validity of the above approach for the whole visible spectral range was recently confirmed by us using experimental data obtained with our recently developed underwater polarimeter. This then opens up the possibility for estimation of attenuation coefficients from measurements of the Stokes components of the upwelling underwater light field which is not possible from unpolarized measurements of the remote sensing reflectance. Results of radiative transfer calculations are also presented. We simulated multiple underwater polarized light fields (for the whole visible spectrum) using a vector radiative transfer code with the purpose of obtaining a parameterization of this relationship for different viewing geometries (which means different solar and zenith/azimuth viewing angles) and in various water conditions (i.e. various IOPs). Results of simulations are compared with below and above water experimental observations to assess the validity of the results.

8030-03, Session 1

Automated detection and removal of cloud shadows on HICO images

R. Amin, U.S. Naval Research Lab. (United States) and Mississippi State Univ. (United States); R. Gould, W. W. Hou, U.S. Naval Research Lab. (United States); Z. Lee, Mississippi State Univ. (United States); R. Arnone, U.S. Naval Research Lab. (United States)

Throughout the year about 2/3 of the Earth's surface is always cloud-covered. Clouds cause a serious problem for optical satellite sensors, especially for new, high-resolution sensors such as the Hyperspectral Imager for the Coastal Ocean (HICO). HICO was built by the Naval Research Laboratory and has been operating aboard the International Space Station since installation on 24 September 2009, providing 100m resolution hyperspectral imagery. Clouds not only conceal the ground, they also cast shadows, which cause either a reduction or total loss of information in an image, by reducing the illumination falling on the shadowed pixels. Ocean color bio-optical inversion algorithms rely on measurements of remote sensing reflectance (Rrs) at each pixel, so if shadows are not removed properly across a scene, erroneous Rrs values will be calculated for the shadowed pixels, leading to incorrect retrievals of ocean color products such as chlorophyll. On the other hand, the contrast of pixels in and outside a shadow provide opportunities to remove atmospheric contributions for ocean color remote sensing. Although identifying clouds is relatively straightforward using simple brightness thresholds, identifying their shadows especially over water is quite challenging, because the brightness of the shadows is very close to the brightness of neighboring, unshadowed regions especially in deep waters. In this study, we present an automated cloud shadow detection and removal approach, couple it to the Lee et al. (2007) cloud and shadow atmospheric correction algorithm, and apply it to HICO imagery. We show examples of the results and discuss limitations of the approach. Furthermore, we analyze the affects of cloud shadows on ocean color products such as chlorophyll.

8030-04, Session 1

Influence of aerosol estimation on coastal water products retrieved from HICO images

K. W. Patterson, G. M. Lamela, U.S. Naval Research Lab. (United States)

The Hyperspectral Imager for the Coastal Ocean (HICO) is a hyperspectral sensor which was launched to the International Space Station in September 2009. The Naval Research Laboratory (NRL) has been developing the Coastal Water Signatures Toolkit (CWST) to estimate water depth, bottom type and water column constituents such as chlorophyll, suspended sediments and chromophoric dissolved organic matter from hyperspectral imagery. The CWST uses a look-up table approach, comparing remote sensing reflectance spectra observed in an image to a database of modeled spectra for pre-determined water column constituents, depth and bottom type. In order to successfully use this approach, the remote sensing reflectances must be accurate which implies accurately correcting for the atmospheric contribution to the HICO top of the atmosphere radiances. One tool the NRL is using to atmospherically correct HICO imagery is Correction of Coastal Ocean Atmospheres (COCOA), which is based on Tafkaa 6S. One of the user input parameters to COCOA is aerosol optical depth or aerosol visibility, which can vary rapidly over short distances in coastal waters. Changes to the aerosol thickness results in changes to the magnitude of the remote sensing reflectances. As such, the CWST retrievals for water constituents, depth and bottom type can be expected to vary in like

fashion. This work is an illustration of the variability in CWST retrievals due to inaccurate aerosol thickness estimation during atmospheric correction of HICO images.

8030-05, Session 1

A plan for the polarimetric remote sensing of the oceans

D. J. Gray, U.S. Naval Research Lab. (United States)

Polarimetry has the potential to greatly enhance the capabilities of visible and near-IR remote sensing systems. For remote sensing of the oceans, the passive polarimetric signal is a complicated function of solar angle and viewing geometry, along with the confounding effects of the atmosphere. The atmospheric polarization signal becomes dominant as the sensor altitude increases, and this can lead to complications with ground truth measurements. The purpose of this study is to investigate the combined effects of solar and viewing geometries and sensor altitude to determine a strategy for polarimetric remote sensing of the oceans. A polarimetric radiative transfer code is used to model the nature of polarized light in a coupled atmosphere-ocean system. Viewing geometries are examined to find the look angles and azimuth angles relative to the sun that provide the maximum information about the ocean. The effect of sensor altitude is shown for different aerosol and hydrosol types and concentrations. Finally, the complications of ground truth measurements will be discussed.

8030-06, Session 1

Infrared imaging of surface waves interaction with a submerged object

I. Savelyev, G. B. Smith, U.S. Naval Research Lab. (United States)

Turbulence generated by the interaction of surface wave orbital motions with a submerged object is studied. As this turbulence propagates away from the object any pre-existing thermal gradient may be modulated. If the energy reaches the water surface thermal signatures may be left. In this laboratory study a high-resolution infrared camera was used to observe these temperature fluctuations for a variety of cases. For this preliminary study spheres of 3 different diameters were rigidly mounted at different depths and subjected to mechanically generated waves of varying length and amplitude. The resulting surface thermal signatures will be presented.

8030-07, Session 2

Optical modulation techniques for underwater detection, ranging and imaging

L. J. Mullen, B. Cochenour, A. Laux, D. Alley, Naval Air Systems Command (United States)

Optical detection and imaging is challenging in the underwater environment due to the fact that light is scattered and absorbed on its path to and from an object of interest. While absorption extinguishes photons from the optical path, scattering causes the transmitted light to deviate from its original propagation direction. Light that is scattered back to the receiver that does not reach the intended object causes a 'headlight in fog' effect that decreases visibility. Light that is scattered in small angles on its way to and from the underwater object causes image blurring and reduces detection sensitivity. Researchers at NAVAIR in Patuxent River, MD have been focusing on optical modulation techniques to help discriminate against unwanted scattered light. The concept is that multiply scattered light will 'wash out' the modulation superimposed on the optical carrier while the light reflected from the object of interest will remain modulated. Another benefit of modulating the transmitted light is that coherent detection of the modulation envelope results in the ability to accurately measure the range to the underwater object. The requirements for the modulation scheme, modulation frequency, and laser characteristics (pulsed, continuous, optical power level) depend on the targeted application. The implementation of this optical modulation technique in a variety of underwater sensors has become possible due to recent advances in laser and receiver technology. A review of the work being done in this area of research will be presented, and results from laboratory experiments will be discussed.

8030-08, Session 2

Impacts of optical turbulence on underwater imaging

W. W. Hou, U.S. Naval Research Lab. (United States)

Optical signal transmission underwater is of vital interests to both civilian and military applications. The range and signal to noise during the transmission, as a function of system and water optical properties determines effectiveness of EO technology. These could include diver visibility, search and rescue, mine detection and identification, and optical communications. The impact of optical turbulence on underwater imaging has been postulated and observed by many researchers. However, no quantative studies have been done until recently, in terms of both the environmental conditions, and impacts on image quality as a function of range and spatial frequencies. Image data collected in lab under controlled conditions, as well as field data during SOTEX (Skaneateles Optical Turbulence Exercise, July 22-31, 2010) using the Image Measurement Assembly for Subsurface Turbulence (iMAST) are presented. Controlled conditions are realized by using heat exchanging plates on the top and bottom of a 5m-long convection tank with water, along with scattering agents. Optical properties of the water column in field were measured using WETLab's ac-9 and LISST (Sequoia Scientific), in coordination with CTD (Seabird), Vector velocimeter and CT combo (Nortek and PME), Vertical Microstructure Profiler (VMP, Rockland). The strong stratification structure in the water column provides great opportunity to observe various dissipation strength throughout the water column, which corresponds clearly with image quality. Initial results indicate general agreement between data collected and model prediction, while discrepancies between measurements and model suggest higher spatial and temporal observations are necessary in the future.

8030-09, Session 2

Turbulence measurements for underwater imaging

S. Woods, W. W. Hou, W. Goode, E. Jarosz, A. Weidemann, U.S. Naval Research Lab. (United States)

Enhancing visibility through scattering media is important in many fields for gaining information from the scattering medium. In the ocean, in particular, enhancement of imaging and visibility is important for divers, navigation, robotics, and target and mine detection and classification. Light scattering from particulates and turbulence in the ocean strongly affects underwater visibility. The magnitude of this degrading effect depends upon the underwater environment, and can rapidly degrade the quality of underwater imaging under certain conditions. To facilitate study of the impact of turbulence upon underwater imaging and to check against our previously developed model, quantified observation of the image degradation concurrent with characterization of the turbulent flow is necessary, spanning a variety of turbulent strengths. Therefore, we present field measurements of turbulence from the July 2010 Skaneateles Optical Turbulence Exercise (SOTEX), during which images of a target were collected over a 5 m path length at various depths in the water column, concurrent with profiles of the turbulent strength, optical properties, temperature, and conductivity. Turbulence was characterized by the turbulent kinetic energy dissipation (TKED) and thermal dissipation (TD) rates, which were obtained using both a Rockland Scientific Vertical Microstructure Profiler (VMP) and a Nortek Vector velocimeter in combination with a PME CT sensor. While the two instrumental setups demonstrate reasonable agreement, some irregularities highlight the spatial and temporal variability of the turbulence field. Supplementary measurements with the Vector/CT in a controlled laboratory convective tank will shed additional light on the quantitative relationship between image degradation and turbulence strength.

8030-10, Session 2

Experimental imaging performance evaluation for alternate configurations of undersea pulsed laser serial imagers

F. R. Dalgleish, A. K. Vuorenkoski, B. Ouyang, F. M. Caimi, G. Nootz, Florida Atlantic Univ. (United States)

No abstract available

8030-11, Session 3

Creation of bathymetric maps using satellite imagery

B. L. McCarthy, The Boeing Co. (United States); R. C. Olsen, A. M. Kim, Naval Postgraduate School (United States)

Coastal bathymetry near Camp Pendleton, California was measured using wave motion as observed by the WorldView-2 commercial satellite imaging system. The linear finite depth dispersion relation for surface gravity waves was used to determine nearshore ocean depth from successive images acquired of the coastal area. Principal component transformations of co-registered 8-color multispectral images were found to very effectively highlight wave crests in the surf zone. Time sequential principal component images then contain both spatial and temporal information. From these change detection images, wave celerity could be determined and depth inversion could be performed. For waves farther from shore, the principal component transformation no longer highlighted wave crests, but crests could be resolved within a single RGB composite image with equalization enhancement. The wavelength of a wave above a point of known depth was measured. The wave period method was used to determine depth for other waves in the propagation direction of this wave. Depth calculations using these methods compared favorably to reference bathymetry. The spatial resolution for this method of determining depth is higher and perhaps more accurate than the reference bathymetry used in this study, particularly in the surf zone.

8030-12, Session 3

Using WorldView-2 to determine ocean bottom-type and bathymetry

K. R. Lee, R. C. Olsen, F. A. Kruse, A. M. Kim, Naval Postgraduate School (United States)

Spectral imagery from Worldview 2 (WV-2) is used here to construct bathymetry maps for several shore regions in the northern Pacific. Eight-band imagery from WV-2 is used in conjunction with HyVista Corporation's HyMap data from shallow water along coastlines for improved bathymetric and bottom-type mapping. Airborne data and ground truth were done in the test areas in March 2010. Work was done on beaches in Guam, along with two Northern Mariana Islands - Pagan and Tinian. The primary topic of interest is the relative utility of the 8-band spectral data from WV-2 with respect to classic 4-band spectral imagery. The new "yellow" spectral band is particularly useful in shallow water. There are significant variations in bottom type between the target areas. The additional bands allow greater separation of bottom types.

8030-13, Session 3

Automated, in-water determination of colored dissolved organic material and phytoplankton community structure using the optical phytoplankton discriminator

G. J. Kirkpatrick, Mote Marine Lab. and Aquarium (United States); S. E. Lohrenz, The Univ. of Southern Mississippi (United States); M. A. Moline, California Polytechnic State Univ., San Luis Obispo (United States); O. Schofield, Rutgers Univ. (United States)

Optical Phytoplankton Discriminator (OPD, a.k.a. BreveBuster) determines colored dissolved organic material (CDOM) absorption spectra and particulate light absorbance spectra. The CDOM absorption spectra and correlation coefficients (referred to as 'similarity indexes') between the particulate absorbance spectra and known phytoplankton classes are available in real-time. Post-deployment processing calculates the best fit of multiple absorbance spectra from known phytoplankton taxonomic classes. Through this process the OPD provides an estimate of the phytoplankton community chlorophyll distribution among the classes included in the fit process. The major components of the OPD include: a liquid-waveguide capillary cell (LWCC), a fiber-optic spectrometer, a tungsten-deuterium fiber-optic light and a 0.2 micrometer pore cross-flow filter. In-water operation of the OPD began in May 2003. Since that date 25 of these instruments have been deployed on a variety of autonomous underwater vehicles, buoys, piers, channel markers and boats and ships. It has been utilized in CDOM studies off the New Jersey coast, in HAB monitoring efforts in the Gulf of Mexico and the Great Lakes, and in phytoplankton community structure studies in the Galapagos Islands and the Mediterranean Sea. Most recently, it has been deployed to Veracruz, Mexico for HAB monitoring. Presently, several OPD's operating on Slocum gliders and coastal buoys make up a local HAB observatory south of Tampa Bay, Florida, partially supported by the NOAA/IOOS through GCOOS. This presentation will detail the OPD's capabilities and report results from several of the deployments listed above. The ongoing effort to effectively visualize 4-D phytoplankton community structure will be discussed.

8030-14, Session 3

Design and implementation of cooperative autonomous underwater vehicles for Antarctic exploration

A. E. Cadena, Jr., Escuela Superior Politécnica del Litoral (Ecuador)

The present work describes the development of two collaborative Autonomous Underwater Vehicles (AUV) for Antarctic exploration to use them in the Ecuadorian Expeditions to the Scientific Base Pedro Vicente Maldonado in Antarctica.

The Ecuadorian Antarctic Institute requires Unmanned Underwater Vehicles to make oceanography studies in open water and an Antarctic Census of Marine Life near to the glacier wall.

One vehicle is an AUV, called TAUV, with classical torpedo architecture, can work as a platform to transport scientific payload in a determined path in open waters. The TAUV length is 2m and diameter of 0.16m and has got three degree of freedom: pitch, yaw and surge. The vehicle achieves stable control with a set of three pairs of control surface. One pair is the rudder to control the yaw angle and the other pairs control the pitch angle. There are four sections in the vehicle, the propulsion module, batteries, scientific payload, electronics compartment and digital camera compartment.

The other vehicle is an AUV, called HAUV, with Hybrid architecture that combines the best characteristics of the ROV and AUV, high stability in the water column, high maneuverability at low velocity without control surfaces and efficient hydrodynamics. The HAUV length is less than 1.50

m. It is composed by the following modules: propulsion, power, motor driver, CPU, sensor suite, camera system and communication module. The propulsion module is formed by four thrusters, three axial and one oriented vertically, this configuration gives to the HAUV three degrees of freedom: heave, surge, and yaw. This vehicle can works as a ROV or an AUV. The hybrid configuration features allows the vehicle to explore dangerous areas near to the glacier wall.

These vehicles use a Data Link in order to work together. Three collaborative behaviors are discussed: formation flying, point inspection near to the glacier wall and replacement of a missing vehicle.

Results of some systems of the TAUV and HAUV from laboratory, sea trials and Antarctic environment are show.

8030-15, Session 3

Automated identification of rivers and shorelines in aerial imagery using image texture

P. McKay, C. A. Blain, U.S. Naval Research Lab. (United States); R. S. Linzell, QinetiQ North America (United States)

A fundamental challenge in the rapid development of hydrodynamic river models is the lack of accurate information describing the river bank geometry. Unlike for coastlines, there is no readily accessible database of river bank locations and what information is available is often outdated and of questionable accuracy and resolution. With rivers of interest to the Navy often being located in denied access areas, it is generally not possible to obtain this information using traditional surveying techniques. However as high resolution satellite and aerial imagery is increasingly available for the entire globe, it is becoming more common to extract river bank locations from this imagery, thus generating an accurate and high resolution bank geometry.

Much of the globe is covered by various sorts of multi- or hyperspectral imagery and numerous techniques have been developed to use the wealth of information contained in these images to identify and extract river features. However these techniques are often closely tied to particular image sources and sensors or else require proprietary software packages and trained operator input. These tools and image sources may not always be readily available, particularly in civilian applications, so alternate techniques must be developed.

A method has been developed which automatically extracts river and river bank locations from arbitrarily sourced high resolution (~1m) visual spectrum imagery without recourse to multi-spectral or even color information. This method relies on quantifying the difference in image texture between the relatively smooth surface of the river water and the rougher surface of the vegetated land or built environment bordering it and then segmenting the image into high and low roughness regions. The edges of the low roughness image mask then define the river banks. The method can be coded in any language without recourse to proprietary tools and requires minimal operator intervention. As this sort of imagery is increasingly being made freely available through such services as Google Earth or Worldwind this technique can be used to extract river features when more specialized imagery or software is not available.

8030-16, Session 3

Merging imagery and models for river current prediction

C. A. Blain, U.S. Naval Research Lab. (United States); R. S. Linzell, QinetiQ North America (United States); P. McKay, U.S. Naval Research Lab. (United States)

While river operations are rapidly becoming a major part of Military Special Operations, they pose one of the most challenging environments to characterize, as they form the interface between land and water in the coastal margin. Further compounding the problem is the inaccessibility of those areas around the globe in which Navy river operations are often conducted. Their geometric complexity and continually changing position and character are difficult to measure under optimal circumstances. Yet such details as the river bank position, bed elevation, upstream discharge, and downstream water level modulations are necessary to initialize accurate predictive river models. To meet this challenge and improve the riverine intelligence available to the warfighter, advanced high resolution river circulation models are combined with remote sensing feature extraction algorithms to produce a predictive capability for currents and water levels in rivers where a priori knowledge of the river environment is limited.

A River Simulation Tool (RST) is developed to facilitate the rapid configuration of a river model. River geometry is derived from the automated processing of available imagery and minimal user input is collected to complete the parameter and forcing specifications for a river model. Contingencies within the RST accommodate missing data such as the lack of water depth information and allow for ensemble computations. Successful application of the RST to river environments as diverse as the Atchafalaya River, LA and the Snohomish River, WA include comparisons to in situ currents and demonstrate the value of the developed approach.

8030-17, Session 3

Using thermal remote sensing as a tool for calibrating a hydrodynamic model in inland waters

N. Pahlevan, A. D. Gerace, J. R. Schott, Rochester Institute of Technology (United States)

Remote sensing has been proven as an effective tool for mapping and monitoring water quality in coastal/inland waters during the past two decades. In light of this, it can also be applied to calibrate hydrodynamic models which predict the distribution of river plumes and streams in coastal/inland waters. This research examines the capability of Landsat 7 thermal data towards calibrating a 3D Hydrodynamic model by simulating two river plumes of different sizes. This model is provided with a set of environmental and physical variables, and involves modeling material transport using finite-differencing method to generate profiles of temperature within the water column. In this way, a Look-Up-Table (LUT) of multiple scenarios of environmental conditions was built by runing the hydrodynamic model for several hours. This process results in various shapes of the thermal plumes out of which one represents the best output which can be determined by comparison with atmospherically compensated Landsat7 thermal data in the sensor-reaching radiance domain. The best agreement with the remotely sensed data is found through optimization in which an error function, calculated between the model outputs and the imagery, is minimized. The root mean squared error (RMSE), computed between the best model match and the observed imagery on a pixel-by-pixel basis, indicates a good fit with errors ranging from 0.03 to 0.04 units of radiance ( ). This research demonstrates the potential of existing Landsat data and the corresponding method for monitoring river plumes in coastal environments.

8030-18, Session 4

Measurement techniques for the Deepwater Horizon (MC-252) oil spill response

R. Crout, National Oceanic and Atmospheric Administration (United States)

The explosion of the Deepwater Horizon (MC-252) drilling platform on 20 April 2010 began a long, unprecedented response from BP and the federal government. Previous responses to oil spills were limited in time due to the amount of oil spilled and were generally confined to the surface. Some of the oil from the Deepwater Horizon wellhead in 1500 meters of water broke into smaller droplets, whose density caused much of the oil to stay within a zone from 1000 to 1300 meters depth. The

Return to Contents

remainder of the oil rose to the surface. The two primary locations of oil required a broad collection of remote sensing techniques to locate and monitor the oil spill.

Surface oil was monitored primarily from the air using aircraft and satellite assets. Satellite visible, infra-red, and radar satellite imagery helped to locate the position of oil in the northern Gulf of Mexico and its potential movement away from the spill site. Daily over-flights by NOAA and other aircraft provided higher spatial and temporal resolution data that were assimilated into daily products.

These remote sensing assets were able to track the surface oil, but the subsurface oil required different techniques. In addition to salinity and temperature profiles to determine the subsurface structure, fluorometry and dissolved oxygen measurements provided information related to oil and its consumption by microorganisms. Water samples collected from CTD casts were analyzed on-board for particle size distribution using a Laser In-situ Scattering Transmissometry (LISST) sensor. Water samples were also returned to on-shore laboratories, where they were subjected to Gas Chromatography and Mass Spectrometry to determine the chemical constituents in the seawater.

8030-19, Session 4

Combining numerical ocean circulation models with satellite observations in a trajectory forecast system: a rapid response to the Deepwater Horizon oil spill

Y. Liu, R. H. Weisberg, C. Hu, Univ. of South Florida (United States)

The Deepwater Horizon oil spill presented an unprecedented threat to the Gulf of Mexico (GOM) marine resources. Needed for mitigation efforts and ship survey guidance was a system for tracking the oil in a timely fashion. We report on such system, implemented immediately upon spill onset, by marshaling numerical model and satellite remote sensing resources available from existing coastal ocean observing activities. Surface oil locations inferred from satellite imagery were used to initialize the positions of the virtual particles in an ensemble of trajectory models, and the particles were tracked using forecast surface currents, with new particles added to simulate the continual release of oil from the well. Timely trajectory forecasts were used to plan scientific surveys and other spill response activities.

In addition to the existing moored ADCP and shoreline-based HF radar arrays for ocean circulation monitoring on the West Florida Shelf (WFS), satellite-tracked drifters were deployed in both the GOM Loop Current and the shelf regions, and subsurface gliders and bottom-stationed ocean profilers were manipulated to observe the ocean circulation and to sample the ocean water properties on the WFS. A new ocean optics product was also used to identify the Loop Current and eddies in the GOM. The integrated ocean observing and modeling systems were demonstrated to be very useful in the rapid response.

8030-20, Session 4

Automated oil spill detection with multispectral imagery

B. Bradford, P. J. Sanchez-Reyes, ITT Corp. Geospatial Systems (United States)

In this publication we present an automated detection method for ocean surface oil, like that which existed in the Gulf of Mexico as a result of the April 20, 2010 Deepwater Horizon drilling rig explosion. Regions of surface oil in airborne imagery are isolated using red, green, and blue bands from multispectral data sets.

The oil shape isolation procedure involves a series of image processing functions to draw out the visual phenomenological features of the surface oil. These functions include selective color band combinations, contrast enhancement and histogram warping. An image segmentation process then separates out contiguous regions of oil to provide a raster mask to an analyst.

We automate the detection algorithm to allow large volumes of data to be processed in a short time period, which can provide timely oil coverage statistics to response crews. Geo-referenced and mosaicked data sets enable the largest identified oil regions to be mapped to exact geographic coordinates.

In our simulation, multispectral imagery came from multiple sources including first-hand data collected from the Gulf. Results of the simulation show the oil spill coverage area as a raster mask, along with histogram statistics of the oil pixels. A rough square footage estimate of the coverage is reported if the image ground sample distance is available.

8030-41, Session 4

Operational mapping of the DWH deep subsurface dispersed oil

H. Seim, The Univ. of North Carolina at Chapel Hill (United States); R. Crout, G. Rice, National Oceanic and Atmospheric Administration (United States)

A mapping of the deep (approximately 1000-1300 m) dispersed oil feature associated with the blowout of the MC252 wellhead was organized by the subsurface mapping unit within the Unified Area Command starting in early August. Colored dissolved organic matter fluorescence, which had been used to establish existence of the subsurface oil prior to this time, had largely fallen below background levels for the sensors by this time. Dissolved oxygen (DO), deficits in which are assumed to be related to the consumption of the oil by microbes, was the only routinely observed variable in vertical profiles that displayed a persistent and obvious anomaly. The presence and magnitude of the DO anomaly was therefore used to identify the presence and magnitude of the dispersed oil impact. A more sensitive hydrocarbon fluorometer used later in the effort justified the use of the dissolved oxygen signal as a proxy for the feature. An adaptive sampling plan employing daily review of DO profiles to provide vessel guidance to a number of participating vessels was established and permitted a coarse mapping of the feature within 4 weeks. The DO anomaly was found to extend from the wellhead to the WSW for more than 350 km, bounded to the north by the upper slope (approximately 1000 m isobath), with a cross-slope extent of 60-100 km. A weak DO anomaly was also present to the ENE of the wellhead out to 60 km. The operational process employed and the challenge presented by the response situation will be reviewed.

8030-42, Session 4

In situ characterization of distributions of dissolved contaminants using underwater mass spectrometry

R. T. Short, R. J. Bell, A. Chaudhary, S. K. Toler, F. H. W. van Amerom, SRI St. Petersburg (United States)

The need for chemical monitoring and profiling in our oceans is driven by basic scientific questions as well as more pressing considerations such as the recent Deepwater Horizon oil spill. Such an episode has accelerated the need for real-time environmental observations. Versatile in situ analyzers are needed to locate, map, and monitor the long-term fate of chemical compounds that create environmental and economic damage and endanger public health. A mass spectrometer is a versatile analyzer with capabilities that far exceed traditional in situ underwater chemical sensing techniques with respect to dynamic range, and to sensitivity, and selectively to a broad range of analytes. The ability to perform in situ mass spectrometry greatly enhances both spatial and temporal densities for environmental chemical analysis. Real-time chemical measurements also allow rapid decision making and lead to the possibility of adaptive sampling strategies. SRI International's in situ membrane introduction mass spectrometry (MIMS) instruments can quantitatively detect volatile organic compounds in water at trace levels, while simultaneously monitoring the concentrations of all light stable dissolved gases to a depth of 1500 meters. The instruments are based on a 200 amu (atomic mass unit) linear quadrupole mass analyzer. Introduction of analytes into the mass spectrometer occurs through a high-pressure PDMS (polydimethlyl siloxane) membrane introduction system. Examples of deployments of SRI in situ membrane introduction mass spectrometers will be discussed, as well as progress in the development of alternative underwater sampling interfaces and micro-fabricated mass spectrometers.

8030-21, Session 5

An empirical approach to derive MODIS ocean color patterns under severe sun glint

C. Hu, Univ. of South Florida (United States)

Oil tracking in the Gulf of Mexico in response to the Deepwater Horizon accident requires timely and accurate observations of major circulation patterns such as the Loop Current and LC eddies. When the eastern GOM becomes nearly isothermal at the surface and the use of sea surface temperature imagery is limited, MODIS ocean color data can be used instead. However, frequent and extensive sun glint prevents such an application when glint reflectance, L¬g, is > 0.01 sr-1. Here, an empirical approach is developed to remove sun glint and clouds based on band ratios between the Rayleigh-corrected reflectance (Rrc) at 469, 555, 645, 859, and 1240-nm. To minimize the effect of residual errors due to variable aerosols and imperfect glint correction, a color index (CI) is derived from to represent the color patterns. Comparison between results from adjacent days with different glint and aerosol patterns suggests that the approach is able to derive consistent color patterns under severe sun glint (L¬g < 0.15 sr-1). Tests of the approach over the Tropical Atlantic, East China Sea, and ocean waters off South Africa further validate the approach's general applicability. The color index (CI) also shows significant correlation with MODIS band-ratio Chl (< 1 mg m-3) for each case examined. The simple design of the approach makes it straightforward to implement for other subtropical and tropical regions when a qualitative MODIS CI is desired to infer circulation patterns and to detect eddies under severe sun glint.

8030-22, Session 5

Texas coastal ocean observation network: data access and archive software

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Abstract: The Conrad Blucher Institute (CBI) at Texas A&M University-Corpus Christi operates the Texas Coastal Ocean Observation Network (TCOON.) TCOON collects near real-time physical oceanographic data at 28 coastal stations along the Texas coast. The data include water level, wind speed & direction, barometric pressure, water temperature, and air temperature from stations placed in bays and estuaries along the Texas coast. TCOON provides this critical data to many users, including those in the commercial shipping industry, marine construction, legal water-land boundaries, recreational boaters, and those responsible for marine safety and emergency evacuation in the event of a hurricane. Data sets are available in near real time via the Internet at CBI's web site, via social networking sites such as Facebook and Twitter and some data sets are accessible via voice over the telephone. All data collected since 1991 is available online along with data search tools. TCOON sponsors and developers believe that the more users and uses the system supports, the more valuable the data becomes. The highest scientific standards are used in data collection as these data often end up in litigation in the courts. Database software and the online tools used for data downloads are also open source.

8030-23, Session 5

Applications of high frequency radar for emergency response in the coastal ocean: utilization of the Central Gulf of Mexico Ocean Observing System during the Deepwater Horizon oil spill and vessel tracking

S. Howden, The Univ. of Southern Mississippi (United States); D. Barrick, H. Aguilar, CODAR Ocean Sensors (United States)

Along much of the U.S. coast, surface currents are being measured in real-time using High Frequency Radar (HFR). Where coverage is adequate, these currents are being utilized in emergency response efforts in tasks such as producing trajectory forecasts for spills of hazardous substances and for search and rescue operations. Although the HFR coverage in the Gulf of Mexico is sparse, the Deepwater Horizon (DwH) oil spill occurred just south of the coverage area of the Central Gulf of Mexico Ocean Observing System (CenGOOS), which operates three long-range CODAR SeaSonde HFRs. NOAA was able to take advantage of the national integration of HFR data, sponsored by NOAA under the Integrated Ocean Observing System, to seamlessly utilize the CenGOOS data in producing the trajectory forecasts for the DwH oil spill event. The value of these surface current data to the emergency response effort will be demonstrated and the importance of extending the HFR coverage in the Gulf will be discussed.

In addition to surface-current maps, the SeaSondes see vessels within their coverage area. At lower HF, this enables beyond-the-horizon, all-weather detection and tracking, overcoming the line-of-sight limitations of conventional microwave radars and VHF AIS ship/shore transponder systems. Programs to develop this dual-use capability have been underway since 2001, funded by DoD and DHS. Offline capability to detect and track vessels has been successfully demonstrated, and examples will be shown. Efforts are underway to upgrade this to a real-time capability. This will be ready for demonstration on coastal SeaSonde systems in early 2011

8030-43, Session 5

Making sense of ocean sensing: the Gulf of Mexico Coastal Ocean Observing System links observations to applications

C. Simoniello, Gulf of Mexico Coastal Ocean Observing System Regional Association (United States) and Univ. of South Florida (United States); A. E. Jochens, M. K. Howard, Texas A&M Univ. (United States); J. Swaykos, The Univ. of Southern Mississippi (United States); D. R. Levin, National Oceanic and Atmospheric Administration (United States); D. Stone, The Florida Aquarium, Inc. (United States); B. Kirkpatrick, Mote Marine Lab. and Aquarium (United States)

The Gulf of Mexico Coastal Ocean Observing System Regional Association (GCOOS-RA) is one of eleven regional partners of the U.S. Integrated Ocean Observing System that work to enhance our ability to collect, deliver and use ocean information through the development of sustained, routine, regional observing systems. The GCOOS-RA Education and Outreach Council works to bring together industry, governments, academia, formal and informal educators, and the public to assess regional needs for coastal ocean information, foster cooperation, and increase the utility of the information. Whether targeting a specific subset of the population (e.g., public health officials) or the community at large, the ultimate goal is to link observations to applications for the direct benefit of human enlightenment.

Knowledge transfer requires two-way communication; clientele need to be aware of observational capabilities, and regional associations must understand and manage client expectations if useful products are to be developed. If done effectively, the observing system generates

Return to Contents

tools that enhance public safety through increased ocean and climate literacy and promote community-level economic stability (e.g., avoiding unnecessary evacuations or beach closures). Examples of data products in various stages of development will be presented. These include novel visualizations of storm surge, public exhibits focused on water quality data, a Harmful Algal Bloom warning system, and a description of the Basic Observational Buoy project designed to engage citizen scientists in Deepwater Horizon Oil Spill monitoring efforts.

8030-44, Session 5

Building interoperable data systems in the Gulf of Mexico: a case study

M. K. Howard, Texas A&M Univ. (United States)

Data collection in oceanography is undergoing a paradigm shift. We are moving from month-long shipboard campaigns and mooring deployments with annual data recoveries to persistent adaptive presences using networked distributed and sometimes autonomous sensor systems returning data in near real-time. Real-time data have value delayed-mode data does not (e.g., oil spills). The challenge is automating conversion and integration of sensor data to an analysis-ready state. The Integrated Ocean Observing System (IOOS) data management group identified the core elements (data discovery, access, transport, etc.) required to build interoperable systems. In practice, these require standards adoption in vocabularies, data models, and web services. The Gulf of Mexico Coastal Ocean Observation System (GCOOS) began as a regional collaboration of eleven non-federal sub-regional observatories whose data systems evolved independently and were not interoperable. Grants allow us to deploy a service oriented architecture consisting of OPeNDAP transports and standards-based Open Geospatial Consortium Sensor Observation Service web interfaces with Observation and Measurement encodings in each of the observatories. We constructed and deployed a common vocabulary based on the NetCDF Climate and Forecast Metadata Conventions and standard names. The observatories host XML files listing their active sensors which are compiled into catalogs of available assets. Our regional data portal aggregates data from the observatories and constructs data products for stakeholder groups. These capabilities were available during and following the Deepwater Horizon oil spill. Interoperability made the data and products readily available to the incident command centers in hours instead of months.

8030-45, Session 5

Developing technologies for regional ocean observing systems

J. R. van Smirren, R. I. Smith, Gulf of Mexico Coastal Ocean Observing System Regional Association (United States); X. Guan, Fugro GEOS, Inc. (United States)

The Gulf of Mexico Coastal Ocean Observing System Regional Association(GCOOS-RA) takes a continuing and proactive role in in-situ monitoring and characterization of the marine environment. This includes the use of near real-time data in the description and prediction of conditions in the Gulf of Mexico (GOM) for multiple user groups. In many ways the GOM is also the epitome of what can be considered a “battle space environment”. Its complex and extreme meteorological and oceanic conditions make it an ideal test bed for characterization of such technologies. Many candidate technologies have been tested and used on an ongoing basis for the support of the offshore oil and gas, fisheries, and other industries in the region. In addition, considerable research on the GOM has been undertaken by academic, industrial and government groups. The recent Gulf Of Mexico Oil Spill brought to bear intense monitoring and the introduction of innovative technologies to monitor the environment. However, many methods remain untried.

This paper identifies some of the more useful techniques that have been adopted in understanding the Gulf. We also identify approaches, as yet untried, that could provide vital data for operational support and the provision of data for initialization, assimilation, and verification of ocean forecast models.

Conference 8031: Micro- and Nanotechnology Sensors, Systems, and Applications III

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8031-01, Session 1

Tip-based manofabrication (TBN): an approach to true nanotechnology

K. Bloschock, A. R. Schofield, System Planning Corp. (United States); T. Kenny, Stanford Univ. (United States)

In order to unlock the true potential of nanotechnology, the development of controlled nanomanufacturing techniques for individual structures is critical. While the capability to grow, deposit, and manipulate nanostructures currently exists, the ability to reliably fabricate these devices with controlled differences in size, shape, and orientation at various substrate positions does not exist. This capability is essential to the emergence of a true technology, and significant effort will be necessary to reach this goal. To bridge this gap, the Defense Advanced Research Projects Agency (DARPA) launched the Tip-Based Nanofabrication (TBN) research program with the intent of achieving controlled nanomanufacturing of nanowires, nanotubes and quantum dots using functionalized AFM cantilevers and tips. This program has been active for almost 3 years, and is beginning to produce compelling demonstrations of technological pathways to real manufactured nanodevices. This paper describes the background, goals, and current approaches being explored during the multi-year TBN program.

8031-02, Session 1

Direct-write scanning probe lithography: toward a desktop fab

L. R. Giam, C. A. Mirkin, Northwestern Univ. (United States)

Recently, massively parallel scanning-probe based methods have been used to address the challenges of nanometer to millimetre scale printing for a variety of materials and mark a step towards the realization of a “desktop fab.” Such a tool enables simple, flexible, high-throughput, and low-cost nano- and microscale patterning, which allows researchers to rapidly synthesize and study systems ranging from nanoparticle synthesis to biological processes at the cell surface. We have developed a new scanning probe-based printing method called polymer pen lithography (PPL), which uses arrays of elastomeric tips to transfer materials (e.g. alkanethiols, proteins, polymers) in a direct-write manner onto a variety of surfaces. Unlike conventional hard silicon tip arrays, one can control the patterned feature dimensions by applying different amounts of force to the polymer pens and thereby access the nano- and microscale easily and rapidly over large areas. We have studied this force dependency in detail, and this work led us to realize that one could align these transparent polymer pens within near-field distance of a surface to generate sub-diffraction limit features. Specifically, Beam Pen Lithography (BPL) utilizes the same two-dimensional PPL arrays coated with an opaque metal layer, except at each nanoscale tip, to channel light to an underlying substrate for conducting a combined scanning probe and photolithography experiment. In summary, the science and development of simple, robust lithographic techniques such as PPL and BPL will lead to promising new directions for researchers who wish to systematically generate surfaces addressing scientific questions in chemistry, biology, and materials science.

8031-03, Session 1

Tip-based patterning of graphite and CVD graphene

B. Hicks, N. Yoshimizu, Cornell Univ. (United States); C. O’ Connell, Univ. of Rhode Island (United States); A. K. Lal, C. R. Pollock, Cornell Univ. (United States)

Nanometer-scale patterning of graphite and graphene has been accomplished through local anodic oxidation using an SPM tip. The graphite etching is caused by aqueous electrochemical oxidation. Oxidation occurs by applying a positive sample bias while the SPM tip is in contact with the graphite surface. With the humidity above 15%, a layer of water adsorbed on the graphite surface can form a meniscus between the tip and surface. Removal of carbon atoms occurs through oxidation caused by applying a bias across the water meniscus. To date, protrusions, holes, trenches, and even words have been patterned on scales ranging from 1 nm2 to 1 mm2 and depths ranging from sub nm to as deep as 200 nm with less than 5nm variation on feature size and placement. An array of 105 trenches with two different lengths was fabricated in HOPG. The array was 3.2 µm across and 2.2 µm down. The two lengths present in the array had an average value of 136 nm for the short lines and 183 nm for the long lines with a variation of 4.4% and 2.7% respectively. This same method has also been applied to CVD-grown graphene providing a resist-free process for patterning graphene at the single nanometer scale. This capability could provide a method to rival e-beam lithography resolution but without any pre- or post-processing.

8031-04, Session 1

Nanofabrication using heated probe tips

J. R. Felts, P. C. Fletcher, S. Somnath, J. Pikul, Z. Dai, Univ. of Illinois at Urbana-Champaign (United States); W. K. Lee, P. E. Sheehan, U.S. Naval Research Lab. (United States); W. P. King, Univ. of Illinois at Urbana-Champaign (United States)

We present progress towards scalable, high precision nanofabrication in a variety of materials using heated Atomic Force Microscope (AFM) probes. Temperature control of a heated AFM tip allows nanometer scale thermo-chemical patterning, deposition of thermoplastic polymers, and surface melting. The challenges that must be overcome to scale such a technology to industrial-scale manufacturing include tip wear, thermal and mechanical control of the cantilever, chemical reaction control at the tip-surface interface, and fabrication throughput. We report several advances that address these issues. To mitigate tip wear, we have integrated nanocrystalline diamond films onto our heated AFM probe tip. Such diamond tips are extremely resistant to wear and fouling at a self-heating temperature of 400 C and load force of 200 nN over long distances. To improve cantilever temperature control, a closed loop feedback control was designed to allow for 0.2 C precision temperature control during nanolithography. To control the amount of polymer on a cantilever tip, we use electrohydrodynamic jetting to directly apply polyethylene onto a heated probe tip. Finally, to address throughput, we have fabricated cantilever arrays having independent temperature control and integrated them into a commercial AFM system. We show these advances by patterning thousands of nanostructures of polyethylene and poly(3-dodecylthiophene), with cumulative length more than 2 mm and patterning accuracy better than 50 nm.

8031-05, Session 1

Laser-assisted nanoprocessing and growth of semiconductor nanostructures

C. P. Grigoropoulos, D. J. Hwang, S. Ryu, E. Kim, J. Yoo, B. Xiang, O. D. Dubon, A. M. Minor, Univ. of California, Berkeley

(United States)

Recent research results will be presented. Lasers of different pulse durations and wavelengths have been coupled to near-field-scanning optical microscopes (NSOMs) through apertured bent cantilever fiber probes as well as with atomic force microscope (AFM) tips in apertureless configurations. Experiments have been conducted on the surface modification of metals and semiconductor materials. By combining nanoscale ablative material removal with subsequent chemical etching steps, ablation nanolithography and patterning of fused silica and crystalline silicon wafers has been demonstrated. Confinement of laser-induced crystallization to nanometric scales has also been shown. In-situ observation of the nanoscale materials modification was conducted by coupling the NSOM tips with transmission electron microscope (TEM) instrument. Nucleation and growth of semiconductor materials has been achieved by Laser Chemical Vapor Deposition (LCVD) at the nanoscale level. Locally selective growth of crystalline silicon nanowires with controlled size heterogeneity and nanometric placement accuracy has been accomplished. Results on the fabrication of binary system semiconductor nanowires will be presented. Optical properties of the grown nanowires have been examined by far-field and near-field laser induced fluorescence spectroscopy.

8031-06, Session 2

Semiconductor nanomembranes: a platform for new science and technology

M. G. Lagally, Univ. of Wisconsin-Madison (United States)

Semiconductor nanomembranes, extremely thin (<10 to ~1000 nm) single-crystal sheets, promise considerable new science and technology. They are flexible, they are readily transferable to other hosts and conform and bond easily, they are stackable, and they can take on a large range of shapes (tubes, spirals, ribbons, wires) via appropriate strain engineering and patterning. The ready ability to stack membranes allows the integration of the properties of different materials and/or orientations. This talk will introduce nanomembrane fabrication and provide a vision for applications in advanced sensors, electronics, optoelectronics, photonics, and thermoelectrics.

8031-07, Session 2

Development of carbon nanotube-based sensors

M. Meyyappan, NASA Ames Research Ctr. (United States)

The talk will address the development of a carbon nanofiber based nanoelectrode array for biosensing using DNA, enzyme and aptamer probes.This talk will also focus on our work on carbon nanotube based chemical sensors for gas and vapor detection. We have constructed an electronic nose using an array of such sensors. Sensing results and integration efforts in both cases will be presented. The author acknowledges Jessica Koehne, Jing Li and Yijiang Lu for their contributions to NASA Ames Sensor Technology development.

8031-08, Session 2

Pillar-structured thermal neutron detectors: performance expectations and fabrication challenges

R. J. Nikolic, A. M. Conway, R. Radev, Q. Shao, L. F. Voss, T. Wang, Lawrence Livermore National Lab. (United States); B. C. L. Cheung, Univ. of Nebraska-Lincoln (United States); L. Fabris, C. L. Britton, Jr., M. N. Ericson, Oak Ridge National Lab. (United States)

Solid state thermal neutron detectors are desired to replace the current 3He tube based technology for the detection of special nuclear materials. 3He tubes have some issues with stability, sensitivity to microphonics and very recently a shortage in 3He. There are numerous solid state approaches being investigated which utilize various architectures and material combinations; these will be reviewed. Our approach is based on the combination of high aspect ratio silicon PIN pillars which are 2 µm wide with a 2 µm separation, arranged in a square matrix, and are surrounded by 10B, the neutron converter material. To date, our highest efficiency is ~ 20 % which is similar to the maximum efficiency of other work in the field. An efficiency of greater than 50 % is predicted for our device while maintain high gamma rejection, low power operation and fast timing for multiplicity counting for our technology once adequate device scaling is carried out. Estimated required pillar height to meet these goals is ~ 50 µm. The fabrication techniques used to scale the pillar detector to 50 µm in height for a 25:1 aspect ratio while being batch compatible have been developed using high density plasma etching. The fabrication challenges related to etching high aspect ratio structures, quenching leakage current in large surface area devices and conformal coating of 10B on high aspect ratio structures will be discussed. Once the pillar height is adequately scaled and integrated with VLSI read-out electronics a compact system level solution is feasible.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, LLNL-ABS-461254. This work was supported by the Domestic Nuclear Detection Office in the Department of Homeland Security.

8031-09, Session 3

The role of THz and submillimeter wave technology in DHS

T. P. Coty, U.S. Dept. of Homeland Security (United States); A. Tedeschi, Strategic Analysis, Inc. (United States)

THz and submillimeter wave technology is of great interest to DHS S&T due to the non-ionizing and clothing penetrating properties of the spectral region. This region allows for standoff imaging of concealed threats such as Improvised Explosive Devices (IED) at operationally relevant distances. DHS S&T is investigating this area with the development of components such as detectors and sources for active imaging as well as full sensor systems in the future. The fundamental characterization of the region is also being explored with DHS funding by imaging well-characterized rough surface scattering targets. Analysis of these images will yield data to be used in evaluating assumptions currently made by performance models. This along with the relevant field applications will be addressed.

8031-10, Session 3

High-performance heterostructure backward diode detectors

P. J. Fay, Z. Zhang, Univ. of Notre Dame (United States)

The combination of atmospheric propagation windows and notches, in concert with the rich spectral signatures of many materials in the millimeter-wave through THz region of the electromagnetic spectrum, make sensing and imaging in this spectral range of particular interest in security, defense, and medical spheres. For sensing and imaging systems, high-sensitivity and low-noise detectors are key components; micro- and nano-scale devices are especially promising for detectors since small device scales naturally lead to lower device capacitances (and thus increased operational frequency) while the exploitation of quantum mechanical tunneling at the nanoscale offers significant potential for improving intrinsic detector performance. In this talk, recent developments in InAs/AlSb/GaSb heterostructure backward diodes for millimeter-wave through THz detection and imaging will be presented. These devices can provide curvature (defined as (d^2I/dV^2)/(dI/dV)) that exceeds the fundamental limits for thermionic devices such as Schottky diodes; we have observed room-temperature curvatures exceeding 47 A/W, while Schottky diodes are limited to 38.5 A/W. Since detector sensitivity is proportional to curvature, these increases in curvature translate directly to improved sensitivity; unmatched sensitivities of 4600 V/W at 94 GHz have been measured. These devices also offer extremely low noise performance; we have measured NEP values below 0.2 pW/Hz^1/2 at 94 GHz. These devices have demonstrated record sensitivity performance, and can be integrated monolithically with antennas for focal plane array applications.

One challenging issue in the design of optimized interband tunneling-based devices such as these is the difficulty in accurately simulating and modeling the devices. We have developed a numerical model based on self-consistent solution of the Poisson/Schrodinger equations coupled with 8-band k-p band structure and transfer-matrix calculations that agrees well with experimental device results and enables projection of performance for novel structures. This simulation framework has revealed promising avenues for device performance improvement (in terms of frequency of operation and sensitivity); the prospects for further improvement in device performance and the limits of the technology will be addressed.

8031-11, Session 3

A micro-fabricated sheet-beam Orotron THz source

S. J. Papadakis, J. A. Hoffmann, A. H. Monica, D. M. Deglau, R. Osiander, The Johns Hopkins Univ. Applied Physics Lab. (United States); J. Yu, T. M. Antonsen, Jr., G. S. Nusinovich, The Univ. of Maryland (United States)

There are applications where active imaging and spectroscopic analyses in the high-GHz to low-THz frequency range yield threat vs. non-threat discrimination. In this range, few sources of radiation are available. For higher frequencies, quantum cascade laser development has begun to address the need; for lower frequencies, conventional RF devices can generate the required radiation. We describe the construction of a discretely frequency-tunable orotron designed to generate radiation from 500 GHz to a few THz. The orotron is in the same class of devices as traveling wave tubes and klystrons, and therefore has their inherent efficiency, but it has a geometry suited to fabrication using lithographic techniques. It uses a rectangular cavity with a Smith-Purcell grating along one wall. The components of the device are fabricated using photolithography, LIGA, deep reactive ion etching, and computer-aided machining. The design allows centimeter-scale components to self-align with micron-scale precision. The electron gun is a carbon nanotube field-emission device that is 1.5 cm square with a total thickness of 1.6 mm. It generates a ~3 keV sheet-beam 6 mm wide and only 5 microns thick. The gun is aligned with the Smith-Purcell grating such that the beam passes within 15 microns of the top of the grating over the 2-cm length of the grating. Beam confinement is straightforward due to the compact nature of the orotron, allowing a simple 2-pole magnet to be used. Device size excluding the magnet is roughly 6 cm x 3 cm x 2 cm.

8031-12, Session 3

MEMS-based uncooled THz detectors for staring imagers

A. Cox, Honeywell ACS Labs. (United States); R. E. Higashi, F. Nusseibeh, C. Zins, Honeywell Solid State Electronics Ctr. (United States)

We review our previous work to develop an uncooled THz detector capable of achieving an NE∆T ~0.5K at 30Hz frame rate. Both predicted and measured results of performance metrics (responsivity, NEP, response time, spectral bandwidth) are presented. The measured performance agrees reasonably well with predictions and is consistent with attaining our NE∆T goal. Thus far, 1x4 detector arrays have fabricated, and 1x8 focal plane arrays have been developed and tested. We briefly discuss our vision to achieve a128x128 detector array needed for a practical staring THz imager and describe the technology challenges needed to realize it.

8031-13, Session 3

Integrated chip-scale THz technology

M. C. Wanke, Sandia National Labs. (United States); M. Lee, The Univ. of Texas at Dallas (United States); C. D. Nordquist, M. J. Cich, A. M. Rowen, J. R. Gillen, Sandia National Labs. (United States); C. L. Arrington, A. D. Grine, LMATA Govt. Services (United States); C. T. Fuller, J. L. Reno, Sandia National Labs. (United States)

The quantum cascade laser (QCL) is currently the only solid-state source of coherent THz radiation capable of delivering more than 1 mW of average power at frequencies above ~ 2 THz. This power level combined with very good intrinsic frequency definition characteristics make QCLs an extremely appealing solid-state solution as compact sources for THz applications. I will present results on integrating QCLs with passive rectangular waveguides for guiding and controlling the radiation emitted by the QCLs and the perfomance of a THz integrated circuit combining a THz QCL with a Schottky diode mixer to form a heterodyne receiver/transciever.

8031-14, Session 4

Programmatic perspectives with technical examples for THz materials characterization

W. R. Buchwald, Air Force Research Lab. (United States)

THz technology has a rich history of use in the field of interstellar molecule identification where a variety of molecule specific vibrational and rotational spectroscopic signatures exist and has been aggressively investigated for use in advanced radar applications because of the immediate improvement in object resolution obtained at higher frequencies. Traditionally, high power THz systems have relied upon millimeter wave sources and frequency multiplication techniques to achieve acceptable output power levels, and lower power, table top spectroscopic systems, have relied on broadband incoherent light sources. With the advent of high power lasers, advances in non-linear optics, and new material systems, a number of promising techniques for the generation, detection and manipulation of THz radiation are currently under development and are considered the enabling technologies behind a variety of advanced THz applications.

This work presents a programmatic overview of current trends in THz technology of interest to a variety of government organizations. It focuses on those techniques currently under investigation for the generation and detection of THz fields motivated, for example, by such diverse applications as metamaterial spectroscopy, TH imaging, long standoff chem/bio detection and THz communications. Examples of these new techniques will be presented which in turn will motivate the need for the characterization of application specific active and passive THz components. The goal of this work is to foster interactions between experts and bring together ideas with the hopes of advancing the state-of-the-art of THz technology.

8031-15, Session 4

THz characterization of hydrated and anhydrous materials

A. U. Sokolnikov, Visual Solutions and Applications (United States)

The characterization of anhydrous and hydrated forms of materials is of great importance to science and industry. Water content poses

difficulties for successful identification of the material structure by THz radiation. However, biological tissues and hydrated forms of nonorganic substances still may be investigated by THz radiation. This paper outlines the range of possibilities of the above characterization, as well as provides analysis of the physical mechanism that allows or prevents penetration of THz waves. THz-TDS is used to measure the absorption coefficient for materials depending on the direction (mostly for crystals). The directional dependence is calculated by the methods based on Network Theory. The discovered dependencies allow designing techniques for material identification/characterization (e.g. drugs, explosives that may have water content). The results are provided.

8031-16, Session 4

THz heterodyne sensing with AlInN/GaN hot-electron microbolometers using quantum cascade lasers

V. V. Mitin, R. Ramaswamy, K. Wang, Univ. at Buffalo (United States); A. V. Muraviev, Univ. at Buffalo (United States) and Rensselaer Polytechnic Institute (United States); G. Strasser, A. G. Markelz, Univ. at Buffalo (United States); M. S. Shur, Rensselaer Polytechnic Institute (United States); R. Gaska, Sensor Electronic Technology, Inc. (United States); A. V. Sergeev, Univ. at Buffalo (United States)

We present our results on design, fabrication, and characterization of hot-electron bolometers based on low-mobility two-dimensional electron gas (2DEG) in AlInN/GaN heterostructures. Electrical and optical characterization shows that these microbolometers combine (i) high coupling to incident THz radiation due to Drude absorption, (ii) significant electron heating by the THz radiation due to small value of electron heat capacity, (iii) substantial sensitivity of the device resistance to the heating effect, (iv) fast operating time (determined by cooling time of hot electrons). A low contact resistance (below 0.2 Ωmm) achieved in our devices ensures that the THz voltage primarily drops across the active region. Due to small electron momentum relaxation time in our devices, the resistive part of their impedances dominates over the inductive part, so these detectors can be combined with standard antennas or waveguides. In the capacity of the THz local oscillator (LO) for heterodyne THz sensing, we fabricated AlGaAs/GaAs QCLs with a stable continuous-wave single-mode operation in the range 2.5-3 THz with milliwatt output power level. It has been demonstrated that the spectral purity of the QCL emission line doesn't exceed used spectrometer resolution limit at the level of 0.1 1/cm (3 GHz). Discrete tuning can be achieved using selective devices; fine tuning can be done by thermally changing the refractive index of the material and by applied voltage. The compatibility of the low-mobility 2DEG microbolometers with QCLs in terms of LO power requirements, spectral coverage, and cooling requirements makes this technology especially attractive for THz heterodyne sensing.

8031-17, Session 4

Ultra-fast metal-insulator transition in vanadium oxide thin films

S. Ramanathan, Harvard School of Engineering and Applied Sciences (United States)

The metal-insulator transition in vanadium oxide is of exceptional interest in variety of infra-red and THz applications. Central to realization of the spectacular changes in functional properties in the vicinity of the metal-insulator transition is the synthesis and compositional control. In this presentation, I will discuss experimental approaches to synthesize high-quality VO2 thin films on a variety of substrates and how to control the phase transition properties. Examples will be given on select properties such as THz spectroscopy, infra-red reflectance changes and exercising control over the phase transition temperature in the absence of an external stress.

8031-18, Session 4

Silicon and nitride FETs for THz sensing

M. S. Shur, Rensselaer Polytechnic Institute (United States)

Mainstream device technology is now reaching dimensions that are smaller than the electron mean free path. For example, INTEL announced plans for 15 nm feature size technology, whereas the mean free path in silicon at room temperature is on the order of 30 to 40 nm. New physics of ballistic transport in such short channel devices enables their applications for THz electronics systems. Two materials systems are of special interest - silicon because of mainstream CMOS technology and nitride semiconductors because of their extremely high current carrying capability and high breakdown voltages. Ultra-short channel silicon and AlN/GaN/InN-based transistors have demonstrated THz operation. Silicon CMOS achieved both THz sensing and amplification. Nitride-based FETs demonstrated THz detection and emission, even THz emission at room temperature. In both materials systems, the THz sensing mechanism is linked to the excitations of the electron density in the device channels. When the mobility is high enough, these excitations are plasma waves with the device channel serving as a resonance cavity. When the mobility is low, the nonlinearities of the electron transport properties still lead to the rectification of the excitations of the electron density caused by the impinging THz radiation. These two regimes correspond to a resonant and a non-resonant detection, respectively. In either case, using grating gate structures or FET arrays considerably enhances the THz detection by dramatically improving coupling of the THz radiation to the device. This presentation will review the state-of-the-art of Si and nitride THz semiconductor sensing, will discuss their potential performance and will address problems to be solved to fully realize the potential of this emerging technology.

8031-19, Session 4

Terahertz active metamaterials and lasers

B. S. Williams, A. A. Tavallaee, P. Hon, T. Itoh, Univ. of California, Los Angeles (United States); Q. Chen, Northrop Grumman Aerospace Systems (United States)

The terahertz frequency range is well suited for exploration of active metamaterials and devices, where metamaterial with unique electromagnetic characteristics can be integrated with semiconductor quantum-cascade gain media. In this way, the intrinsic losses of metamaterials can be compensated via stimulated emission, and novel active devices and lasers can be obtained. In particular, we consider the feasibility of active 1D and 2D planar THz metamaterials based on the composite right/left-handed (CRLH) transmission-line metamaterial design scheme, which can be naturally implemented using the metallic waveguide technology used for terahertz quantum-cascade lasers. As a model device, we propose a so-called zero-index QC-laser, which is designed to oscillate in a mode with a zero-phase index, and should exhibit a uniform mode in the longitudinal direction. We also propose novel active metamaterial waveguide and leaky-wave antenna concepts for efficient coupling to radiative modes. The use of these concepts for the design of cavities can to address several outstanding problems in the practical implementation of THz quantum-cascade lasers as sources - efficient optical outcoupling, beam-shaping, and tunability. We present theoretical analysis, and our latest experimental progress in achieving such active terahertz quantum-cascade metamaterial lasers and antennas. These devices will provide new functionality for terahertz sources, enabling applications in terahertz sensing and spectroscopy.

8031-20, Session 5

Technology for Navy and Marine Corps EO/IR sensors and sensor systems

M. Duncan, Office of Naval Research (United States)

Small unmanned aerial systems are becoming increasingly important for the Navy and Marine Corps. This has driven the need for lighter, smaller, and more highly capable sensor payloads. I will describe current and future programs at the Office of Naval Research that are focused on developing these payloads. I will also describe programs that are devoted to developing the technology for the next generation of EO/IR sensors and sensor optics.

8031-21, Session 5

MEMs adaptive optics at the Naval Research Laboratory

S. R. Restaino, J. R. Andrews, T. Martinez, C. C. Wilcox, F. Santiago, D. M. Payne, U.S. Naval Research Lab. (United States)

Our program for the upgrade of the Naval Prototype Optical Interferometer with large telescopes and adaptive optics has produced a test-bed for the in system evaluation and testing of our MEMs adaptive optics components and system performances. We have already reported in recent publications the basic characteristics of the test-bed. In order to improve the capabilities of such laboratory set-up we have started an upgrade that aims at developing a Multi Conjugate Adaptive Optics (MCA) test-bed. This test bed is based on the use of multiple Liquid Crystal Spatial Light Modulators (LCSLMs) for producing different phase screens at different spatial locations within the set-up. Details of this new set-up are presented in another paper in these proceedings. This paper specifically deals with the analytic portion of the MCAO test-bed.

8031-22, Session 5

Actuation for deformable thin-shelled composite mirrors

C. C. Wilcox, U.S. Naval Research Lab. (United States); D. V. Wick, B. E. Bagwell, Sandia National Labs. (United States); R. C. Romeo, R. N. Martin, Composite Mirror Applications, Inc. (United States); M. S. Baker, N. L. Breivik, B. L. Boyce, Sandia National Labs. (United States); T. Martinez, S. R. Restaino, U.S. Naval Research Lab. (United States)

Thin-shelled composite mirrors have been recently proposed as both deformable mirrors for aberration correction and as variable radius-of-curvature mirrors for adaptive optical zoom. The requirements on actuation far surpass those for other MEMS or micro-machined deformable mirrors. We will discuss recent progress on developing the actuation for these mirrors, as well as potential applications.

8031-23, Session 5

Micro ion frequency standard

P. D. Schwindt, Y. Jau, H. Partner, R. H. Olsson III, K. Wojciechowski, D. K. Serkland, L. Fang, A. Casias, R. P. Manginell, M. Moorman, Sandia National Labs. (United States)

We are developing a highly miniaturized trapped ion clock to probe the 12.6 GHz hyperfine transition in the 171Yb+ ion. The clock development is being funded by the Integrated Micro Primary Atomic Clock Technology (IMPACT) program from DARPA where the stated goals are to develop a clock that consumes 50 mW of power, has a size of 5 cm3, and has a long-term frequency stability of 10-14 at one month. One of the significant challenges will be to develop miniature single-frequency lasers at 369 nm and 935 nm and the optical systems to deliver light to the ions and to collect ion fluorescence on a detector.

8031-24, Session 5

Imaging a linearly or circularly polarized scene: micro-components and shrimp

S. A. Kemme, D. A. Scrymgeour, A. A. Cruz-Cabrera, A. R. Ellis, R. R. Boye, J. R. Wendt, T. R. Carter, S. Samora, Sandia National Labs. (United States)

Polarimetric imaging captures the polarization state of light from all the points of a scene. Polarization information can help classify materials and identify objects of interest for remote sensing and military applications. Traditionally, sequential polarimetric imaging sensors produce scenes with polarization information through a series of subtracted images. Snapshot polarimetric imaging collects the Stokes' parameters spatial distribution simultaneously. In this way any noise due to scene movement between frames is eliminated. Along with the advantage of simultaneous capture of the polarimetric image with one shot, comes the challenge associated with fabricating and interpreting data produced by micro-components within the imaging array.

We will discuss the state-of-the-art achievements and some fundamental diffraction limitations in polarimetric imaging with a pixelated array of micro-components. We will also look at a natural system with many of the same sensing abilities, the stomatopod crustacean (mantis shrimp), which has evolved an exquisite vision system, possessing a tunable, eight-channel color vision system (Marshall, Nature, 1988; Cronin et al, Nature, 1989), a complex linear polarization vision (Marshall et al, Curr. Biol., 1999; Marshall et al, Trans. B-Biol., Sci., 1991), and a recently discovered circular polarization vision (Chiou et al, Curr. Biol., 2008; Kleinlogel et al, PLoS One, 2008). This comprehensive polarization vision may enable imaging/communicating advantages in the underwater environment (Chang, et al, Appl. Opt., 2003; Kartazayeva et al, Opt. Ltts., 2005; Row et al, Opt. Ltts., 1995) as well as more general turbid environments such as smoke and fog.

8031-25, Session 6

Trends in nanophotonics

G. S. Pomrenke, Air Force Office of Scientific Research (United States)

Over the last decade we have seen remarkable progress, perhaps even a revolution, in nanophotonics. By good fortune this progress has been in parallel with significant national and international investments in nanotechnology, such as through the NNI (www.nano.gov) since 2001; each has benefited from the other. Lead agencies in the US government for investments in this area have been the DoD and NSF; however, industry and small business efforts have played an important role in advancing the technology.

Nanophotonics has the potential for new capabilities in information, computing and communications technologies; medical diagnostics and disease treatment; enhanced solar cells and energy harvesting; lighting; sensing, and many other applications. Besides electromagnetic detectors there is a demand for highly selective, highly sensitive smart sensor systems capable of detecting multiple species; a trend recently highlighted by the NNI and its associated agencies.

Nanophotonics continues to be an area of new discoveries utilizing nanoscale structures and phenomena to couple, transduce, or compress light at the nanoscale. It has been significantly impacted by research and investments in such areas as high-index-contrast Si and III-V nanostructures; quantum dots and wires; nano-particles in glasses, semiconductors, and polymers; plasmonics; metamaterials; silicon photonics; polymers in Si and III-V nanostructures; nanomembranes and flexible electronics; and a recent push toward the integration of photonics with electronics. Sponsored work has resulted in tunable interleaver-based optical mux/demuxes on silicon with a 40X reduction in volume and power of <1.0W for three interleavers including control circuitry; demonstration of a photonic crystal waveguide Mach-Zehnder modulator with an interaction length of 80 micrometer, power consumption below 2mW, and 30X smaller in size than conventional approaches; improved efficiency of organic solar cells through special carbon nanomaterials; novel pixellated polarimeters through nanoimprinting; and multispectral detectors exploiting resonant plasmonic cavities.

The next decade promises further advances with the further integration of photonics and electronics, devices with dramatic reductions in energy of operation, imagers with enhanced spatial resolution, sensors with increased sensitivity and specificity, and new energy harvesting solutions.

8031-26, Session 6

Nanomembranes for optofluidic and autonomous systems

O. G. Schmidt, Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden (Germany)

Nanomembranes are thin and flexible. They can be made out of practically any material and formed into almost arbitrary geometry. We shape nanomembranes into micro-and nanotubes by careful strain engineering and create an entirely new platform to realise ultra-compact optofluidic components and autonomous self-propelled systems. The optical microtube resonators have high Q-factors and provide cylindrical, high perfection channels for fluid transport at the same time. If made catalytically active the tubes act as world smallest microjet engines, which can be remotely controlled by magnetic fields, transport heavy loads of cargo and move at high velocities.

8031-27, Session 6

Integrated microsystems for molecular pathology

A. Scherer, California Institute of Technology (United States)

Lithographically defined electronic, fluidic, and optical systems can be integrated to create diagnostic microdevices. Compact and efficient immuno-assay chips, cell analysis chips and pathogen identification systems have evolved. In the near future, we can expect similar success from lithographically integrated opto-fluidic, optomechanical, magnetooptical and magneto-fluidic systems. We have developed qPCR amplification techniques that can be used for rapid diagnosis of viruses and other pathogens, demonstrated amplification of 10 microliter clinical samples within 90 seconds, and optimized single-cell analysis chips in which the RNA libraries of up to 30 individual cells can be analyzed and compared. We also use microfluidic systems for human blood serum analysis. We also integrate microfluidics with nanophotonics for spectroscopy systems to determine concentrations of gases and ions in solution, and develop “smart dust” platforms for powering and data communications within dimensions approaching individual cell sizes. To reduce the overall size of diagnostic systems, we introduce electro-chemical dissociation to generate pressure and shape memory alloy micro-valves and micro-pumps to replace expensive pneumatic control circuitry. We have developed silicon nanowire transistors for sensitive chemical nano-transistors, and the improvement of microfluidic control and the maturity of nano-devices for spectroscopic applications now enable us to define new classes of miniaturized chemical and biological sensors.

8031-28, Session 7

Efficient light-trapping nanostructures in thin silicon solar cells

S. E. Han, A. Mavrokefalos, M. Branham, C. G. Chen, Massachusetts Institute of Technology (United States)

The cost of crystalline silicon solar cells is expected to reduce significantly when the silicon layer thickness can be decreased by more than an order of magnitude. However, in this case light absorption becomes poor and efficient techniques are needed to enhance absorption. Ideally, the maximum absorption, known as the Lambertian limit, can be obtained with isotropically-scattering rough surfaces. This is the thermodynamic limit for isotropic incident radiation in the geometric optics regime. To realize this limit, current solar cells based on thick crystalline silicon wafers use surface structures of ~10 microns. However, it has not been possible to realize structures that approach this limit when the film thickness is only a few microns. In this talk, we explore how the Lambertian limit can be obtained in thin structures. First, we discuss general principles that yield efficient light-trapping surface structures. Our progress in fabrication of such structures is also discussed. Second, we use group theory to improve such structures. Our results show that systematic symmetry breaking lead to surface structures that achieve an absorptance higher than the Lambertian limit over a broad band at normal incidence. Further, we demonstrate that the absorptance of nanorod arrays closely follows the Lambertian limit for isotropic incident radiation. Our results show that crystalline silicon nanostructures with a thickness in the range of 1-3 microns can have absorptance comparable to 100-300 micron thick silicon wafers and point to the promising future of thin crystalline silicon solar cells. Experimental progress guided by modeling will be presented.

8031-29, Session 7

Magnetically responsive photonic nanostructures: making color with magnets

Y. Yin, Univ. of California, Riverside (United States)

This presentation will be focused on our recent work on magnetically tunable photonic nanostructures. Superparamagnetic iron oxide colloidal particles are synthesized by using a high temperature hydrolysis reaction, and then self-assembled into ordered photonic crystal structures in solution phase using external magnetic fields. The colloids form chain-like structures with regular interparticle spacing of a few hundred nanometers along the direction of the external field so that the system strongly diffracts visible light. The balance between attraction (magnetic dipole interaction) and repulsion (electrostatic force) dictates interparticle spacing and therefore optical properties. By changing the relative strength of these two forces, we can tune the peak diffraction wavelength over the entire visible spectrum. By controlling the surface properties of the magnetic particles so that the repulsive forces involved, we have been able to assemble the photonic structures in water, alcohols, and nonpolar solvents. The fast, reversible response and the feasibility for miniaturization impart these photonic materials great potential in applications such as optoelectronic devices, sensors, and color displays. In this presentation, I will also discuss some applications of this responsive photonic system, such as security and sensing devices, high resolution patterning of multiple structural colors.

8031-30, Session 8

Functionalized DNA materials for sensing and medical applications

D. L. Woolard, U.S. Army Research Office (United States); J. O. Jensen, U.S. Army Edgewood Chemical Biological Ctr. (United States)

The U.S. Army has strong interests in developing capabilities for the engineering of specialized nanoscale architectures that allow for the enhanced extraction and controllable multiplication of the THz/IR regime spectral signatures associated with specific bio-molecular targets. This presentation will describe a joint U.S. Army Research Office (ARO) and U.S. Army Edgewood Chemical Biological Center (ECBC) program that is supported by the U.S. Defense Threat Reduction Agency (DTRA) for the purposes of defining DNA-based nano-assemblies (i.e., either materials or structural devices) that realize novel sensing paradigms through the incorporation of organic and/or biological molecules such that they effect highly predictable and controllable changes into the electro-optical properties of the resulting superstructures. This goal of defining a new class of functionalized DNA materials is being addressed by the three thrust efforts: (i) artificial antibodies for biological sensing based upon DNA origami; (2) molecular-level platforms for electrical and spectral characterization of bio-molecules; and, (3) nanofluidic sensor platforms for spectroscopic fingerprinting of bio-molecules. This presentation will overview these three thrusts and illustrate how they are collectively working towards the development of THz/IR-sensitive material systems and associated devices with measurable macroscopic THz/IR electro-optical properties that reveal the underlying states and vibration dynamics of bio-molecular targets of interest. Here, the ability to capture, incorporate and interrogate the geometrical and dynamical properties of target bio-molecules has important ramifications for threat-agent sensing, and has broad implications for the future study and development of artificial antibodies and vaccines. Results from this ongoing program will be given to illustrate the utility of functionalized DNA materials in sensing as well as how the basic science is to be leveraged to address medical applications.

8031-31, Session 8

Photonic meta materials, nanoscale plasmonics, and super lens

X. Zhang, Univ. of California, Berkeley (United States)

Surface plasmons (SPPs) represent a great opportunity in nanoscale science and application among many emerging technologies. Because SPPs produce strong enhancement and confinement of the electromagnetic near-field in their vicinity, numerous research fields have been focused on utilizing SPPs for variety of applications, including the fields of surface chemistry, physics, biology and nanoscale engineering. The use of SPPs opens up potential applications in nanoscale optical spectroscopy, surface-enhanced spectroscopy, surface plasmon resonance sensing, and nanolithography.

In invited talk, we will report our recent progress in the field of micro- and nano-technologies focused SPPs applications and other related fields, including meta-materials, nano-scale imaging, high throughput nano-lithography, photonics, bio-molecule sensing, and etc. Our work can potentially facilitate the next generation micro- and nano-technologies including the development for defense, security, biomedical, and space applications in the future, and promise a new route towards the next generation nano-manufacturing.

8031-32, Session 8

Manufacturing coatings of micro- and nanoparticles by controlled evaporation of drops and thin films

D. Attinger, Columbia Univ. (United States)

The engineered deposition of self-assembled colloidal crystal coatings on solid surfaces has applications in photonic crystals, optoelectronic devices, sensors, waveguides and antireflective coatings. Besides lithographic, etching or vapor deposition methods, 2-D crystals of colloidal micro- or nano-particles can be self-assembled by the controlled evaporation of a solvent, in a process called convective deposition. Convective deposition is a multiscale, multiphysics process involving transient fluid dynamics, heat and mass transfer in the deforming geometry of a drop or a meniscus. This talk first describes the competing mechanisms controlling the formation of micro- and nano-particle deposits during the drying of nanoliter drops containing colloidal particles. The system studied involves aqueous drops containing Titania nanoparticles evaporating on a glass substrate. Our results show that the pH of the solution influences the dried deposit patterns, which can be ring-like or more uniform. The transition between these patterns is explained by considering how DLVO interactions such as the electrostatic and van der Waals forces modify the particle deposition process. Deposits created using non-polar solvents are also presented and discussed. Then, a multiphysics modeling of a convective deposition process where a blade pulls an evaporating film along a flat substrate is presented, and compared with experiments featuring self-assembled colloidal crystals. Finally, an outlook is given on the technical challenges and opportunities related to the use of convective deposition techniques in electronic manufacturing processes.

8031-33, Session 8

Graphene optoelectronics based on antidot superlattices

E. Yang, S. Strauf, Stevens Institute of Technology (United States)

Graphene is well known for its outstanding electronic, thermal, and mechanical properties and has recently also gained tremendous interest as a nanomaterial for optoelectronic devices. In this talk we will review some of our recent work on large-area CVD grown graphene transferred onto flexible substrates, which gives rise to photocurrent generation, with the ultimate goal to create strain-tunable graphene nanoribbon arrays for continuously-tunable IR detectors. We also show that Raman spectroscopy can not only be used for layer metrology but also to monitor and even manipulate the composition of graphenes zigzag/armchair edges. Finally, we demonstrate that antidot superlattices etched into graphene create an effective p-type doping as well as a lateral built-in electric field of up to 260 mV, which effectively dissociates electron-hole pairs from attached dye molecules, providing novel possibilities for light harvesting applications such as dye-sensitized photodetectors and solar cells.

8031-34, Session 9

Results from MAST joint experiment 3.1

J. G. Rogers III, Georgia Institute of Technology (United States) and Univ. of Pennsylvania (United States); A. Cunningham, M. Paluri, H. I. Christensen, Georgia Institute of Technology (United States); N. Michael, V. Kumar, Univ. of Pennsylvania (United States); L. H. Matthies, J. Ma, Jet Propulsion Lab. (United States); F. Dellaert, Georgia Institute of Technology (United States)

This paper will describe the results of a Joint Experiment performed on behalf of the MAST CTA. The system developed for the Joint Experiment makes use of three robots which work together to explore and map an unknown environment. Each of the robots used in this experiment is equipped with a laser scanner for measuring walls and a camera for locating doorways. Information from both of these types of structures is concurrently incorporated into each robot's local map using a graph based SLAM technique.

The Distributed-Data-Fusion algorithm is used to efficiently combine robot's local map into a shared global map. Each robot computes a compressed local feature map and transmits it to neighboring robots, which allows each robot to merge its map with the maps of its neighbors. Each robot caches the compressed maps from its neighbors, allowing it to maintain a coherent map with a common frame of reference.

The robots utilize an exploration strategy to efficiently cover the unknown environment which allows collaboration on an unreliable communications channel. As each new branching point is discovered by a robot, it broadcasts the information about where this point is along with the robot's path from a known landmark to the other robots. When the next robot reaches a dead-end, new branching points are allocated by auction. In the event of communication interruption, the robot which observed the branching point will eventually explore it; therefore, the exploration is complete in the face of communication failure.

8031-35, Session 9

Autonomous navigation with teams of aerial robots

N. Michael, Univ. of Pennsylvania (United States)

There are many examples in nature where large groups of individuals are able to maintain three-dimensional formations while navigating in complex environments. This paper addresses the development of a framework and robot controllers that enable a group of aerial robots to maintain a formation with partial state information while avoiding collisions. The central concept is to develop a low-dimensional abstraction of the large teams of robots, facilitate planning, command, and control in a low-dimensional space, and to realize commands or plans in the abstract space by synthesizing controllers for individual robots that respect the specified abstraction.

The fundamental problem that is addressed in this paper relates to coordinated control of multiple UAVs in close proximity. We develop a representation for a team of robots based on the first and second statistical moments of the system and design kinematic, exponentially stabilizing controllers for point robots. The selection of representation permits a controller design that is invariant to the number of robots in the system, requires limited global state information, and reduces the complexity of the planning problem by generating an abstract planning and control space determined by the moment parameterization. We present experimental results with a team of quadrotors and discuss considerations such as aerodynamic interactions between robots.

8031-36, Session 9

Vision-aided landing and ingress of a micro-air-vehicle using a monocular camera

R. Brockers, Jet Propulsion Lab. (United States); P. Bouffard, Univ. of California, Berkeley (United States); J. Ma, L. H. Matthies, Jet Propulsion Lab. (United States); C. Tomlin, Univ. of California, Berkeley (United States)

Micro air vehicles for urban reconnaissance missions will be greatly enhanced by capabilities for autonomous landing for persistent stare and for autonomous ingress into buildings. We describe the design of vision and control capabilities for these functions. To achieve initial capability, we assume the landing site is a planar surface above a planar background (e.g. flat roof seen against flat ground) and that the ingress point is a rectangular opening in a planar surface (e.g. door or window in a flat wall). To provide these capabilities with a compact sensor suite, we use monocular visual feature tracking and multi-planar homography to find the planar surfaces. Our algorithms are implemented on a quadrotor UAV in our lab, where aircraft position and velocity are determined by a Vicon motion capture system. Feature points on the landing pad are triangulated and centroided to generate a 3-D waypoint for the control system to target for landing. Windows or doors are detected by finding pairs of parallel line segments in the plane of a perceived wall, with feature points seen between the line segments at distances beyond the wall. Real-time performance is achieved with these algorithms running in an embedded Pentium processor on the aircraft. We show live demonstration results from experiments in our lab.

8031-37, Session 9

Estimation of vehicle velocity and proximity via wide-field integration of optic flow

J. S. Humbert, S. Gerardi, A. Hyslop, Univ. of Maryland, College Park (United States)

Wide-Field Integration (WFI) of optic flow, a method for information extraction modeled on the spatial decompositions of specialized inter-neurons in the insect visuomotor system, can provide useful information about the proximity and relative speed of a vehicle with respect to objects in the environment. In this paper, it is shown how weighted summations of optic flow measurements can be used as static estimators of vehicle proximity and velocity. A two step approach is presented for the selection of weighting patterns that accounts for uncertainty in the environment as well as noise in the measurements, and employs LQR to produce feedback gains. Stability is proven via local asymptotic analysis and the quadrotor MAV is simulated in an urban-like environment.
WFI has potential for implementation using analog VLSI, making it an attractive option for small, payload-constrained aerial platforms.

8031-38, Session 9

Compact beam scanning 240GHz radar for navigation and collision avoidance

K. Sarabandi, M. Vahidpour, M. Moallem, J. R. East, Univ. of Michigan (United States)

Autonomous small robotic platforms require a suite of sensor to navigate and function in complex environment. Due to limited space, onboard power, and processing capability these sensors must be low mass, compact in size, low power, and run with minimal processing requirement. Whereas optical camera and stereo vision can significantly assist in navigation and obstacle detection, their operation is severely hampered in the dark and in poor atmospheric conditions (dust, smoke, haze, rain). We are developing a compact and low-power imaging mm-wave radar system operating at Y-band to allow navigation and obstacle detection in conditions that make the use of passive optical sensors difficult or impossible. The radar system is being fabricated and assembled using silicon micromaching technique with the overall mass of 5 grams, peak power of 200 mW, and operational power of 6.7 mW for one frame per second update rate, filed of view of 50 degrees , angular resolution of 2 degrees, range resolution of 30cm, and range of 400m. The beam steering is accomplished by frequency scanning and the range resolution is obtained from the standard FMCW technique utilizing a chirped signal waveform with step discontinuities. This paper will present the overall architecture of this radar system in addition to the phenomenological investigation of scattering from obstacle in indoor environment. It is also shown how radar images taken from indoor scenes can be interpreted and utilized to create the interior layout of a building as the radar platform navigates through the corridors.

8031-39, Session 10

New techniques for efficient flexible wireless transceivers in nanometer CMOS

M. Flynn, Univ. of Michigan (United States)

Nanometer CMOS processes have proven to be surprisingly effective for analog and RF design. New design techniques have greatly improved the efficiency of ADCs and RF interfaces and also enabled new flexibility. Moving to techniques that are more digital in nature allows fast and easy changes in architecture and performance. Furthermore, from the standpoint of energy efficiency there can be fundamental advantages to processing signals in the digital domain. This paper discusses digital dominant nanometer CMOS transmitter and receiver schemes that are the basis of flexible efficient wireless transceivers for the MAST platforms. A mostly digital fractional-N PLL modulator scheme can be adapted to different constant-envelope modulation schemes. As an example 2.4GHz OQPSK and GSMK signal have been demonstrated with one prototype device. A multi-mode receiver architecture, which exploits a filtering-ADC, can adapt to wireless signals over a frequency range spanning from 500MHz to 3.5GHz. A prototype receiver has been demonstrated with 900MHz and 2.4GHz 802.15.4 communication and also tested with WiFi signals. This receiver, implemented in 65nm CMOS occupies a die area of only 0.4mm2 and consumes as little as 5mW. New ADC architectures exploit the speed of scaled CMOS processes. For example a 12b 50MS/s hybrid-successive approximation pipeline ADC consumes only 3.5mW and achieves a FOM of 52fJ/conv.step.

8031-40, Session 10

Reconfigurable firmware-defined radios synthesized from standard digital logic cells

D. D. Wentzloff, M. Faisal, Y. Park, Univ. of Michigan (United States)

Radio frequency (RF) front-end circuits designed today for operation in the 1GHz to 10GHz range are almost exclusively fabricated in CMOS processes for reduced cost. This includes LNAs, mixers, oscillators, ... all the components that enable radios to communicate wirelessly. Traditional design of these RF components relies on precise RF models, high-quality passives, and time-consuming custom layout. CMOS logic has become so fast, it is now realistic to implement full-swing logic from standard cell libraries that switch at >10GHz speeds. Logic has become so small, it is also realistic to fit 1000's of gates in the same area occupied by one RF inductor. In this paper, we describe RF circuits and architectures to realize the same functionality of phase- and frequency-discriminating RF front-ends, but do so using only logic gates as the core building blocks. Results from an ultra-wideband transmitter and time-to-digital converter implemented in 65nm CMOS will be shown that were synthesized from only digital logic gates. By implementing these all-digital architectures in a reprogrammable sea-of-gates on a single integrated circuit, a reconfigurable, firmware-defined RF front-end can be achieved. Also in this paper, a firmware-defined demodulator for FM radio is described that has been implemented in a field programmable gate array (FPGA) without requiring an analog-to-digital converter. All analog receiver circuits have been implemented using only logic gates, and synthesized on the FPGA. When combined with a frequency-selective RF front-end, this radio can demodulate FM radio signals using a fraction of the number of gates compared to software-defined radios using digital signal processing.

8031-41, Session 10

Radio signal strength tracking and control for robotic networks

B. M. Sadler, P. Yu, J. Twigg, U.S. Army Research Lab. (United States)

Radio signal strength (RSS) is a reasonable proxy for link quality, but its accurate estimation requires frequency and spatial diversity due to fluctuation caused by fading. We consider a Rayleigh/Rician fading model, and gather RSS measurements during motion in a complex environment to enable gradient estimation. Using the RSS gradient, we develop control laws to track active sources. These may be used to establish and preserve connectivity among collaborative autonomous agents, to locate and approach radio sources, as well as deploying agents to assist mobile ad hoc networks (MANETs).

8031-42, Session 10

Enhanced ad hoc wireless connectivity in complex environment using small radio repeater systems

K. Sarabandi, Y. Song, J. Oh, Univ. of Michigan (United States)

Ad hoc communication among small robotic platforms in complex indoor environment is further challenged by three limiting factors: 1) limited power, 2) small size antennas, and 3) near-ground operation. In complex environments such as indoor scenarios often times the line-of-sight communication cannot be established and the wireless connectivity must rely on multi-path propagation. As a result, the propagation path-loss is much higher than free-space, and more power will be needed to obtain the need coverage. Near ground operation also leads to increased path-loss. To maintain the network connectivity without increasing the required power a novel high gain miniaturized radio repeater is presented. Unlike existing repeater systems, this system utilizes two closely spaced low profile miniaturized planar antennas capable of producing omnidirectional and vertical radiation patterns as well as a channel isolator layer that serves to decouple the adjacent antennas. The meta-material based channel isolator serves as an electromagnetic shield, thus enabling it to be built in a sub-wavelength size of 0.001 cubic wavelength, the smallest repeater ever built. Also wave propagation simulations and measurements have been conducted to determine the required gain of such repeaters so to ensure the signal from the repeater is the dominant component. A prototype of the small radio repeater is fabricated to verify the design performance through a standard free-space measurement setup.

8031-43, Session 11

Precision navigation and timing enabled by microtechnology: are we there yet?

A. M. Shkel, Defense Advanced Research Projects Agency (United States)

It is clear that some significant advances have been made over the years in development of inertial micro-sensors and chip-scale clocks, and we see a footprint of the technology in an ever-growing consumer electronic market full of interactive products enabled by inertial and timing micro-technologies. These products include accelerometers for gaming applications, gyros for auto safety, and resonators for clocks - just to name a few. The question remains, however: Is the technology really on the level of what we consider to be precision navigation and timing? In reality, “small technology” remains several orders of magnitude short with respect to long-term stability, dynamic range, and accuracy. Why? We don't yet have a complete answer, and we are still working hard to disprove the statement that “high-performance inertial micro-instrument is a contradiction in terms.” It is indisputable that we can make things small, but we cannot make them sufficiently precise and uniform. We know we can deposit materials layer-by-layer, but we cannot make micro-devices truly 3-D, as is readily accomplished using conventional machining. We consistently have an excellent case for low-cost and bulk fabrication, but we cannot seriously challenge “boutique” processes when it comes to achieving precision, performance, and stability. We need new knowledge regarding the dimensional stability of materials. We need a better understanding of scaling, surface effects, and fabrication imperfections. PNT applications demand unusual new fabrication technologies and new materials with special properties. To achieve the required phenomenal accuracy, we need a new wave of innovation in design and refinement of many emerging electromechanical transducers. A new wave of innovation in PNT will likely rely on yet-to-be-utilized physics, highly specialized fabrication technologies and batch assembly techniques, selective wafer-level trimming and polishing, a combination of passive and active calibration techniques strategically implemented right on-chip, and introduction of innovative test technologies. This presentation will discuss the growing interest in micro-technology for PNT within the Microsystems Technology Office (MTO) of the Defense Advanced Research Projects Agency (DARPA).

8031-44, Session 11

Energy dissipation in micro-mechanical resonators

F. Ayazi, Georgia Institute of Technology (United States)

Recent years have witnessed breakthrough researches in micro and nano mechanical resonators with small dissipation. Nano-precision micromachining has enabled the realization of integrated micromechanical resonators with record high Q and high frequency, creating new research horizons. Not too long ago, there was a perception in the MEMS community that the maximum f.Q product of a microresonator is limited to a frequency-independent constant determined by the material properties of the resonator. In this paper, the contribution of phonon interactions in determining the upper limit of f.Q product in micromechanical resonators will be discussed and shown that after certain frequency, the f.Q product is no longer constant but a linear function of frequency. This makes it possible to reach very high Qs in GHz micro and nano-mechanical resonators and filters. Contribution of other loss mechanisms such as thermoelastic damping and support loss in the quality factor of a microresonator will be discussed as well.

8031-45, Session 11

The effect of surface chemistry on the quality factors of micromechanical resonators

M. A. Hines, Cornell Univ. (United States)

As researchers have continued to push the limits of detection sensitivity, the size of micromechanical resonant sensors has continually decreased. A number of researchers have noted a puzzling anticorrelation between resonator size and quality factor -- smaller resonators almost invariably have lower Q's, a trend that often offsets the expected gains in sensitivity from decreased size. We will show that energy dissipation in micromechanical silicon resonators is often dominated by the chemical state of the surface, a suprising and unexpected conclusion. By changing a single monolayer of molecules on the surface of a 250-nm-thick resonator -- less than 0.07% of the total mass -- the resonator's quality factor can be improved significantly. Interestingly, resonators terminated with a thin oxide layer, which is standard for commercial silicon devices, have particularly low Q. The chemical origins of surface-induced mechanical energy dissipation will be discussed. We will show that low quality factors are not due to dissipation within surface monolayers, but are instead correlated with the passivation properties of the monolayer. The implications of these findings on resonant sensors will be discussed.

8031-46, Session 11

Finite element modeling and simulation of thermo-elastical damping of MEMS vibrations

S. Kausinis, Kaunas Univ. of Technology (Lithuania); K. Y. Yee, Jet Propulsion Lab. (United States); R. Barauskas, Kaunas Univ. of Technology (Lithuania)

In many applications, the benefits of using micro-electromechanical (or MEM) resonator structures relate directly to the small size, the (relatively) high frequency and the spectral purity. The latter quantity is defined by high values of the mechanical quality factor, the Q-factor. The Q-factor determined by thermal-elastic damping of MEM resonators, the QTED, is a very important dynamic characteristic since it provides the upper limit of the quality factor that is possible to achieve in a structure of given geometry and material.

It appears that in-depth theoretical models and analysis tools are needed to reveal underlying different energy loss mechanisms and to determine the dominating energy dissipation processes in these structures.

The contribution is directed to both developing an in-depth understanding of the behaviour of MEM resonators involving the integration of modelling, verification and evaluation tools for maximum MEMS performance achievement, and providing accurate simulation and approximation of the QTED in complex MEM resonators.

The base model created in this work is presented as a system of partial differential equations that describe the elastic and thermal phenomena in the MEM structure. The FEM calculations were performed in COMSOL Multiphysics environment by using quarter-symmetry models.

Investigation of longitudinal and bending vibration modes in 3D of a beam resonators was accomplished by taking into account the layered structure of the resonator and the influence of the geometry of the clamping zone. Modal properties of square- and ring-shaped bulk-mode MEM resonators were examined, too.

The investigations of QTED in these structures pave the way for optimal design of MEMS.

8031-47, Session 11

Thermal energy loss mechanisms in micro- to nano-scale devices

A. E. Duwel, J. Lozow, C. Fisher, T. Phillips, Draper Lab. (United States); R. H. Olsson III, Sandia National Labs. (United States); M. S. Weinberg, Draper Lab. (United States)

In micro- and nanoscale resonators, a key metric for performance is the quality factor (Q), the ratio of stored mechanical energy to energy dissipated. In well-optimized designs, fundamental thermal physics limits Q. Specific mechanisms include thermoelastic, Akhieser, and Landau-Rumer damping. The relative importance of each effect depends on the time and length scales dominating the device. Most analyses focus on special regimes where only one mechanism dominates, though real devices may operate in regimes that are not a limiting case. This paper discusses thermal damping across the range of frequency and length scales. Data on acoustic loss is compared with theory.

8031-48, Session 11

Computational modeling of anchor loss in MEMS devices and correlations with experiments

K. C. Park, Univ. of Colorado at Boulder (United States)

A computational multiphysics model of the coupled beam-substrate-electrostatic actuation dynamics of MEMS resonators has been developed for the model-based prediction of Q-factor and design sensitivity studies. The substrate and resonator beam are modeled independently and then integrated by enforcing their interface compatibility condition and the electrostatic force equilibrium to arrive at the multiphysics model. The present model has been validated with several reported sing-beam resonators. The validated model indicates that: the anchor loss is primarily engendered through coupling between the resonant modes and the waves propagating through the substrate inner layers; the resonant frequency of the beam decreases up to 5 % due to substrate flexibilities interacting with the beam at the anchors; and, for a given design the beam mass and its relative compliance with respect to the substrate are key parameters that influence the Q-factor degradation. In addition, the coupled model has also been used to predict the Q-factor of a paired-beam mechanical filter device with high fidelity when compared with the experimentally observed Q-Factor.

8031-49, Session 12

An analysis of microsystems development at Sandia National Laboratories

G. V. Herrera, Sandia National Labs. (United States)

The talk will begin with a brief overview of Sandia National Laboratories' microsystems capabilities and the range of micro- and nano-technologies currently being developed at Sandia. This will be followed by an in-depth analysis of the evolution of Sandia's MEMS program over the last quarter century. Specifically, while the early MEMS devices were direct analogies of existing macroscale structures, present designs embody innovative approaches that directly exploit the unique microscale phenomena. The challenge in working at the micro- and nano-scale is learning to take advantage of the fundamentally different material properties to develop structures and devices that could not be designed at the macro scale.

8031-50, Session 12

MEMS performance challenges: packaging and shock tests

L. Lin, Univ. of California, Berkeley (United States)

MEMS packaging and shock test are two of the major challenges for commercialization but often neglected in the research field. In the past twenty years, the application of microelectronic technology to the fabrication of mechanical devices stimulated emerging research in semi-conductor microsensors and microactuators. However, research projects on MEMS packaging and shock tests have been generally ignored as compared with device research. This talk will introduce several MEMS packaging technologies in an effort to address the MEMS packaging issues for various applications. These include an integrated LPCVD nitride bonding process; localized eutectic, fusion and solder bonding processes; RTP (rapid thermal processing) bonding processes; nano-second laser welding process; ultrasonic sealing process; localized CVD sealing process and low-temperature solder bonding processes. Specific issues in MEMS packaging applications will also be discussed, including vacuum encapsulation, accelerated testing and long-term reliability of the encapsulated MEMS devices. Furthermore, efforts in combined MEMS package and shock resistance simulation with experimental verification will also be discussed to address the MEMS performance challenges for applications in consumer electronics.

8031-51, Session 12

Sensors for hydraulic-induced fracturing characterization

J. Mireles, Jr., Univ. Autónoma de Ciudad Juarez (Mexico); H. Estrada, Ctr. Nacional de Metrología (Mexico); R. Ambrosio, Univ. Autónoma de Ciudad Juarez (Mexico)

Hydraulic induced fracturing (HIF) in oil wells is done to increase productivity of oil by making the subterranean terrain more deep and permeable. Also, in some cases HIF connects multiple oil pockets to the main well. Currently there is a need to understand and control with a high degree of precision the geometry, direction, and the physical properties of fractures. By knowing the specifications of fractures, other drill well locations and set-ups of wells are designed to increase the probability of connection of the oil pockets to main well(s), i.e, increase productivity. The current state of the art of HIF characterization does not meet the requirements of the oil industry.

In Mexico, the SENER-CONACyT funding program recently supported a three party collaborative effort between the Mexican Petroleum Institute, Schlumberger Dowell Mexico, and the Autonomous University of Juarez to develop a sensing scheme to measure physical parameters of a HIF like, but not limited to Pressure, Temperature, Density and Viscosity. We present in this paper progress of the sensing development for down hole measurement parameters of wells for the Chicontepec region of Mexico.

The most important aspect of designing sensors for HIF characterization is the understanding of the conditions and tools used during the HIF. Also, the integration of MEMS sensors down hole for HIF characterization is not a trivial task. The presentation will be focused on the technology implemented for designing sensors for harsh environments and meeting the requirements of proper design for down hole measurement.

8031-52, Session 12

Tribology in MEMS

M. T. Dugger, Sandia National Labs. (United States)

MicroElectroMechanical Systems (MEMS) have become commercially successful in a number of niche applications. However, commercial success has only been possible where design, operating conditions, and materials result in devices that are not very sensitive to tribological effects. The use of MEMS in defense and national security applications will typically involve more challenging environments, with higher reliability and more complex functionality than required of commercial applications. This in turn will necessitate solutions to the challenges that have plagued MEMS since their inception, namely adhesion, friction and wear. Adhesion during fabrication and immediately post-release has largely been resolved using hydrophobic coatings, but these coatings are not mechanically durable, and do not inhibit surface degradation during extended operation.

In this presentation, the tribological challenges associated with MEMS will be reviewed, and some of the approaches to mitigate the effects of adhesion, friction and wear will be discussed. A new concept for self-lubrication of silicon MEMS using gas phase species will be introduced. This “vapor phase lubrication” process, or VPL, has resulting in remarkable operating life of devices whose functionality relies on mechanical contact. VPL is also an effective lubrication approach for devices that use materials other than silicon, where traditional solid or liquid lubrication approaches are not feasible. The current status of this lubrication technology and remaining challenges that must be overcome for maturation will be identified.

8031-53, Session 12

MEMS and nanostructures: challenges and opportunities

V. M. Castano, Univ. Nacional Autónoma de México (Mexico)

Will revise, from the point of view of chemistry and materials science, the main challenges that nanotechnologies pose for a MEMS experts. In particular, thermodynamical long-term behavior, as well as size-dependant properties, will be analyzed, in terms of how far off we are from direct application to devices

8031-54, Session 13

Thermoelectric energy conversion using nanostructured materials

C. G. Chen, A. Muto, D. Kramer, K. McEnaney, H. Feng, Massachusetts Institute of Technology (United States); W. S. Liu, Q. Zhang, B. Yu, Z. Ren, Boston College (United States)

Seebeck effect can be exploited to generate power when there is a temperature difference. The efficiency of thermoelectric power generation systems depends on the materials’ thermoelectric figure-of-merits, heat source temperatures, and heat transfer in and out of the devices. This paper reports recent progresses in improving materials’ figure-of-merits based on nanostructured bulk materials and discuss their potential applications. Although there are many available heat sources, the key for the application of thermoelectric generators are to create a temperature difference across thermoelectric devices. Examples will be given on current and future applications of thermoelectric generators in sensors, waste heat recovery, and renewable energy.

8031-55, Session 13

Engineering carbon nanomaterials for future applications: energy and sensor

W. Choi, Florida International Univ. (United States)

We present engineering of carbon nanomaterials for various applications: (i) A novel binder-free multi-wall carbon nanotube (MWCNT) structure as anode in Li-ion batteries. The interface-controlled MWCNT structure, synthesized through a two-step process of catalyst deposition and chemical vapor deposition (CVD) and directly grown on copper current collector, showed very high specific capacity - almost three times as that of graphite, excellent rate capability - even at a charging/discharging rate

Return to Contents

of 3C and nil capacity degradation up to 50 cycles. (ii) A large graphene film on flexible substrate. Graphene film was grown on Cu foil by thermal chemical vapor deposition and transferred to various substrates including PET, glass and silicon by using hot press lamination and etching process. The graphene/PET film shows high quality, flexible transparent conductive structure with unique electrical-mechanical properties; ~88.80 % light transmittance and ~ 100 Ω/sq sheet resistance. We demonstrate application of graphene/PET film as flexible and transparent electrode for solar cell and field emission displays. (iii) Application of individual carbon nanotube as nanoelectrode for high sensitivity electrochemical sensor and device miniaturization. An individual CNT is split into a pair of nanoelectrodes with a gap between them. Using a quasi-Ag/AgCl reference electrode, the nanoelectrodes were subject to cyclic voltammetry. An excellent electrocatalytic behavior was found: The observed detection limit was as low as 10 pM dopamine. Another scheme was for electronic detection of DNA hybridization at the single molecule level. Hybridization of the probe with its complementary strand results in an appreciable change in the electrical output signal.

8031-56, Session 13

Developments in MEMS scale printable alkaline and Li-ion technology

K. Littau, C. L. Cobb, Palo Alto Research Center, Inc. (United States)

Two technologies for MEMS scale cell formation are discussed. First, the fabrication of planar alkaline cell batteries compatible with MEMS scale power storage applications is shown. Both mm scale and sub mm scale individual cells and batteries have been constructed. The chosen coplanar electrode geometry allows for easy fabrication of series connected cells enabling higher voltage while simplifying the cell sealing and electrode formation. The Zn/Ag alkaline system is used due to the large operating voltage, inherent charge capacity, long shelf life, and ease of fabrication. Several cells have been constructed using both plated and spun-on silver. The plated cells are shown to be limited in performance due to inadequate surface area and porosity; however, the cells made from spun-on colloidal silver show reasonable charge capacity and power performance with current densities of up to 200 uA/mm2 and charge capacities of up to 18 mA-s/mm2. Three-cell series connected batteries have been fabricated capable of cell potentials up to 4.5V. Second, a new printing method for interdigitated 3-D cells is introduced. A microfluidic printhead capable of dispensing multiple materials at high resolution and aspect ratio is described and used to form features as small as 5 um in width and aspect ratios of greater than 10:1. Various structures enabled by this method are modeled electrochemically, and the energy and power density improvements are reported.

8031-57, Session 13

Further studies in the electrochemical/ mechanical strength of printed microbatteries

D. A. Steingart, The City College of New York (United States)

Flexible electronics require flexible energy storage, and electrochemical batteries are currently the strongest option for such devices. In this talk we further our previous investigation, beginning to add quantitative analysis to the composite mechanical/electrochemical performance of printed electrodes. The presented work will explain the principles of microfluidic stress analysis and how it provides insight into the operating conditions of real microbatteries. channels are formed around printed battery electrodes, allow in-situ measurement of electrode cycling behavior (color change, volume change, erosion, etc) by varying electrolyte flow rate and composition. Electrodes over silver, silver-oxide, zinc (both plated and printed) and manganese oxide will be demonstrated. Flow rate will be correlated with electrode shear strength and cell cycle life.

8031-58, Session 13

Energy and size-scalable 3D battery architecutres

J. W. Long, U.S. Naval Research Lab. (United States)

Battery architectures comprising electrochemical interfaces that are interpenetrated in three dimensions (3D) offer major gains in energy and power density as compared to conventional 2D battery designs, particularly with respect to the limitations imposed by many devices on the footprint available for the power source. We are developing 3D solid-state Li-ion batteries that are sequentially assembled from interpenetrating and tricontinuous networks of anode, cathode, and electrolyte/separator materials. Fiber-paper-supported carbon nanofoams are an ideal base platform for 3D battery architectures because of their through-connected networks of porosity with readily tunable pore sizes (nanometers to micrometers), a conductive carbon framework, and scalability in area (to hundreds of square centimeters) and thickness (70 to 300 m). To functionalize carbon nanofoams we use simple, scalable electroless deposition methods to incorporate conformal nanoscale (~10 nm) coatings of either manganese or iron oxides that ultimately serve as one of the two active electrodes in a 3D Li-ion battery configuration. In the next fabrication step, the metal oxide-coated nanofoam electrode must be passivated with a film that is ultrathin, conformal, pinhole-free, electronically insulating, and Li-ion conductive, which we achieve via the self-limiting electrodeposition of phenol-based polymer coatings. Self-wired RuO2 nanoparticle networks, deposited via solution-based reactions using RuO4 as precursor, can then serve as the opposing charge-storage electrode when incorporated into the remaining void volume of the polymer-coated metal oxide-carbon nanoarchitecture. At each step en route to the ultimate 3D battery architecture, we characterize the individual components using electron microscopy, X-ray photoelectron spectroscopy, electroanalytical methods, and impedance spectroscopy.

8031-59, Session 13

Ultrathin, microscale epitaxial compound semiconductor solar cells

J. A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Compound semiconductors like gallium arsenide provide advantages over silicon for photovolatics, due to strong absorption and high energy conversion efficiencies. Difficulties in growing large, high quality wafers of these materials, and in intimately integrating them on substrates such as glass or plastic restrict their use. Here we describe the use of functional films in multilayer epitaxial assemblies formed in a single deposition sequence on a growth wafer. Release and separation of the individual active layers yields large quantities of high quality material for subsequent device integration in large area formats, in a manner that also allows the wafer to be reused for additional growths. Demonstrations in photovoltaic modules on sheets of plastic, illustrate some capabilities.

8031-60, Session 13

Little Robeep: miniature power sources for autonomous systems

S. Ramanathan, Harvard School of Engineering and Applied Sciences (United States)

We will discuss our recent progress in fabricating micro-solid oxide fuel cells devices and stacks for autonomous systems. Approaches to fabricate large area power skins will be presented. A detailed study on the structure-composition-electrochemical property relations in oxide fuel cell materials will be discussed along with novel experimental techniques being developed to understand rate limiting processes. The role of stresses in affecting fuel cell membrane morphology and their evolution with temperature will be discussed.

8031-61, Session 13

Self-powered nanosystems: nanogenerators, piezotronics, and piezo-phototronics

Z. L. Wang, Georgia Institute of Technology (United States)

Developing wireless nanodevices and nanosystems is of critical importance for sensing, medical science, environmental/infrastructure monitoring, defense technology and even personal electronics. It is highly desirable for wireless devices to be self-powered without using battery. This is a new initiative in today's energy research for mico/nano-systems in searching for sustainable self-sufficient power sources [1]. It is essential to explore innovative nanotechnologies for converting mechanical energy, vibration energy, and hydraulic energy into electric energy that will be used to power nanodevices. We have invented an innovative approach for converting nano-scale mechanical energy into electric energy by piezoelectric zinc oxide nanowire arrays [2]. The operation mechanism of the nanogenerator relies on the piezoelectric potential created by an external strain; a dynamic straining of the nanowire results in a transient flow of the electrons in the external load due to the driving force of the piezopotential. We have developed the nanogenerator from fundamental science, to engineering integration and to technological scale-up [3-6]. As today, a gentle straining can output 1-3 V from an integrated nanogenerator [6], using which a self-powered nanosensor has been demonstrated [6]. A commercial LED has been lid up [7]. This is a key step for developing a totally nanowire-based nanosystem [6]. Alternatively, by substituting the gate voltage in a field effect transistor (FET) with the piezopotential creating by an external strain, we have fabricated a series of devices that rely on a coupling between semiconductor and piezoelectric properties and are controlled/tuned by externally applied force/pressure, such as diode, strain sensor and strain-gated logic unites, which are a new field called piezotronics [8]. A three way coupling among piezoelectricity, semiconductor and photonic excitation has demonstrated the piezo-phototronic effect [9].

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8031-62, Session 13

Nanotechnology enabled flexible energy harvesting

M. C. McAlpine, Princeton Univ. (United States)

The development of a method for integrating highly efficient energy conversion materials onto stretchable, biocompatible rubbers could yield breakthroughs in implantable or wearable energy harvesting systems. Piezoelectric crystals represent particularly interesting smart materials which function as energy converters. Here, we present a scalable and parallel process for transferring piezoelectric nanoribbons (NR) of PZT from host substrates onto flexible rubbers over macroscopic areas. The nanoribbons are fabricated via the recently developed PENCiL approach, which allows for location-determinant PZT NR arrays hierarchically patterned over wafer scales. Fundamental characterization of the ribbons by piezo-force microscopy (PFM) indicates that their electromechanical energy conversion metrics are among the highest reported on a flexible medium. Finally, integration into energy harvesting devices reveals the ability to harvest energy from common body movements such as finger tapping.

8031-63, Session 14

Cancer nanotechnology: new pipeline for diagnostics, imaging agents, and therapies

K. Ptak, NCI Ctr. for Strategic Scientific Initiatives (United States)

Nanotechnology is a 'disruptive technology', which can lead to a generation of new diagnostic and therapeutic products, resulting in dramatically improved cancer outcomes. The National Cancer Institute (NCI) of National Institutes of Health explores innovative approaches to multidisciplinary research allowing for a convergence of molecular biology, oncology, physics, chemistry, and engineering and leading to the development of clinically worthy technological approaches. These initiatives include programmatic efforts to enable nanotechnology as a driver of advances in clinical oncology and cancer research, known collectively as the NCI Alliance for Nanotechnology in Cancer (ANC). Over the last 5 years, ANC has demonstrated that multidisciplinary approach catalyzes scientific developments and advances clinical translation in cancer nanotechnology. The research conducted by ANC members has improved diagnostic assays and imaging agents, leading to the development of point-of-care diagnostics, identification and validation of numerous biomarkers for novel diagnostic assays, and the development of multifunctional agents for imaging and therapy. Numerous nanotechnology-based technologies developed by ANC researchers are entering clinical trials. NCI has re-issued ANC program for next 5 years signaling that it continues to have high expectations for cancer nanotechnology's impact on clinical practice. The goals of the next phase will be to broaden access to cancer nanotechnology research through greater clinical translation and outreach to the patient and clinical communities and to support development of entirely new models of cancer care.

8031-64, Session 14

Nanomaterial strategies for immunodetection

M. D. Porter, The Univ. of Utah (United States)

The explosion of innovations across biotechnology underscores the importance of ultra sensitive, high-speed diagnostic tests. This presentation will describe efforts to develop a readout methodology that potentially addresses these needs by coupling gold nanoparticle (i.e., spheres and rods) labeling concepts with surface enhanced Raman scattering (SERS) or superparamagnetic nanoparticle labeling concepts with giant magnetoresistors (GMRs). Strategies will be detailed for both the fabrication and readout of chip-scale platforms by examining fundamental dictates for optimal performance. Results from experiments

Return to Contents

that focus on the use of immunoassays for the ultralow level detection of viral and microbial pathogens, along with challenges central to analytical sensitivity, speed, nonspecific adsorption, and fluidics manipulation, will be discussed.

8031-65, Session 14

Nanoparticle-targeted therapy against childhood acute lymphoblastic leukemia

N. Satake, UC Davis Medical Ctr. (United States); J. S. Lee, K. Xiao, J. Luo, S. Sarangi, UC Davis Cancer Ctr. (United States); A. Chang, B. McLaughlin, P. Zhou, E. Kenny, L. Kraynov, S. Arnott, J. McGee, J. Nolta, UC Davis Medical Ctr. (United States); K. S. Lam, UC Davis Cancer Ctr. (United States)

The goal of our project is to develop a unique ligand-conjugated nanoparticle (NP) therapy against childhood acute lymphoblastic leukemia (ALL). LLP2A, discovered by my mentor, Dr. Kit Lam, is a high-affinity and high-specificity peptidomimetic ligand against an activated $\alpha4\beta1$ integrin. Our previous study using 11 fresh primary ALL samples (10 precursor B ALL and 1 T ALL) showed that childhood ALL cells expressed activated $\alpha4\beta1$ integrin and bound to LLP2A. Normal hematopoietic cells such as activated lymphocytes and monocytes expressed activated $\alpha4\beta1$ integrin; however, normal hematopoietic stem cells showed low expression of $\alpha4\beta1$ integrin. Therefore, we believe that LLP2A can be used as a targeted therapy for childhood ALL. The Lam lab has developed novel telodendrimer based nanoparticles (NPs) which can carry drugs efficiently. We have also developed a human leukemia mouse model using immunodeficient NOD/SCID/IL2R null mice engrafted with primary childhood ALL cells from our patients. LLP2A-conjugated NPs will be evaluated both in vitro and in vivo using primary leukemia cells and this mouse model. NPs will be loaded first with DiD near infra-red dye, and then with the chemotherapeutic agents daunorubicin or vincristine. Both drugs are mainstays of current chemotherapy for childhood ALL. Targeting properties of LLP2A-conjugated NPs will be evaluated by fluorescent microscopy, flow cytometry, MTS assay, and mouse survival after treatment. We expect that LLP2A-conjugated NPs will be preferentially delivered and endocytosed to leukemia cells as an effective targeted therapy.

8031-66, Session 14

Microfluidic and nanofluidic systems for the detection and quantification of biomolecules

P. N. Nge, M. Yu, W. Yang, J. Xuan, M. N. Hamblin, A. R. Hawkins, M. L. Lee, A. T. Woolley, Brigham Young Univ. (United States)

Micromachined fluidic networks offer novel capabilities in chemical analysis. We have been developing broadly applicable polymer microfluidic system fabrication techniques and forming affinity columns in microdevices to purify target analytes from complex samples for microchip electrophoresis separation. We have utilized our integrated microchips in the quantitation of multiple cancer biomarkers in human serum at low ng/mL levels. We have also demonstrated on-chip integration of analyte preconcentration with separation, as well as sample labeling with parallel analysis. These microfluidic systems are facilitating the rapid quantitation of clinically relevant biomarkers in a miniaturized and automated platform. In addition, we are exploring the fabrication of nanofluidic capillary arrays and their application in the size-selective fractionation of nanoparticles and biomolecules. Devices are constructed using a thin-film micromachining protocol, enabling nanocapillaries to be formed with a critical dimension as small as ~10 nm. We are exploring capillary action and other flow methods for loading analytes into these nanocapillaries, and have demonstrated the size-selective trapping of nanoparticles and viruses in these systems. Our nanofluidic arrays offer considerable potential to provide novel methods for separating nanoscale materials and biomolecules.

8031-67, Session 14

Quantum dots and microfluidic single molecule detection for screening genetic and epigenetic cancer markers in clinical samples

T. Wang, The Johns Hopkins Univ. (United States)

Genomic analysis of biomarkers, including genetic markers such as point mutations and epigenetic markers such as DNA methylation, has become a central theme in modern disease diagnosis and prognosis. Recently there is an increasing interest in using single-molecule detection (SMD) for genomic detection. The driving force not only comes from its ultrahigh sensitivity that can allow the detection of low-abundance nucleic acids with reduced or without the need of amplification but also from its potential in achieving high-accuracy quantification of rare targets via single-molecule sorting. The unique photophysical properties of semiconductor quantum dots (QDs) have made them ideal for use as spectral labels and luminescent probes. QDs also make excellent donors to pair with organic dyes in the fluorescence resonance energy transfer (FRET) process due to the features of narrow emission spectra and small Stokes shift. This enables FRET with minimal direct acceptor excitation and donor-acceptor crosstalk, thereby permitting the design of FRET molecular sensors with extremely low intrinsic fluorescence backgrounds necessary for detecting biomolecular targets at low abundance. We have developed highly sensitive, quantitative and clinically relevant technologies for analysis of genomic markers based on the convergence of SMD, microfluidic manipulations, and quantum dot fluorescence resonance energy transfer technology (QD-FRET). Extraordinary performances of these new technologies have been exemplified by analysis of a variety of biomarkers including point mutations, DNA integrity and DNA methylation in clinical samples.

8031-68, Session 15

Growth of carbon-based nanostructures

W. C. Mitchel, J. J. Boeckl, Air Force Research Lab. (United States)

Carbon nanostructures such as carbon nanotubes (CNTs) and graphene are being applied to a wide variety of sensor applications. Both CNTs and graphene can be grown from hydrocarbons using metal catalysts. CNTs can be grown on a variety of substrates after deposition of the appropriate catalyst while graphene requires continuous metallic films for CVD growth and the graphene must be transferred, usually by chemical etching of the metal, to appropriate substrates. CNTs can be grown without metallic catalysts by decomposition of SiC in vacuum. This process yields a dense carpet of vertically aligned CNTs. By varying the ambient and pressure, graphene can also be grown on SiC. Graphene grows at both ultra high vacuum and in atmospheric pressure Argon while CNTs form at intermediate vacuum pressures. The role of residual oxygen in the formation of CNTs will be discussed. In addition, it has recently been shown that graphene can be deposited directly on SiC as well as other substrates by direct deposition of carbon without catalysts. Carbon source molecular beam epitaxy of graphene has been demonstrated using heated graphite filaments and thermally evaporated C60. Both sources give graphene films with strong Raman G and 2D bands. Different carbon sources result in different structural and electrical properties. Graphite filaments result in p-type material while C60 sources result in n-type graphene.

8031-69, Session 15

Micro- and nano-electronic technologies and their qualification methodology for harsh environment applications

Y. Chen, NASA Langley Research Ctr. (United States); M. Mojarradi, E. Kolawa, Jet Propulsion Lab. (United States)

This paper gives an overview of the micro- and nano-electronic technologies, including the technology reliability and limitations, for space applications under harsh environments, i.e. for operation temperatures beyond the range of -55°C to 125°C, and with radiation exposure.

The paper also addresses the challenges and the qualification approaches for the harsh environment applications with a case study. The case study highlights the design-for-reliability approach developed and used to successfully design, fabricate, qualify, and infuse a microelectronic device into a flight mission, which requires an operational temperature of -128°C to +85°C.

8031-70, Session 15

Electronics for harsh environments in space exploration: now and beyond

J. U. Patel, Jet Propulsion Lab. (United States)

A brief overview of harsh space environments encountered during current space mission will be presented. A detailed discussion on the presence of various forms of space radiation and their effects of a spectrum of electronic components and systems will be described. Additionally, effects of extreme temperatures in space and their effects in conjunction with the radiation will be discussed. An account of the performance of conventional silicon electronics in space missions will be presented. A projection on the future electronics needs for more ambitious exploration frontiers, with added environmental and operational parameters reflecting longevity and reliability will be discussed. A future roadmap of materials, devices and circuit solutions will be presented to meet the challenges of future space explorations.

8031-71, Session 15

Chemical vapor sensing with carbon

F. K. Perkins, U.S. Naval Research Lab. (United States)

Chemical vapor sensors are used to identify and monitor ambient levels of various volatile organic compounds. The best sensor system is simultaneously cheap, fast, sensitive, and accurate. Pristine carbon nanotubes and graphene are almost the ideal transducer materials for such systems. However, as grown, these materials have little to no specificity. Indeed, there are very few substances to which these materials do not provide an easily measureable physical response. Efforts to provide specificity by incorporation of certain functional groups or polymer layers have been somewhat successful, usually by narrowly enhancing response to one class of analyte at the expense of response to everything else. A better means of meeting requirements would combine the nano-phase carbon transducer with a MEMS-based pre-concentrator and gas chromatograph technology. Such a system can be made almost arbitrarily robust: the carbon transducers are very nearly chemically inert, the selection of surface linings or functionalities in the first two stages can take into account application and environmental issues, and all of the components are widely scalable. The performance, utility, and manufacturability of such as system as this will be discussed.

8031-72, Session 15

Graphene field-effect transistors for label-free chemical and biological sensors

Y. Ohno, K. Maehashi, K. Matsumoto, The Institute of Scientific and Industrial Research (Japan)

Electrical biomolecule detection has been expected for biochips used at home for medical diagnosis. Carbon nanotubes are promising candidates for chemical and biological sensors due to their unique structural and electrical characteristics. Graphene, planar sheet of sp2-bonded carbon atoms densely packed in a honeycomb crystal lattice, is also an attractive material for sensors. Several investigations have been conducted on the use of graphene for chemical and biological sensors. In this paper, we report label-free immunosensors based on aptamer-modified graphene field-effect transistors (G-FETs). They electrically detected only target immunoglobulins.

Monolayer graphene flakes were obtained by micro-mechanical exfoliation using kish graphite with adhesive tape. The G-FETs were fabricated on a 280-nm-thick thermally grown SiO2 layer on degenerately doped p-Si substrates. After confirming the number of the graphene layer by Raman spectroscopy, gold source and drain electrodes were formed on the monolayer graphene by conventional e-beam lithography and lift-off method. Anti-immunoglobulin E (IgE) aptamer was used as a receptor in this work. Aptamers are artificial oligonucleotides and are produced in vitro. From the atomic force microscope images, approximately 3 nm thick IgE-aptamer-functionalized channels were observed. And the drain current increased after functionalization due to the negatively charged IgE aptamers, indicating the IgE aptamers were successfully functionalized. The aptamer modified G-FETs detected the only IgE molecules. These results show that modified G-FETs is promising for the specific biological sensing.

8031-73, Session 15

Graphene transistors: from rad-hard electronics to radiation detection

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 transistor devices with various structures. Our studies have yielded important results for the radiation-harness of graphene electronics, as well as novel graphene-based devices for detecting ionizing radiations.

8031-85, Poster Session

On chip MWCNT-PDMS micro-temperature sensors for MEMS/MST

A. Khosla, Simon Fraser Univ. (Canada)

A micropatternable mutli-walled carbon nanotube (MWCNT) and polydimethylsiloxane (PDMS) conductive nanocomposite polymers has been fabicated via solvent assisted high frequency ultrasonics (~ 42-50 kHz) dispersion of MWCNT in PDMS matrix. The prepared nanocomposites are micromolded using soft lithography techniques down to a feature size of 5µm against a micropatterned SU-8 polymer master. these tiny microstructures can be embedded are on a nonconductive PDMS substrate using novel and improved fabrication techniques. The percolation threshold of the prepared nanocomposite is achieved at 1.34 weight percentage (wt.%) of MWCNT in the PDMS matrix. Resistivity levels at 2 wt.% of functionalized MWCNTs are 9.12 ohm-meter or better. The nanocomposites also have fairly uniform dispersion and no agglomeration of MWCNT as shown by SEM analysis. The prepared nanocomposites show a negative temperature coefficient of resistivity (NTCR), The MWCNT-PDMS nanocomposite samples were loaded onto the four probe test fixture and placed in the thermal chamber. The temperature was increased in steps of 20 degree Celcius up to a maximum temperature of 500 degree Celcius and the corresponding value of resistance was recorded at each temperature. For every 20 degree Celcius rise in temperature, a predictable trend is that there is a decrease in resistivity with an increase in temperature, thus showing a negative temperature coefficient of resistivity. Negative temperature coefficients are of interest because they can be exploited for on-chip temperature sensors for, e.g., measuring local temperature during on-chip chemical reactions for lab on a chip devices, explosive detection etc.

Return to Contents

8031-86, Poster Session

Integration of CMM software standards for nanopositioning and nanomeasuring machines

E. Sparrer, T. Machleidt, E. Manske, K. Franke, Technische Univ. Ilmenau (Germany)

Micro- and nano-fabrication suffer from similar errors as known from macroscopic fabrication processes. The implementation of a quality monitoring system is capable of reducing rejects and enables the controlling of the fabrication process. Due to their flexibility coordinate measuring machines (CMMs) are widely used to test the conformity of fabricated parts with regard to shape and dimension. In 1999 the standard Inspection-plusplus for Dimensional Measurement Equipment (I++DME) was introduced to promote interoperability of CMMs and third-party controlling and analyzing software. I++DME caused a big improvement of CMMs usability. Regrettably macroscopic CMMs do not fulfill the requirements of quality control in microscopic dimensions. They lack sufficient resolution, impart high probing forces and are not capable of utilizing sophisticated sensors for micro- and nano-profiling.

Nanopositioning- and -Measuring Machines (NPMMs) are able to fill this gap. These devices possess a measuring volume of 25x25x5mm³ and a positioning resolution of 0.1 nm, can apply various tactile and non-tactile sensors for measurements from microns down to the atomic scale and are well-suited to fulfill the needs of microscopic quality monitoring. Recent work has focused on the implementation of an I++DME compliant command interpreter to allow the use of standardized measuring software, well-established in macroscopic fabrication processes. By enabling the use of macroscopic third-party measuring software on NPMMs, measuring tasks in the microscopic scale can be done traceable, intuitively and quickly.

We will demonstrate the feasibility of CMM-aided quality monitoring by applying established workflows to the microscopic scale using the example of third-party measuring software utilizing a NPMM and a tactile microprobe. Repeatability tests are done on a pitch standard and the shape deviation is determined.

8031-87, Poster Session

A novel atomic layer deposition method to fabricate economical and robust large-area microchannel plate detectors

A. Mane, Q. Peng, M. Wetstein, Argonne National Lab. (United States); H. J. Frisch, The Univ. of Chicago (United States) and Argonne National Lab. (United States); O. H. Siegmund, Univ. of California, Berkeley (United States); J. W. Elam, Argonne National Lab. (United States)

Microchannel plate (MCP)-based detectors have a combination of unique properties like high gain, high spatial resolution and high temporal resolution. They can be used in wide variety of applications including imaging spectroscopy, astronomy, photo-detectors, electron microscopy, Time-of-Flight mass spectrometry, molecular and atomic collision studies, and cluster physics. The same MCP-based technology is used to make visible light image intensifiers for night vision goggles and binoculars. We demonstrate an economical and robust route to fabricate large-area MCP-based detectors that can be used in the above applications. We use atomic Layer Deposition (ALD), a powerful thin film deposition technique, to tailor the electrical resistance and secondary electron emission (SEE) properties of capillary glass arrays. The self limiting growth mechanism in ALD allows atomic level control over the thickness and composition of layers that can be deposited conformally on all surfaces of the high aspect ratio capillary glass arrays. We have developed processes for the ALD resistive coatings and SEE layers to give us precise control over the resistance (10Mohm-5Gohm) and SEE coefficient (up to 5). This novel approach allows us to control the geometry of the electron cascade itself, to enable functionalization of MCP substrates with high gain and low noise. This capability allows the separation of the properties of the substrate material from the amplification functionality. Here we will discuss a complete process flow to fabricated working large area MCPs.

8031-88, Poster Session

Fabrication of plasmonic nanopore array for biomolecule sensor

S. S. Choi, Sun Moon Univ. (Korea, Republic of); M. J. Park, Korea Military Academy (Korea, Republic of); D. Kim, N. K. Park, Seoul National Univ. (Korea, Republic of)

We microfabricated the plasmonic nanopore on top of the pyramid for single molecule dynamics. The fabricated plasmonic cavity with nanosize waveguide presents the huge transmission ratio possibly due to cavity- waveguide resonance and cavity-cavity resonance. The transmittance through a nanosize aperture is the ratio of the transmitted photon intensity to the free space intensity. Hence, the transmittance will be the radiant pressure differences. In our case, the photonic pressure difference is order of 103, much greater than 1. Therefore, this huge photonic pressure device can translocate the DNA through the nanosize aperture. Furthermore, the hotspot zone between the nanosize aperture can be utilized as SERS measurments.

8031-89, Poster Session

Compacted nanoscale sensors by merging ZnO nanorods with interdigitated electrodes

Q. Wang, B. Gavric, S. Almqvist, A. Bergström, W. Kaplan, J. Y. Andersson, Acreo AB (Sweden)

There are many applications that require new and smart chemical and biological sensors to secure borders, aircrafts, and airports which are considered vulnerable to terrorism. As the demand for the sensors continues to grow, there is increasing pressure to develop advanced sensor concepts, sensing materials and device architectures. In particular, nanoscale sensors are expected to offer ultrahigh sensitivities in very small amounts of chemical and biological species, and even for single entities detections.

We report on nanoscale sensors consisted of interdigitated electrodes (IDEs) and ZnO nanorods (NRs). The metal IDEs with their sizes ranging from sub-microns to a few microns were fabricated on SiO_2/Si substrates by nanoimprint lithography or conventional photolithography, etching and metallization techniques, whereas the ZnO NRs were grown by chemical deposition from solution phase. The average diameter and length of the ZnO NRs are about 60 nm and 2 μm, respectively. Three approaches were employed to construct the nanoscale sensors. One method was to drop-cast the NRs solution onto the areas between IDEs. The others were to utilize patterned photoresist to selectively grow NRs in the areas between the IDEs either vertically or laterally.

The ZnO NRs are used as sensing media. When sensing objects bind onto the NRs, the conductance measured between IDEs will be changed. As probing test, II-VI quantum dots were attached on the NRs, and clear responses were observed, which demonstrated good sensitivity of this type of sensor owing to its compact configuration and excellent surface to volume ratio.

8031-90, Poster Session

Optimization of plasmonic grating THz source using finite element analysis

J. W. Cleary, Solid State Scientific Corp. (United States); B. Haji-saeed, J. Khoury, W. R. Buchwald, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific

Corp. (United States)

In this paper we present the simulation results, using finite element analysis, of our broadband solid-state optically and electrically pumped THz source design. Our design consists of a thin layer of dielectric sandwiched between a nanograting and a thin film, such as metal, semiconductor, or high electron mobility material. By passing a DC current through the lower layer, a THz emission will be radiated from the nanograting. We optimize the layers' thicknesses using COMSOL Multiphysics.

8031-91, Poster Session

Highly tunable corrugated metal nano-grating laser using current injection

J. Khoury, B. Haji-saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States)

We designed a highly tunable laser with a corrugated nano-grating metal consisting of a nano-film evaporated over a PMMA nano-grating, through which current is injected. The electrons in the injected current experience an oscillating motion due to the corrugation. If the mean-free-path of the electrons within the nano-grating is long enough compared to the spacing, the electron wave produces electromagnetic emission. We developed the theory by solving Maxwell's equations, considering the electron mean-free-path, for a corrugated nano-grating with injected current. A 300 μm × 300 μm corrugated nano-grating with 30 nm spacing was fabricated and experimental results will be provided.

8031-92, Poster Session

Design of an ultrasensitive active pixel sensor that is based on silicon nanostructures

W. Richardson, Qusemde (United States)

The standard noise-related performance limit of a typical image sensor, especially for detection from a weak source, is set by the temporal noise in the pixel. In many applications the background noise is extremely small; the photon noise is smaller than the electronic noise. In addition the pixel noise dominates the noise that is due to the rest of the Read-Out Integrated Circuit (ROIC). To date it has not been possible to attack the fundamental source of noise in the pixel. That is, to date, the basic preamplifier in the pixel has been one of the standard circuits: source follower, direct injection, or capacitance transimpedance amplifier. In this work we turn away from those basic mosfet circuits, and look towards charging effects in nanoscale devices as a way to improve the basic sensitivity. We have designed a novel active pixel sensor that is based on silicon nanostructures, and silicon single-electron amplifiers. Analysis of the detector shows that the noise referred to the input can be in the subelectron regime, and a factor of thirty smaller than for a typical detector which is based on conventional mosfets. A preliminary design of the entire image sensor chip has been completed. The work included 1) design of the pixel array control logic, 2) design of the readout circuitry, and 3) the output Interface logic. Progress on the fabrication will also be discussed.

8031-93, Poster Session

Zero-bandgap graphene for infrared sensing applications

N. Xi, Michigan State Univ. (United States)

In recent years, global scientists have been looking for novel materials to improve the performance of optoelectic devices. Graphene has a strong graphene-photon interaction because of its unique and remarkable properties, and this opens up new possibilities for optoelectronic and infrared (IR) sensing applications. A pristine graphene conducts like a metal with zero bandgap and it is possible to open a very small bandgap in bilayer graphene by an applied electric field. These properties make graphene extremely important for IR detection because sensitivity of IR photodetectors is limited by bandgap of sensing materials. With a zero-bandgap graphene, electron-hole pairs can be generated easily by low energy photons such as middle-wave infrared signal. And the generated electron-hole pairs can contribute to a net photocurrent by designing the graphene structure carefully. In the experiment, we use an electric-field-assisted method to manipulate graphene flake between metal microelectrodes successfully. The devices are made from few-layer-graphene and multi-layer-graphene which are confirmed by Raman spectroscopy and atomic force microscopy. When the graphene contacts with a metal, a Schottky barrier forms at the contact. Therefore, built-in potential forms at the interface and it separates the generated electron-hole pairs that flow as photocurrents. Based on this principle, we demonstrate using the graphene-based devices for infrared detection under a zero-bias operation. The results show high potential applications of the electric-field-assisted technique and nano assembly to fabricate graphene-based infrared photodetectors.

8031-94, Poster Session

Scalable fabrication of micro- and nanoparticles utilizing the Rayleigh instability in multi-material fibers

S. Shabahang, J. Kaufman, A. F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We present a novel approach to fabricating micro- and nano-particles over a wide range of sizes and from a variety of materials. The technique relies on capillary instabilities in multi-material optical fibers.

The typical fiber design incorporates a core made of the target material for the particles and having size close to the desired particle diameter, while the cladding is a thermoplastic polymer. The fiber is heated to reduce the viscosity of the core material. The Rayleigh capillary instability results in the growth of a sinusoidal modulation on the core surface which grows without bound until the core breaks up into a string of spherical droplets. The time needed for this process depends on size of the core, and the temperature (and hence viscosity). The particles are then removed from the polymer matrix by dissolving the polymer with an organic solvent.

Using a stack-and-draw procedure, cores ranging from 200 microns down to 50 nanometers are achieved. Core materials from which we have succeeded in fabricating micro- and nano-particles include soft glasses, polymers, and low-melting-temperature metals. Results demonstrating the efficiency of particle extraction, uniformity of size distribution, as well as the controllability of particle size will be discussed. This approach allows for the scalable production of micro- and nano-particles for a variety of applications. In particular, we discuss the use of these particles as fluorescent and nonlinear nanoprobes.

8031-95, Poster Session

Differential thermal analysis microsystem for explosive detection

J. K. Olsen, Technical Univ. of Denmark (Denmark); L. R. Senesac, Oak Ridge National Lab. (United States); T. G. Thundat, Univ. of Alberta (Canada); A. Boisen, Technical Univ. of Denmark (Denmark)

Under the X-sense framework program a micro differential thermal analysis (DTA) system has been developed to detect traces of explosive. The demand for fast reliable screening of explosives is increasing every year. To increase screening speed and enable detection of trace amounts a very high sensitivity is required. To achieve this we have developed a micro DTA system that that selectively can determine types of explosive traces and differentiate them from non energetic compounds.

The system consists of two micro hotplates used for reference and sample analysis. The hotplates are designed as suspended silicon-nitride membranes. Each membrane measures 500 x 500 µm2 with a thickness of 200 nm, and has integrated silicon heaters and temperature resistors. To achieve high sensitivity the thickness is kept low, while maintaining a large surface area. This enables caption of more analytes on the surface while maintaining a low thermal mass. With this design the whole membrane can be heated rapidly, which is necessary to reach deflagration before all trace particles are evaporated. Using the integrated temperature resistors the resulting temperature change is monitored, and by subtracting the signal from the reference hotplate a signature of the thermal properties, of the trace particles are recorded.

By continuing the temperature ramp until 500°C all material on the surface will be either evaporated or burned, leaving the surface clean and ready for the next measurement. We have demonstrated using nanograms of analytes that individual signatures can be obtained for TNT, PETN and RDX with high reproducibility.

8031-96, Poster Session

Spatially resolved leakage radiation spectroscopy of integrated plasmonic microresonators

P. G. Kik, A. Ghoshal, C. Lumdee, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The development of next generation plasmon enhanced biosensors requires detailed control over localized and propagating plasmon resonances. In this presentation we discuss experiments on nanostructures that have been designed to maximize plasmon excitation under normal incidence illumination. The structures consist of periodic patterns of gold nanoparticles with dimensions 130 nm x 50 nm x 35 nm placed above a gold surface on a 30 nm thick silica spacer layer. This system enables the excitation of enhanced local fields through the use of localized plasmon resonances in combination with the constructive excitation of propagating plasmon modes that are strongly coupled to the nanoparticle resonances. Leakage radiation spectroscopy of a structure with a single row of particles reveals a single spectral peak at 650 nm, providing evidence for the excitation of localized plasmon modes on the nanoparticles, as well as for the excitation of propagating surface plasmons by the particles. As the number of particle rows is increased, the single resonance peak is seen to develop into two pronounced peaks, resulting in leakage radiation maxima at 615 nm and 685 nm. The observed peak splitting is attributed to the coupling between localized and propagating plasmon modes. Through measurements of the radiation intensity as a function of the number of particles, we demonstrate that the field enhancement converges to its maximum value at an array size of 5 um. These observations are described in terms of a model taking into account both plasmon excitation and plasmon scattering and damping.

8031-97, Poster Session

Rapid laser direct writing for extremely sensitive surface-enhanced Raman scattering substrates based on the photoreduction mechanism of silver nanoparticles

C. Huang, H. Lin, National Chung Cheng Univ. (Taiwan) and National Cheng Kung Univ. (Taiwan)

A simple and single-step approach to fabricate silver nanoparticles with a desired pattern on arbitrary material substrates via the photoreduction process by laser direct writing is investigated. The central wavelength, repetition rate, and pulse width of the ns laser are 355 nm, 30 kHz, and 25 ns respectively. The fabrication laser power is tested from 0.1~1 W and the tested concentration of AgNO3 solution is from 0.01~0.1 M. Results demonstrate that Ag nanoparticles are densely and uniformly distributed on specimen surfaces. The particle density is suitable to form lots active "hot spots" to significantly enhance the localized electric field (E-field) for Raman scattering detections. The Raman spectra of Rhodamine 6G (R6G) molecules and the monolayer of 4-mecaptopyridine (4-MP) molecules in machined and un-machined area are measured and compared with each other. The detection limit of patterned area for adenine is about 10-12 M, which is comparable to the chemically immobilized Ag nanoparticle substrate. The Raman spectra and Raman signal enhancement are only observed on the machined area and the enhancement factor is up to 1013. The rapid photo-induced chemical reduction of Ag nanoparticles has potential to integrate the functional microchips for active surface-enhanced Raman scattering detections on arbitrary material substrates in a desired pattern, very attractive to special productions of miniature active SERS sensors for trace amount sample detections.

8031-98, Poster Session

Nanofabrication of large-scale periodic metal nanostructure arrays by nano-imprint lithography and laser annealing

C. Huang, H. Lin, National Chung Cheng Univ. (Taiwan) and National Cheng Kung Univ. (Taiwan)

Large-area and periodic metal nanoparticle arrays with precisely controlled particle sizes and spherically round shape on polydimethylsiloxane (PDMS) substrates are fabricated via nano-imprint lithography and laser annealing. Template-guided physical self-aggregation of sputtered metal thin film under a 532-nm laser illumination is used to create nanoparticle cluster arrays of defined sizes with nanoscale interparticle separations at pre-defined pattern locations, built by nanotransfer printing that can stamp out well-defined large area nanohole arrays on PDMS. Results demonstrate that the particle size is determined by the bottom hole sizes and deposited film thickness. Highly ordered metal particles with various diameters ranging from 75~300 nm can be easily obtained. Besides, the nanoparticle cluster arrays provide strong and reproducible SERS signals of probe Rhodamine 6G (R6G) molecules at 10-9 M. This approach provides a precise control in structural parameters of metal nanoparticle array generations which is very suitable for sensitive SERS detections and SERS imaging of biological samples.

8031-99, Poster Session

An implementation for the detection and analysis of negative peaks in an applied current signal across a silicon nanopore

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Translocation of DNA through a silicon nanopore with an applied voltage bias causes the ionic current signal to spike sharply downward as molecule contact is made with the walls of the pore. Proper processing of the sampled signal is paramount in obtaining accurate translocation kinetics from the negative peaks, but manual analysis is time-consuming. Here, an algorithm is reported that automates the process. It imports the signal from a tab-delineated text file, automatically zero-baselines, filters noise, detects negative peaks, and estimates each peak's start and end time. The imported signal is processed using a zero-overlap sampling window. Peaks are detected by comparison of the window's standard deviation to a threshold standard deviation in addition to a comparison against a peak magnitude threshold. Zero-baselining and noise removal is accomplished through calculation of the mean of non-peak window values. The start and end times of a peak are approximated by checking where the signal becomes positive on either side of the peak. The program then stores the magnitude, sample number, approximate start time, and approximate end time of each peak in a matrix. All these tasks are automatically done by the program, requiring only the following initial input from the user: window size, file path to sampled signal data file, standard deviation threshold, peak magnitude threshold, and sampling frequency of the sampled signal. Trials with signals from an 11-micron pore sampled at 100 kHz for 30 seconds yielded a high rate of successful peak detection with a magnitude threshold of 600, a standard deviation threshold of 1.25, and a window size of 100.

8031-100, Poster Session

Nanostencil lithography for high-throughput fabrication of infrared plasmonic sensors

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We will demonstrate a novel fabrication approach for high-throughput fabrication of engineered infrared plasmonic nanorod antenna arrays with nanostencil lithography (NSL)1. NSL technique, relying on deposition of materials through a shadow mask, offers the flexibility and the resolution to fabricate radiatively engineer nanoantenna arrays for excitation of collective plasmonic resonances. Nanorod arrays obtained by NSL are investigated using SEM and optical spectroscopy, and compared against the nanorods with the same dimensions fabricated using EBL. No irregularities on the periodicity or the physical dimensions are detected for NSL fabricated nanorods. We also confirmed that the antenna arrays fabricated by NSL shows high optical quality similar to EBL fabricated ones. Furthermore, we show nanostencils can be reused multiple times to fabricate repeatedly and reliably selfsame structures with identical optical responses. This capability is particularly useful when high-throughput replication of the optimized nanoparticle arrays is desired. In addition to its high-throughput capability, NSL permits fabrication of plasmonic devices on surfaces that are difficult to work with electron/ion beam techniques. Nanostencil lithography is a resist free process thus allows the transfer of the nanopatterns to any planar substrate whether it is conductive, insulating or magnetic. As proof of the versatility of the NSL technique, we show fabrication of plasmonic structures in variety of geometries and on different substrates. Nanostencil Lithography enables plasmonic substrates supporting spectrally narrow far-field resonances with enhanced near-field intensities. Overlapping these collective plasmonic resonances with molecular specific absorption bands can enable ultrasensitive vibrational spectroscopy2. We will also present our recent results on spectroscopic identification of proteins with antenna arrays fabricated by nanostencil lithography.

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8031-101, Poster Session

Cathodoluminescence of metal gratings and electron-beam induced current in metal-oxide-metal junctions for plasmonic applications

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Practical nano-photonic integrated circuits based on Surface Plasmon Polaritons (SPP) will require all-electronic I/O. We investigate SPP excitation by electron beams, which may be realized at chip scale using e.g. field emitters. Electron-beam excited SPPs on metal lamellar gratings of period 7.5 or 20 microns and amplitudes 0.1 to 4.6 microns are observed simultaneously with transition radiation using a cathodoluminescence (CL) system. The overall intensity of the 400-800 nm range emission band depends little on the grating amplitude or e-beam energy. However, for the larger grating amplitudes, when the grating lines are perpendicular to the axis of the collection optics, the emission spectrum is modulated with a period that increases with wavelength. The depth of the modulation is about 30% for the highest amplitude gratings. When the grating lines are aligned parallel to the mirror axis, the modulation is almost eliminated. Two possible explanations are explored. The first is interference of transition radiation from neighboring grating stripes. Second, we consider SPPs out-coupled into a finite and wavelength-dependent number of collected orders. Neither hypothesis can explain the observed modulation period or depth unless the acceptance angle of the CL collection optics is artificially assumed to be very small. Also, SPP detection by Metal-Oxide-Metal junctions having dissimilar metals is investigated via electron-beam-induced current measurements. Here, the electron beam is focused on metal SPP waveguides at various distances up to 1 micron on either side of the junction to seek current asymmetry and distance dependence that correlates with SPP propagation length.

8031-102, Poster Session

Nanochemical sensors: polyaniline nanofibers and graphene

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We have been investigating nanostructured materials for chemical sensors based on polyanilne nanofibers and most recently graphene. Conducting polymers have been widely used to develop fast and efficient chemical sensors. We have shown that polyaniline nanofibers synthesized using a simple chemical method perform much better than conventional polyaniline and respond well to a number of different gases including hydrochloric acid, ammonia, hydrazine, organic solvents, hydrogen sulfide, arsine, phosgene and hydrogen gas. Through the use of composite materials enabled by our unique water dispersions of polyaniline nanofibers, gases that do not cause a response in unmodified polyaniline can be detected. As a result a wide range of detection capabilities is possible with sensors based on polyaniline nanofibers. Most recently we have been developing chemical sensors based on graphene, both chemically produced from graphite oxide and single layer graphene deposited by CVD. Our recent work in the area will be reviewed and an overview of graphene-based sensors will be presented.

8031-103, Poster Session

Nanosensors: from near-field to far-field applications

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The Center for Chemical Sensors Development (CCSD) has worked in developing sensors for threat agents for over 8 years. The approaches for sensing have covered many types of threat chemicals and some types of biological simulants, including high explosives, homemade explosives, mixtures and formulations, chemical agents simulants, toxic industrial chemicals and spore forming microorganisms. Sensing in the far field has been based in vibrational spectroscopy: Raman and infrared. Near field detection has been mainly based in nanotechnology enabled Surface Enhanced Raman Scattering (SERS). Initial use of colloidal suspensions of silver, gold and copper nanospheres and spheroids eventually evolved to metallic and metal oxide nanorods and to particle immobilization, including sample smearing on substrates and drop-on-demand thermal inkjet printing of nanoparticles. Chemical reduction of metal ions has been substituted by clean photonic reduction. New avenues have open wide research endeavors by using laser techniques to form nanoprisms and interference based metallic nano-images and micro-images. UV based metal reduction on top of metal oxides nanostructures promises to provide the selectivity and sensitivity expected for the last 30-40 years. Various applications and experimental setups will be discussed.

8031-104, Poster Session

Plasmonic photonic crystal MEMS platform for IFF and sensing applications

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We describe a new class of plasmonic photonic (PPh) crystal structures integrated onto a MEMS platform for high temperature-intensity, high speed, and high efficiency narrow band emitting and sensing applications in the infrared.

Light-weight, low-power consumption, low-cost IR sources are required for covert military applications for IFF (identify friend or foe), pallet markers, etc. They must be visible with conventional viewers at large distances in 3-5 or 8-12 micron bands and emit no visible or near-infrared radiation. We exploit 2D organized metallo-dielectric surface structures for angular and spectral control of reflection, absorption and emission in narrow bands from surfaces in infrared. The 2D PPh structures are built on a MEMS platform, for thermal isolation from the environment. Recent advances in the design of the 2D PPh structures allows for tremendous performance enhancement: high temperature/high intensity operation close to 1000 C and high speed (200Hz with 50% modulation), opening new applications in spectroscopy, infrared imaging, and signaling. Demonstrated wafer-level vacuum sealing improves the wall plug efficiency dramatically allowing these devices to be portable, light and battery operated.

PPh crystal MEMS act simultaneously as emitters and sensors in a defined narrow waveband. They sense a change in returned radiation when a particular gas is present in the optical path via a change in temperature. CO_2 and CH_4 sensing is demonstrated. This combined capability opens new avenues for research in vital commercial and military applications such as environmental protection, household safety, bio-hazardous material identification, industrial environments, medical monitoring of vital signs and surveillance.

8031-105, Poster Session

Hydrogenation effect on graphene field effect devices relevant to photonic device application

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Fundamental investigation was carried out to understand the hydrogenation effect on graphene based thin film transistors (TFTs). Graphene was synthesized by a CVD process followed by a transfer technique on SiO_2 substrate. Bottom gate TFTs were fabricated with gold source and drain electrodes. These device structure was tested modified by treatment of hydrogen ambient. The characteristics of TFTs were measured as a function of treatment conditions. In addition, the effect of hydrogenation was tested based on electrical and optical measurement methods. Finally the photo effect of TFT structure was investigated to understand the band-gap-engineering of graphene. In this paper, details of experimental theoretical investigations towards understanding of fundamental properties of graphene will be presented.

8031-106, Poster Session

Design of low-cost photonic crystal-based three-dimensional invisibility cloak

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Design schemes for cloaking devices have recently been proposed using transformation optics and conformal mapping. In this paper, we propose to design a photonic-crystal based three-dimensional (3D) cloaking structure with low-cost and improved performance. The carpet cloaking structure with truly 3D geometry will be designed at optical wavelengths. Compared with microwave cloaks where materials with large anisotropy and wide material parameter (i.e. permittivity and permeability) range are needed, the proposed 3D cloak can be constructed using isotropic dielectric materials with small material parameter variations, which makes it suitable for practical implementation. To further reduce the material parameter variation range, we study the carpet-cloak with various bottom curved surface shapes. In this way, an optimized curved surface is designed without compromising the cloak performance. Moreover, a small cloak to object area ratio is desired to achieve cloak with compact size. Thus we study the relation between the area ratio and the constructing material parameter range in order to minimize this ratio. To verify our design concept, the performance of the proposed cloaking structure is simulated using full-wave electromagnetic simulator. The simulation will be performed in 3D photonic crystals which can be fabricated by two-layer phase mask based holographic lithography. We calculate refractive index as a function of laser exposure doses and refractive index mapping is predicted for the 3D photonic crystal-based cloaking structure. Such phase mask-based holographic fabrication of the proposed cloaking structures will pave the way towards the mass production of invisibility cloak.

8031-107, Poster Session

Microoptoelectromechanical (MOEM) accelerometers: possibility versus performance

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Micro Electro mechanical (MEM) accelerometers have grown to the state of commercial exploitations [1,2]. However, the relatively low performances of these accelerometers limit their use to less demanding automotive applications. High performance accelerometers are in demand for navigation of vehicles and micro spacecraft. Sensors based on micro-opto-electro-mechanical (MOEM) which makes use of guided wave optical phenomena controlled by micromechanical structure, seem to hold the potential for high performance and in fact a few of these are emerging from laboratories[3,4,5]. This paper analyzes the issues involved in the performance and limitations of MOEM accelerometers.

Optical and MEM accelerometers technology and commercial status are critically reviewed and presented. The configuration, performance limit key to the high accuracy accelerometers and related critical technology are discussed.

As case study two types of MOEM accelerometers based on optical intensity modulated schemes, and interferometric method of acceleration sensing are analyzed. Analytical model relating the optical output variation with the acceleration induced deflection and stress in the cantilever for intensity modulated and Interferometric sensor respectively. Simulation results of MOEM accelerometer with a resolution of 1 micro g, a dynamic range better than 100 g and shock survivability of better than 3000 g are presented.

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8031-108, Poster Session

Nanowire-based photodetectors: growth and development of chalcogenide nanostructured detectors

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This work will showcase recent developments in the growth and performance of nanowire (NW) based photodetectors. Specifically the ability to transition from single NW devices to arrays of detectors will be discussed. We have demonstrated the growth of semiconducting nanowires (NWs) using the physical vapor transport (PVT) method. CdSe and ZnSe NWs were grown from Au catalysts on various substrates. Numerous techniques were developed to control growth orientation and morphological uniformity, including growth on patterned substrates, selective catalyst deposition and surface chemical functionalization. Based on these results we were able to develop a novel kinetic pathway for stabilizing the NW growth orientation. Furthermore, we were able to show promising optical properties, including high transparency and for photoluminescence a high ratio of band edge/deep level defect emission.

As-grown material was also used for fabrication of photodetectors. Metal-semiconductor-metal (MSM) structures were fabricated from an array of ZnSe NWs and Ti/Au contacts. The array of devices was tested using a 150W tungsten halogen lamp and an automated probe station. Current-voltage plots from -20 to 20V show generally symmetric behavior, with schottky barriers from the Ti/Au contacts. Upon illumination through a microscope objective lens, the nanowire devices showed an average increase of 10x in photocurrent and up to 100x for an individual device. These results will provide the foundation for developing nano-avalanche photodiodes (nanoAPDs), in which p-type and n-type NWs will be utilized to create high efficiency, low noise junctions.

8031-109, Poster Session

Effect of dielectric layer on the response times of electrostatic MEMS switches

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Electrostatic MEMS switches have become prevalent because of low power consumption and ease of integration in micofabrication technology. The equations governing their dynamic response obtained by energy methods are nonlinear differential equations. Even the unit-step response of these devices requires numerical computation. Depending on the magnitude of the applied step voltage and the presence of dielectric in the actuator, the response could be recurring or non-recurring. Estimating the period time and the switching time in these cases proves to be hard because one has to solve the energy equation numerically which could be time consuming or difficult to converge if it is not posed properly. Elata et al. have developed excellent methods to obtain these times on a logarithmic scale of voltage more easily for the undamped case. This paper extends their work for the case when the bottom plate is covered with a dielectric layer. The stagnation time occurring before dynamic pull-in, and the switching time thereafter are first shown as nonlinear graphs with the dielectric permittivity as a parameter. They are also linearized on a logarithmic scale and made useful for quick look up and convenience of designers.

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8031-110, Poster Session

Tuneable optical waveguide using dielectrophoretically manipulated nanoparticles in microfluidics

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In this work, we developed a novel system that couples light from a polymeric waveguide into the dielectrophoretically manipulated nanoparticles within a microfluidic system. A multimode SU-8 core waveguide is fabricated on a lower KMPR cladding enclosed in a microfluidic channel. An array of DEP microelectrodes, capable of forming dense nanoparticle bands along the center of the microfluidic channel is integrated into the system. These DEP electrodes position the moving suspended nanoparticles within the evanescent wave sensitive region. Subsequently, silica and tungsten trioxide nanoparticle suspensions in the microfluidic channels are manipulated via the DEP forces, forming the top cladding for the waveguide. The system is comprehensively investigated at different frequencies to observe coupling behaviour of the optical waves from the waveguide into the surrounding media. We showed that using the DEP force nanoparticles could be closely packed near the evanescent region of the optical waveguide. As tungsten trioxide has a higher refractive index, while silica and polysterene have lower refractive indices compared to the rib-waveguide core, the optical response differed significantly. Under the DEP focusing conditions, the higher index tungsten trioxide particles were positioned within the evanescent wave region, with the volume ratio of more than 26%, causing significant leakage of the optical wave into the surrounding media. Conversely for silica and polysterene, the refractive index of the surrounding media was lower than the rib-waveguide core, confining the optical waves in the waveguide with some minimal scattering. Applications of these devices are immense in the fields of optofluidic sensing. Future studies include demonstrations of dielectrophoresis along with various particles for the detection of biochemical activity in evanescent regions. Different DEP microelectrode geometries capable of precision particle sorting can provide better performance.

8031-111, Poster Session

Dielectrophoresis-Raman spectroscopy system for analysing suspended WO3 nanoparticles

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A microfluidic dielectrophoresis (DEP) platform consisting of curved microelectrodes was developed and integrated with a Raman spectroscopy system. The electrodes were patterned on a Raman transparent quartz substrate, and integrated with a microfluidic channel, which was imprinted in poly-dimethylsiloxane (PDMS). This novel integrated system can be efficiently used for the determination of suspended particles type and the direct mapping of their spatial concentrations. We will illustrate the system's unique advantages over conventional optical systems through the use of tungsten trioxide (WO3) nanoparticles. The WO3 particles are approx. 80nm in diameter and are suspended in deionised water mixed with Triton X-305 surfactant. The mixture, with a concentration of 6.5 % w/w, was placed into the microchannel and drawn though at a rate of 4 µl/min. An electric field was applied to the gold electrodes, causing the suspended particles to experience a dielectrophoretic force. For this test we demonstrate only positive dielectrophoretic forces, where the particles are pushed towards areas of highest electric field strength. In order to quantify the concentration of particles the magnitude of the WO3 Raman pattern peaks were measured, and the local spatial concentrations were calculated. These values were normalised against the zero DEP field Raman measurement, which corresponds to the 6.5 % w/w. Assuming that the WO3 concentration increases linearly with the increase of the Raman peak intensity, we calculated the maximum local volume fraction of WO3 between the electrodes to be 85.2 % w/w (11.9 % v/v).

8031-74, Session 16

Xsense: a miniaturised multisensor platform for explosives detection

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There is an ever increasing demand for fast, portable, reliable, selective and sensitive detection methods for explosives in both military, humanitarian and homeland security applications. In an attempt to address this issue, the Danish Agency for Science and Technology's, Program Commission on Nanoscience Biotechnology and IT, has initiated the Xsense project (running 2008 to 2012).

The key challenges in the future development of sensor based explosives detectors are reliability, selectivity, stability and cost. Our hypothesis is that reliability can only be improved by combining several independent and sensitive measuring principles. Therefore the Xsense project is developing four individual sensor technologies (surface enhanced Raman scattering, cantilever-based sensors, calorimetric sensors and colorimetric sensors). Each sensor principle is based on different physical phenomena thus increasing the reliability and decreasing the adverse effects of varying environmental conditions. Proof-of-concept has already been established for all four sensor technologies as will be shown. Using micro- and nanotechnological fabrication techniques the four sensing methods are being integrated into one sampling platform enabling simultaneous sensing. Advanced signal processing utilizing data driven modelling is used for statistical analysis of the output data. It is the goal of the Xsense project to provide explosives detection capabilities, otherwise only available to trained dog teams, to personnel with minimal training in for example land mine clearing actions.

8031-75, Session 16

Explosives detection using nanoporous solids

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Nanoporous solids are abundant, and of a varied nature, including carbon, silicon, silicates, polymers, organosilicas, ceramics, metallic minerals and metal-organic frameworks. As could be expected, the distribution of sizes, shapes and volumes of the void spaces in porous materials, coupled with their chemical structure and composition, have a direct influence on their performance as receptors for sensing applications. In particular, materials with tailor-made porosity and chemical specificity hold considerable promise for the development of chemical sensors. In view of the molecular recognition properties that nanoporous solids can afford, our strategy for vapor detection of explosives involves the use of Si based nanoporous solids (micro and mesoporous; i.e zeolites, M41S, titanosilicates) whose adsorption properties have been tailored towards the selective adsorption of nitro-derivatives. Molecules containing the nitro group are often used as targets in the field of explosives detection because these components are used in the preparation of plastic explosives. As a rough rule of thumb a method that is suitable for direct explosive detection should be able to detect explosives concentrations down to less than 1 ng/l. To this end, the developed nanoporous materials are mainly deployed in the form of isolated entities (individual nanoporous crystals) on high sensitive Si mechanical transducers-cantilevers provided with internal heating elements. The working sensing principle combines the partial selectivity imposed by nanoporous solid based layers with the thermally induced properties of adsorbed molecules.

8031-76, Session 16

The photonic nose: a simple and versatile tool for sensing

L. D. Bonifacio, A. Arsenault, Opalux, Inc. (Canada); G. A. Ozin, Univ. of Toronto (Canada)

Artificial noses have attracted a great deal of attention in the past decade for a wide range of applications, including foodstuff monitoring, security, environmental monitoring and disease diagnostics. By use of combinatorial responses coming from a variety of sensing units, artificial noses provide a platform for the analysis of samples with complex composition without the necessity to identify individual components in a mixture.

Most of the current nose technology is based on relatively complex and costly platforms. Photonic Nose (P-Nose) is a simple and cost effective concept for the analysis of both liquid and vapour phase samples. It is based on arrays of specially designed photonic sensors, in which the combinatorial response can be analyzed by use of simple digital cameras for remote and near instantaneous verification.

With a P-Nose array made from photonic crystals bearing distinct surface functionalities, we were able to demonstrate highly selective discrimination of components in solvent atmospheres. For instance, alkanes and alcohols of varying chain-length could be readily discriminated and identified.

This platform was also applied to more complex systems, where its potential in disease diagnostics was demonstrated through the discrimination of different bacterial cultures. In addition to gas phase analysis, this platform also lends itself to direct analysis of liquids and fluids. Analysis in aqueous systems was demonstrated through the detection of lead ions in water. Lead present in water at low concentration levels could be detected by use of a photonic nose array.

8031-77, Session 17

Quantum cascade lasers: a game changer for defense and homeland security IR photonics

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In a short period of sixteen years, quantum cascade lasers (QCL) have made significant inroads into applications areas where a number of alternate laser technologies have already been extensively deployed in the midwave infrared (MWIR) and longwave infrared (LWIR) regions. QCLs have now been developed to provide, on a commercial basis, continuous wave, room temperature (CW/RT) power of over 3 W (at 4.6 µm) with a wall plug efficiency of over 15% and over 2 W (at 4.0 µm). Over all QCLs now cover a wavelength region from 3.8 µm to longer than 12 µm. The applications include laser sources for MWIR countermeasures, MWIR and LWIR target illuminators and designators, MWIR beacons (IFF), test equipment for measuring the efficacy of infrared countermeasures and sources for MWIR and LWIR radiation for high sensitivity, very low probability of false alarm spectroscopic measurements of chemical warfare agents and explosives, both in-situ as well as in standoff applications. The drivers are the small size, reduced weight and high wall plug efficiency, which makes the overall systems more attractive. In this paper, I will describe the recent developments of 1W+ CW/RT power QCLs at wavelengths as shorter than 3.8 µm as well as extension of the high power QCL designs to longer wavelengths. I will also describe the insertion of QCLs into above mentioned applications where QCLs have begun a rapid displacement of the earlier laser sources.

8031-78, Session 17

QCL-assisted infrared chemical imaging

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Micro- and nano- technologies (MNT) have opened up the mid-infrared (IR) spectral region to room temperature techniques that are enabling new applications in chemical imaging. The mid-IR is rich in wavelength specific absorptions that can be used to identify different chemicals and materials. It is only in the last decade, however, that mid-IR cameras and tunable, intense mid-IR laser sources have become available that are compact and operate at room temperature. MNT has allowed these developments; micro-bolometer arrays are now routinely fabricated with 25 um resolution and the ability to sense mid-IR radiation from 7 to 14 um. Quantum cascade (QC) lasers fabricated with exquisite control of semiconductor layers and waveguides serve as the gain media for tunable mid-IR lasers, some even tuned with MEMS feedback elements. The current state of mid-IR imaging and illumination is discussed, and specific examples of its use in chemical imaging are presented. First, passive mid-IR imaging is considered, along with its ability to be used for chemical identification. The use of tunable mid-IR lasers as an illumination source is then considered. Technical aspects of illumination and detection paradigms are presented, with a consideration of how spectroscopic information gathered in both stimulated thermal emission and reflectance modes can be analyzed to determine chemical composition in an image. Finally, specific examples of QC laser assisted chemical imaging are presented.

8031-79, Session 17

Ultrafast bandgap photonics

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Ultra-short pulse is able to change the optical state of some conventionally non-transparent solids. Ultra-short pulses can make them transparent and can change polarization characteristics of the interacting light. The effect is most pronounced in semiconductors were the presence of essential but width-limited bandgap amplifies the effect in highly non-linear manner and make easily observable. Changes in solids optical state are occur on the scale that is comparable with recombination and relaxation times. Such short time changes in optical characteristics of conventionally non-transparent solids depend on the bandgap structure and its width. The phenomenon is time-dependent and bandgap-dependent. Therefore we are introducing the new term - Ultrafast Bandgap Photonics. Applications of Ultra-fast bandgap photonics are remote control of optical and electronic characteristics of solids and distant managing of material properties. In this paper we discuss some foundations of ultra-fast bandgap photonics - based on observations that has been done specifically for low pulse energy ultrafast lasers in its interaction with semiconductors. Nanotechnology benefits are based on dynamic management of properties of semiconductor arrays:nano-antenna arrays,new type of photodetector focal plane arrays.

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8031-80, Session 17

Vibrational spectroscopy standoff detection of threat chemicals

S. P. Hernandez-Rivera, J. R. Castro-Suarez, L. C. Pacheco-Londoño, W. Ortiz, H. Felix-Rivera, J. L. Ruiz-Caballero, Univ. de Puerto Rico Mayagüez (United States)

Standoff detection systems: Raman spectroscopy and FTIR spectroscopy based have been tested for detection of threat chemicals, including high explosives, homemade explosives, explosives formulations and high and low explosives mixtures. Other treat chemicals studied included toxic industrial compounds (TICs) and chemical agents simulants. Microorganisms have also been detected at standoff distances. Open Path FTIR has been used to detect vapors and chemicals deposited on metal surfaces at ug/cm2 levels at distances as far as 30 m, both in passive mode as well as in active mode. A telescope coupled mid-IR source was used in the active mode detection experiments. In the case of Raman telescope, standoff distances for acetonitrile and ammonium nitrate were 140 m.

8031-81, Session 17

Nano-antenna-based detectors for focal plane arrays across the electromagnetic spectrum (from mmW to IR)

M. A. Gritz, B. P. Kolasa, R. Burkholder, Raytheon Co. (United States)

Millimeter-wave (mmW)/sub-mmW/THz region of the electro-magnetic spectrum enables imaging thru clothing and other obscurants such as fog, clouds, smoke, sand, and dust.Therefore considerable interest exists in developing low-cost passive millimeter-wave imaging (PMMWI) systems.Previous PMMWI systems have evolved from crude mechanically scanned, single element receiver systems into very complex multiple receiver camera systems.Initial systems required many expensive mmW integrated-circuit low-noise amplifiers.In order to reduce the cost and complexity of the existing systems, attempts have been made to develop new mmW imaging sensors employing direct detection arrays.In this presentation, we report on Raytheon's recent development of a unique focal plane array technology, which operates broadly from the mmW through infrared (IR) wavelengths.Raytheon's innovative nano-antenna based detector enables low-cost production of staring 128×128 mmW focal plane arrays (mmW FPA), which not only have equivalent sensitivity and performance to existing PMMWI systems, but require no mechanical scanning.We also present recently generated images of objects obscured under clothing using our 2D mmW staring FPA.

8031-82, Session 17

Standoff detection of explosives: a challenging approach for optical technologies

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Standoff detection of explosives residues on surfaces at few meters was made using optical technologies based on Raman scattering, IR radiometry and Laser-Induced Breakdown Spectroscopy (LIBS). By comparison, detection and analysis of nanogram samples of different explosives was made with a microscope when a micron-size single point illuminated crystal of explosive producing Raman scattering. Results from standoff detection experiments using a telescope were compared to experiments using a microscope to find out important parameters leading to the detection of explosives from contaminated surfaces. While detection and spectral identification of the micron-size explosive particles was possible with a microscope, standoff detection of these particles was very challenging due to undesired light reflected and produced by the background surface or light coming from contaminants other than explosives. Results illustrated the challenging approach of detecting at a standoff distance the presence of micron or sub-micron explosive particles in trace amount.

8031-83, Session 17

Standoff detection of chemicals using IR spectroscopy

P. G. C. Datskos, L. R. Senesac, C. Van Neste, M. E. Morales, Oak Ridge National Lab. (United States)

No abstract available

8031-84, Session 17

Mid-wave/long-wave infrared lasers and their sensing applications

K. K. Law, Naval Air Warfare Ctr. Weapons Div. (United States)

Much advances have been made recently in both solid-state and semiconductor based mid-wave infrared (MWIR) and long-wave infrared (LWIR) laser technologies, and there is an ever growing demand for these laser sources for Naval, DOD and homeland security applications, including directed infrared countermeasures, anti- submarine warfare countermeasures, and standoff chemicals and explosives sensing. We will present various current and future programs and efforts at Naval Air Warfare Center Weapons Division on the development of high-power, broadly tunable MWIR and LWIR lasers and their related systems applications.

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8032-01, Session 1

Analysis on polarization interference imaging spectroscopy in remote sensing

H. Gao, C. Zhang, Xi'an Jiaotong Univ. (China)

Polarization interference imaging spectroscopy in the application of remote sensing is introduced. The operation principle of a polarization interference imaging spectrometer based on the technique is introduced, and typical configuration of the spectrometer is given and analyzed. The key component of the polarization interference imaging spectrometer is a polarization beam-splitter and its principle of operation is analyzed. There are two kinds of a polarization beam-splitter employed in the spectrometer, one is an angle polarization beam-splitter and another is a lateral displacement polarization beam-splitter. A polarization interference imaging spectrometer is very suitable to explore and detect the remote targets as it has the advantages of high throughput, high spectral resolution, etc. The instrument is small volume, light mass, simple configuration and is easily carried on the satellite to explore objects in a wide range of field. The information of objects obtained by a polarization interference imaging spectrometer is more reliable and richer than those of other conventional equipments because this kind of instruments concentrates many advantages of measuring instruments and current advanced techniques. For improving the accuracy of information of aims acquired by the instrument, the calibration for a polarization interference imaging spectrometer is required and the principles, strategies, methods, contents, steps and etc of calibration for it are introduced. The recent development of polarization interference imaging spectroscopy is given. Some expectations of applications of polarization interference imaging spectroscopy are put forward in more fields.

8032-02, Session 1

Light focusing by chirped waveguide grating coupler

P. Kumar, Wayne State Univ. (United States); B. C. Bergner, D. Cook, Spectum Scientific, Inc. (United States); I. A. Avrutsky, Wayne State Univ. (United States)

Waveguide grating couplers (WGC) are used for input and output coupling in many planar waveguide based sensors. By using a chirped grating, guided light can be decoupled and focused to a desired location. The location and spot size of focused beam depends upon the size and chirp of the grating as well as the wavelength of the light. The locus of the focused beams for different wavelengths lies along a curve. In many applications a planar detector array is used to capture spectral data. Where the planar detector array does not intersect this focal curve, images of a point source will be defocused. We develop a theoretical model to calculate the image location and geometric spot size for a given set of grating parameters.

In order to experimentally verify the model, chirped waveguide grating couplers were fabricated on HfO2/Quartz planar waveguides using e-beam lithography. The spot size, intensity, and location of diffracted beam was measured at several wavelengths and compared with the theoretical results.

8032-03, Session 1

New generation of compact femtosecond system for laser-based detection and identification of biological materials

K. Lim, Y. Liu, M. Baudelet, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); E. Slobodtchikov, P. Moulton, Q-Peak, Inc. (United States); A. W. Miziolek, U.S. Army Research Lab. (United States); M. C. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Laser-Induced Breakdown Spectroscopy (LIBS) for biological detection started in 2003 with the projects at ARL in the United States and DGA in France. Since this time, several groups have explored this technique and the particular work of Baudelet et al. has shown advantages of the use of femtosecond lasers for LIBS detection of bacteria: shorter continuum emission making the detection of minor and trace elements feasible. They showed that an analysis based on the elemental profile of the bacteria is a possible way towards detection and discrimination without using sophisticated multivariate analytical algorithms. Later works have shown the efficiency of chemometrics techniques for detection of bacteriological species even discrimination of strains.

In this study, we show the use of a new generation of femtosecond lasers: a near-IR diode-pumped Yb:doped CPA system (PFL-1047, Q-Peak) delivering pulses at 1047 nm, with a duration of 600 fs and an energy of 1.8 mJ at a repetition rate of 250 Hz. Comparison with a conventional nanosecond laser (Brillant, Quantel) in similar conditions on biological samples such as yeast. The spectral detection range from 140 to 920 nm shows different spectral features between the two regimes.

The advantages of femtosecond and its implementation as a compact system for LIBS will be discussed as well as the future development for femtosecond LIBS on biological samples.

8032-04, Session 1

A MEMS-based tunable Fabry-Perot filter

N. Gupta, U.S. Army Research Lab. (United States); S. Tan, D. R. Zander, Infotonics Technology Ctr. (United States)

We present a miniature tunable Fabry-Perot (F-P) filter development effort using MEMS technology. The tunable filter development is intended to cover spectral regions from the visible to the longwave infrared by developing a number of different filters each operating over a different wavelength region. The main objective of developing such miniature tunable filters is to use each in a miniature hyperspectral imager by placing it in front of a commercial focal plane array with suitable optics. Such a miniature tunable device has many more applications, i.e., in developing tunable sources. Recently, we have succeeded in fabricating some operational F-P filters operating in the visible/near infrared (VIS/NIR) wavelength region from 450 to 900 nm. The filter design uses one fixed mirror and the second mirror moves using electrostatic force. The device was composed of two parts with a dimension of 18 x 24 mm2: one fixed Ag mirror and one electrostatically moveable Ag mirror. Quartz wafers with low total thickness variation (TTV) were used as the substrates of these two parts. Au bumps were deposited in both parts in order to control the initial air gap distance and Au-Au bonding was used to bond two parts together. This paper will describe the device design consideration, the fabrication process, the electrostatic force simulation, the optical spectrum measurement, and the preliminary test results.

8032-05, Session 2

Microsensors based on quantum cascade lasers

S. Wu, A. Deev, California Institute of Technology (United States)

We show that Quantum Cascade Lasers (QCLs) could be efficiently coupled into micro Whispering Gallery Resonators (WGR), small bore hollow waveguide[1,2]. The reason behind such high coupling effciency is the unique high brightness of QCLs --- the same property that enabled semiconductor lasers as the working horse for telecom and digital media discs.

The resulting micro sensors will improve the Infrared sensors' sensitivity significantly, while reducing their size and sample volume and improve their mass manufacturebility. By coupling QCLs into hollow waveguide and work as an online sensor for Gas Chromatography (GC), we show that GC-Infrared sensors' sensitivity could be improved by over 4 orders of magnitude, bringing it on par with Mass Spectrometry for GC[1].
We also demonstrate that the WGR coupled with QCLs could realize equivalent optical path length over 100 meters and yet the sampling volume is only nanoliters. We also show that hollow waveguide coupled with QCLs could work as a microliter volume photoacoustic sensor with improved sensitivity over free-space photoacoustic sensors.

1. S.Wu et al., Hollow waveguide quantum cascade laser spectrometer as an online microliter sensor for gas chromatography, J. Chromatogr. A 1188 (2), pp. 327-330, 2008.

2. S.Wu and A. Deev, Observation of whispering gallery modes in the mid-infrared with a quantum cascade laser: possible applications to nanoliter chemical sensing, Proc. SPIE 7222, p. 72220F, 2009.

8032-06, Session 2

Development of a field-deployable isotopic N_2O analyzer based on mid-infrared cavity ringdown spectroscopy

A. D. Farinas, E. R. Crosson, Picarro Inc. (United States); D. Balslev-Clausen, T. Blunier, Univ. of Copenhagen (Denmark)

This work presents both laboratory and continuous infield measurements of N2O concentrations and 15N isotopologues of N2O with a field-deployable, mid-infrared cavity-ringdown spectroscopy (MIR-CRDS) prototype instrument. This instrument operates using thermoelectrically cooled technology, enabling the system to be run unattended for extended periods of time without the use of liquid nitrogen. The light source is a room temperature, modehop-free, CW, external-cavity quantum cascade laser centered at 4.55 µm, with a narrow linewidth and power exceeding 100 mW. A fast, low-noise, TE-cooled, MCT detector is used to record the ~10 µs optical decay from the ring-down cavity, which provides an effective absorption path length of many kilometers. Ambient atmospheric gas samples are introduced directly into the instrument which achieves a N2O concentration precision < 0.1 ppb in less than a minute of data acquisition time, while the isotopologues 15N of N2O are analyzed at < 1   precision within a few minutes.

The device is being developed as a general MIR-CRDS platform that, with changes in lasers and software, will provide enhanced sensitivity to several species of molecules, of which CO2, CH4, NO, NO2, and isotopologues of these gases are only a few. In this work N2O is being addressed, because it is a potent greenhouse gas which is increasing in atmospheric concentration by 0.25%/yr, and because its sources and sinks are not yet fully understood. Although the sensitivity of the new instrument is not as good as that of IRMS (± 0.1), MIR-CRDS has the advantage of being easy to use and is able to directly distinguish the isotopomers of N2O which is not possible with conventional IRMS.

8032-07, Session 2

Mid-infrared absorption spectroscopy using quantum cascade lasers

E. Deutsch, J. F. Heanue, Block Engineering, LLC (United States)

Block Engineering has developed an absorption spectroscopy system based on widely tunable Quantum Cascade Lasers (QCL). The system rapidly cycles through a user-selected range of the mid-infrared spectrum anywhere between 6 to 12 µm (1667 to 833 cm-1). The system can detect and measure substances on surfaces from a standoff distance of up to 2 feet. It can identify bulk materials and detect sub-micron films based on their absorption characteristics. It can also analyze vapors or liquids, in a single device.

The higher power density allows measurements from diffuse and highly absorbing materials and substrates. Other advantages over FTIR include portability, ruggedness, fast analysis, and the ability to work at a distance either through free space or a fiber. The system has been able to analyze trace amounts of explosives at a standoff of 2 feet using an eye-safe laser.

This paper will discuss the basic technology behind the system, empirical data on various samples, a comparison of the technology relative to FTIR and Raman, and a review of potential applications.

8032-08, Session 2

Accuracy of miniature tunable diode laser absorption spectrometers

M. B. Frish, M. A. Druy, Physical Sciences Inc. (United States)

Tunable Diode Laser Absorption Spectroscopy (TDLAS) is finding ever increasing utility for industrial process measurement and control. The technique's exquisite sensitivity and selectivity to selected target gases benefit continuous concentration measurement of trace analytes in complex gas mixtures. Tradeoff options among optical path length, absorption linestrength, linewidth, cross-interferences, and sampling methodology enable sensor designers to optimize detection for specific applications. Robust design generally provides excellent accuracy and linearity over two or three orders of magnitude dynamic range for spectral absorbances of less than 0.1%. Industrial quality TDLAS sensors achieve noise-equivalent absorbance detection below 10^-5/Hz^½, limited generally by coherent optical effects, rather than electronic noise. This paper describes TDLAS measurement accuracy limitations in emerging applications that demand increasing volumes of distributed miniaturized sensors at diminishing costs. In these situations, the TDLAS specificity is a key attribute, while high sensitivity enables novel sampling package designs with short optical pathlengths. Under these circumstances, the traditional approaches to optimizing performance may fail as analyzer features, such as reference paths for wavelength control, are sacrificed to reduce cost but can lead to reduced accuracy despite very low noise. We present the theoretical foundation affecting accuracy and methods for optimizing it.

8032-09, Session 3

Advances in QCL for security and crime fighting

S. A. Nicholson, Cascade Technologies Ltd. (United Kingdom)

New techniques for explosive (ED) detection are seen as key where the ability to identify and quantify hazardous materials can provide advanced warning of potential dangers allowing evacuation and counter measures to be employed. Traditional detection methods such as Ion mobility spectroscopy (IMS) and Gas Chromatograph Mass Spectroscopy (GCMS) do not lend themselves to ease of deployment in many scenarios in particular the high throughput screening of individuals, vehicle or packages. This particularly true for the related improvised or home made explosive devices (IED, HME). They lack adequate sensitivity and suffer from high false alarm rate. Moreover these techniques are in majority point sensing technique and do not allow stand off observation and detection at 50m - 200m range.

Cascade Technologies has focussed on addressing the above security gap, where high throughput screening of individuals, vehicle or items for detecting improvised explosive devices (PB-VBIED). Cascade's work has demonstrated the potential of a novel stand off new trace gas detection technology for the rapid identification of certain explosive threats at remote distance up to 10's of metres range. The novel stand off platform is targeted at the detection and identification of HME's as well as common commercial and military explosive compounds.

The Quantum Cascade laser (QCL) based portal has already demonstrated excellent selectivity (potential for low false alarm), high throughput and sensitivity at ranges of 10s of metres.

Current portal detects:

- Hydrogen peroxide and peroxide-based HMEs (e.g TATP, MEKP).
- Ammonia and ammonia based-HMEs.
- EGDN and EGDN based dynamites (retro-fit).

None invasive

- Privacy (no image)
- Safe/perceived to be safe (e.g. no ionising radiation...)

Walkthrough portal

Very high sensitivity / selectivity

No consumables

The strengths of such infrared based techniques for ED applications can be summarised as:

- High sensitivity to required levels.
- Fast- continuous online monitoring - zero down time.
- Highly specific - low cross interference - specific spectroscopic features.
- Safe for public deployment.
- No privacy concerns.

8032-10, Session 3

Quantum cascade laser-based substance detection

C. C. Harb, UNSW@ADFA (Australia); T. G. Spence, Loyola Univ. (United States)

Our central approach entails novel refinements of Cavity Ringdown Spectroscopy (CRDS), implemented in the mid-infrared region of the electromagnetic spectrum between 4 and 12 micrometers. There we can take advantage of chemically specific molecular vibrations to unambiguously identify and detect compounds of interest in terms of each compound's molecular fingerprint for applications to forensic analysis and security screening.

For example, we are addressing the needs of security agencies in their fight against improvised explosive devices (IED), with particular regard to novel instrumentation that can detect the presence of IEDs and identify post-blast residues in investigative situations such as the Bali bombings (2002 and 2005). We intend to devise instruments that could allow security agencies to detect an IED before it has been detonated or examine a crime scene for the presence of a particular IED faster and more accurately than by conventional means.

To achieve such objectives, we are developing new digital quantum control and filtering techniques to maximize CRDS measurement sensitivities and ultimately achieve real-time chemical detection for forensic analysis. This approach will be implemented and validated on CRDS test beds in the molecular fingerprinting wavelength range.

8032-11, Session 3

Small, low-power consumption CO-sensor for post-fire cleanup aboard spacecraft

J. L. Bradshaw, J. D. Bruno, K. M. Lascola, R. P. Leavitt, J. T. Pham, F. J. Towner, Maxion Technologies, Inc. (United States); D. M. Sonnenfroh, K. R. Parameswaran, Physical Sciences Inc. (United States)

In this presentation we report on our progress in developing a small, lightweight and low power consumption carbon monoxide (CO) sensor for detection and post-fire cleanup aboard manned spacecraft. This application requires the sensor to have a dynamic range for detection and monitoring of CO from approximately 1 to 500 ppmv with a resolution of 1 ppmv. Also, the sensor must have a high degree of reliability, be operable with minimal maintenance and be self-calibrating under varying humidity and ambient pressure conditions. Our sensor is a tunable diode laser-based absorption spectrometer (TDLAS) based on a Quantum Cascade (QC) laser operating at 4.61 microns developed by Maxion Technologies, Inc. and a single-board wavelength modulation spectroscopy (WMS) module developed by PSI.

The presentation will detail the laser design and performance and the bench-top performance of the tunable diode laser absorption spectrometer including sensitivity and Allan variance measurements. Our initial measurements indicate a minimum detectable CO concentration of 0.04 ppmv. This bench-top result allows us considerable trade-off flexibility in the design of the prototype sensor for both detection and monitoring functions with acceptable size, weight and power consumption for a spacecraft application. The status of the prototype sensor including size, weight and power consumption estimates and measurements and our progress with first and second generation low-power consumption single-mode 4.61 micron QC lasers will be presented.

8032-12, Session 3

Intracavity laser absorption spectroscopy using mid-IR quantum cascade laser

G. Medhi, Univ. of Central Florida (United States); A. V. Muraviev, H. Saxena, Zyberwear, Inc. (United States); C. J. Fredricksen, T. N. Brusentsova, R. E. Peale, Univ. of Central Florida (United States); O. J. Edwards, Zyberwear, Inc. (United States)

Intracavity Laser Absorption Spectroscopy (ICLAS) at IR wavelengths offers an opportunity for spectral sensing with sufficient sensitivity to detect vapors of low vapor pressure compounds such as explosives. Reported here are key enabling technologies for this approach, including multi-mode external-cavity quantum cascade lasers and a scanning Fabry-Perot spectrometer to analyze the laser mode spectrum in the presence of a narrow band intracavity absorber. Reported also is the design of an integrated data acquisition and control system that facilitates man-portability. Numerical solution of the laser rate equations yield sensitivity estimates, and preliminary sensing results are presented. In addition, original mid-IR spectroscopic reference data for TNT vapor measured in a hot cell at 170C are reported. Applications include military and commercial screening for threat compounds and contraband.

8032-13, Session 3

On the accuracy of decay constant measurement by heterodyne cavity ringdown spectroscopy

D. K. K. M. B. Silva, A. van der Walt, J. M. Dell, L. Faraone, The Univ. of Western Australia (Australia)

Cavity ringdown spectroscopy (CRDS) is a high sensitivity technique for

Return to Contents

detecting and measuring low concentrations of gas or vapor species. The technique encloses the measurand within an optical cavity, and measures the cavity decay time as a function of optical frequency. The decay time is modified by absorption within the cavity medium and, while the strength of the absorption will indicate the concentration of the absorbing species, the spectral variation of the absorption can identify it.

As coupling light into a high-finesse optical cavity is difficult, the throughput of the cavity is small. A recent variant, heterodyne CRDS, interferes the backward escaping cavity light, with the light reflected from the cavity input mirror, providing better signal sensitivity due to the heterodyne advantage. The output mirror position is dithered, so that the interference signal is chirped, beating at integer multiples of the moving mirror's Doppler frequency. This interference signal is demodulated and log-amplified to produce a signal whose slope is representative of the cavity decay time.

This paper, for the first time, examines the conditions required for high-fidelity measurements of the cavity decay time using the heterodyne CRDS and log-amplification technique. We demonstrate that, due to the very large bandwidth and dynamic range of the log-amplifier, for realistic measurement conditions, the log-amplifier does not impose any significant restrictions on the measurement accuracy. We also demonstrate, however, the measurement accuracy is limited by two factors, the detector bandwidth, and segment of acquired data used to extract the linear fit parameters.

8032-14, Session 4

Rapid and field-deployable biological and chemical Raman-based identification

E. Botonjic-Sehic, M. Lesaicherre, H. Boudries, Morpho Detection (United States)

Using Raman spectroscopy, the StreetLab Mobile delivers quick, accurate and user-friendly 2-in-1 chemical and biological identification capabilities.

The chemical identification requires no sample preparation at all while the biological identification requires very little sample manipulation, thus minimizing hands-on time and maximizing ease of use.

In order to reduce the effect of commonly found interferents, the biological identification proceeds first with a concentration of the pathogen of interest with antibody-coated magnetic capture beads. Sensitive and selective Raman-based detection is achieved using antibody-coated nanometer sized SERS tags synthesized from gold nanoparticles.

Assays developed for the identification of E.coli and Bacillus Anthracis have been developed and integrated onto a portable Raman device to allow for rapid & field deployable biological pathogen identification. Results from third party validation of the E.coli and Bacillus Anthracis assays will be presented. Assays conditions were optimized for improved assay performances and recent optimization studies will also be discussed. Finally, results of assays developed for the identification of additional pathogens will also be presented.

8032-15, Session 4

Detection of fire protection and mineral glasses in industrial recycling using Raman mapping spectroscopy

M. De Biasio, T. Arnold, M. Kraft, R. Leitner, Carinthian Tech Research AG (Austria); D. Balthasar, V. Rehrmann, TITECH GmbH (Germany)

Similar to polymer and paper recycling, recovery glass must be sorted within the recycling process. The main concern requiring glass sorting is that different glass formulations have substantially deviating melting points; an uncontrolled mixture of collected waste glass will result in recovered glass prone to cracking during cooling, and non-molten components in the melt can damage the machines. The standard methods - sorting with visual camera systems and X-ray fluorescence systems - are limitedly selective respectively expensive. As an alternative, the viability of Raman spectroscopy for glass sorting has been investigated. Raman is a popular and powerful method for material analysis but, until recently, was considered unsuitable for most industrial imaging applications as it requires long measuring times and is sensitive to stray light.

Advances in camera and spectrometer technology now allow acquiring Raman signals with high spatial and spectral resolution. This paper describes a macroscopic Raman mapping system that can detect and distinguish in particular fireproof and mineral glasses from standard household glass. Test sets of glass samples were extracted from an industrial recycling process and Raman spectra of the samples measured using a laboratory instrument. Characteristic spectral features were identified and used to build a chemometric model, which was then implemented in a macroscopic Raman system. Our experimental results show that it is indeed possible to detect and discriminate fireproof and mineral glasses in recovery glass streams using a Raman mapping system. As the components used are also suitable for industrial conditions, we conclude that this approach is appropriate for real-time industrial recycling.

8032-16, Session 4

Toward non-invasive detection of concealed energetic materials in-field under ambient-light conditions

E. L. Kiriakous, Queensland Univ. of Technology (Australia)

Non conventional spatially offset Raman technology is demonstrate for the non-contact detection of energetic materials concealed within non-transparent diffusely scattering packaging. A new design of an inverse SORS probe has been developed and tested. The new inverse SORS probe has been successfully used for the detection of different energetic substances under incandescent and fluorescent light conditions. Different container materials have been interrogated from a working distance of 6 cm using a 785 nm NIR laser beam. The interrogation time of the concealed energetic substances was less than 1 minute for near real time detection of hazards for both forensic and homeland security investigations.

8032-17, Session 4

Integration of optical devices and nanotechnology for conducting genome research

P. Chung, H. Luo, G. Schultz, P. Jiang, C. D. Batich, Univ. of Florida (United States)

Novel nanofabrication methodologies enable observation of extraordinary optical phenomena on the nanostructured devices. In recent years, these phenomena have been widely applied for the development in such fields as optical bandpass filter, sensor technology, and energy storage device. In addition, portable spectroscopic devices dramatically expand the applicability of sensor technologies for point-of-care medical diagnosis, real-time environmental testing, and homeland security. For multiplexed analyses, integrating and combining multiple spectroscopy technologies would make systems more useful for detections in complex samples. In this study, we present a spectral-based biosensor by utilizing a portable UV-Vis spectrometer, nanostructured arrays, and multimode data processing for DNA oligomers analysis. Moreover, the capability was expanded by integration of nanostructured arrays into a Raman spectroscopy. The specific features in the surface enhanced Raman scattering (SERS) spectrum provided information of DNA conjugated on the nanostructured surface. This emerging approach suggests potential applications in integration of multiple spectroscopy technologies for conducting genome research.

8032-18, Session 4

Application of an ion mobility spectrometer with pulsed ionization source in the detetction of dimethyl methylphosphonate and toluene diisocynate

F. Gunzer, The German Univ. in Cairo (Egypt); W. Baether, Draegerwerk AG & Co. (Germany); S. Zimmerman, Leibniz Univ. Hannover (Germany)

Ion mobility spectrometry (IMS) is a well known technique used in the analysis of gases. Small size and a sensitivity in the PPB range make it a typical technique fort he detection of explosives or chemical warfare agents. Ordinary IMS devices use typically a continuously working radioactive ionization source. We use a pulsed non-radioactive electron source for ionization which offers the innovative possibility of introducing delay times in between ionization and ion detection. As different substances have different signal decay times during such a delay, the selectivity of IMS is enhanced. The application and benefits of such a pulsed ionization source in the detection of the chemical warfare agent simulant dimethyl methylphosphonate (DMMP) and the toxic toluene diisocynate (TDI) will be demonstrated. As DMMP belongs to the substances with a comparable long signal decay time, its signal can be extracted in the presence of contaminating substances with e.g. similar ion mobility which would otherwise lead to a false-positive detection result. Furthermore, the monomer and dimer signal behave differently so that DMMP can be used as an example how the pulsed ionization source helps in identifying the origin of certain IMS signals. TDI behaves differently from DMMP but also shows a typically long signal decay time. Here it will be demonstrated how the pulsed ionization leads to benefits in terms of sensitivity, detector response and recovery time.

8032-19, Session 4

Detection of trace concentrations of TATP in complex surroundings using SERS

K. M. Spencer, S. L. Clauson, J. M. Sylvia, EIC Labs., Inc. (United States)

Surface-enhanced Raman spectroscopy (SERS) has repeatedly been shown to be capable of single molecule detection in laboratory controlled environments. However, other factors besides sensitivity need to be optimized for superior detection of the desired compound in a more complex situation. For example, SERS sensors are metals with surface roughness in the nm scale. This metallic roughness scale may not adsorb the analyte of interest but instead cause a catalytic reaction. In addition, the SERS sensor needs to be sensitive only to the desired analyte(s) or a small subset of analytes; detection of every analyte would saturate the sensor and make data interpretation untenable. Finally, the SERS sensor has to be a preferable adsorption site in passive sampling applications, whether vapor or liquid. In this presentation, EIC Laboratories will discuss modifications to SERS sensors that increase the likelihood of detection of the analyte of interest. We will then demonstrate data collected for TATP, a compound that rapidly destructs and is undetected on standard silver SERS sensors. With TATP and the modified SERS sensor, creation of ROC curves for room temperature vapor detection, detection of TATP in a non equilibrium vapor environment in 30 s, detection of TATP on a sensor exposed to a ventilation duct, and detection of TATP in the presence of fuel components were all shown and will be presented herein.

8032-20, Session 5

Two novel static polarization imaging spectrometers

T. Mu, C. Zhang, Xi'an Jiaotong Univ. (China)

In this paper, we present two novel schemes of compact static polarization imaging spectrometers. The first one is based on the combined Savart plate that is made of the positive and negative uniaxial crystals to get straight fringes over wide field of view. The straight fringes are expected for abstracting data accurately in some special application. However, the fringes produced by a single Savart plate interferometer are distorted by the Savart plate itself; that is the fringes are not perfectly straight, even for small angles of incidence. The combined Savart plate can overcome this drawback.

The second one is based on the combination of the Savart plate and Wollaston prism to acquire inphase and antiphase interferograms simultaneously. Subtracting the antiphase interferogram from the inphase interferogram, the interference component becomes twice as large and the noninterference component disappears. Noninterference background always distribution in the interferograms, but the background needs to be abstracted during the Fourier transform of the interference signal. To remove background, digital image processing is welcomed in non-polarization imaging spectrometer, but optical method is achieved in polarization imaging spectrometer. In conventional polarization system, however, inphase and antiphase interferograms is often acquired sequentially by rotating a linear polarizer, and thus some drawbacks such as rapid change of observed scene and perturbation would be introduced. Therefore, simultaneous acquisition of the inphase and antiphase interferograms with one CCD camera would be a good choice.

8032-21, Session 5

Photonic crystal slot waveguide optical absorption spectrometer for high-sensitivity near-infrared detection of xylene in water

S. Chakravarty, Omega Optics, Inc. (United States); W. Lai, The Univ. of Texas at Austin (United States); X. A. Wang, Omega Optics, Inc. (United States); C. Lin, R. T. Chen, The Univ. of Texas at Austin (United States)

We experimentally demonstrate a 300 micron long silicon photonic crystal slot waveguide near-infrared absorption spectrometer for the spectroscopic detection of xylene in water. A lab-on-chip integrated infrared spectrometer for remote, in-situ sensing and spectroscopic identification of volatile organic compound contamination in ground water and drinking water is highly desired. Defect engineered photonic crystals, with sub-micron dimensions have demonstrated high sensitivity to trace volumes of analytes; however exact identification of analyte through spectroscopic signatures has not been demonstrated. Based on the Beer-Lambert law, the photonic crystal slot waveguide device combines slow light phenomenon in photonic crystal waveguides with large optical field intensity in a low index slot at the center of the photonic crystal waveguide to enhance interaction between the optical field and the analyte and thus effectively increases the optical absorption path length. The waveguide is fabricated on a silicon-on-insulator wafer with standard CMOS fabrication steps. We integrate a PDMS sensing phase for xylene extraction from water. Transmission spectrum through the PDMS coated photonic crystal slot waveguide is measured in presence and absence of xylene in water and absorbance determined from difference in transmission. Three absorbance maxima were observed in the near-infrared corresponding to xylene absorbance maxima at 1674nm, 1697nm and 1720nm. Xylene concentrations up to 100ppb (v/v) (86 microgram/L) in water were measured. Remote monitoring is enabled by optical fibers; our device is five times more sensitive to xylene in water than existing devices in near-infrared on more than an order of magnitude smaller length scale.

8032-22, Session 5

A compact and portable IR analyzer: progress of a MOEMS FT-IR system for MIR sensing

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We show results on the progress in system integration and the performance of a new MOEMS based FT-IR spectrometer. This collaborative research within an EU-FP7 research project aims at showing the feasibility of miniaturised high performance infrared spectroscopic chemical analysers. Exploiting the high analyte selectivity of the mid-IR paired with the inherent sensitivity of an FT-IR spectrometer, such devices could be used in a wide range of applications, from air monitoring over in-line real-time process control to security monitoring. For practical applicability in these fields, appropriate detection limits and spectral quality standards have to be met. The presented system measures in the range 5000 - 700 1/cm at a spectral resolution better than 10 1/cm, which clearly outmatches previous MOEMS based spectrometer approaches. In addition to a newly developed MOEMS device capable of a piston-like movement of 1mm in total, which enables the spectral performance, a specially developed miniature IR source and a dedicated, highly sensitive thermoelectrically cooled MCT detector complete the fully integrated spectrometer system. A further technological advantage is the rapid-scan capability. The MOEMS devices oscillate at 500 Hz, i.e. a spectrometer based on this device can acquire 1,000 scans per second in forward-backward mode. The interplay of all these components with the challenges in system integration will be described in detail and experimental results will be shown, presenting a significant step forward in smart spectroscopic sensors, microsystems technology and vibrational spectroscopy instrumentation.

8032-23, Session 5

Portable coherent frequency domain terahertz spectrometer

J. R. Demers, R. T. Logan, Jr., B. L. Kasper, EMCORE Corp. (United States)

Coherent frequency-domain THz spectrometers with high signal-to-noise ratio and wide tuning range have been realized and shown to be capable of collecting unique spectroscopic signatures of many materials of interest, particularly explosives. Previous implementations have been as expensive laboratory instruments that are not easily field-portable. We will present the characterization of a portable, battery operated, highly-compact, coherent THz frequency domain spectrometer which may be operated via an integrated touch-screen control. Approximately 30 cm long, 25 cm wide and 8 cm high with a mass under 4.5 kg, the objectives of size, power and cost reduction are realized by leveraging commercial telecom fiber-optic packaging techniques to manufacture the 14-pin butterfly packaged DFB/DBR lasers with PM fiber outputs and integrated isolators and the compact photomixing head units. While the THz source and detector heads can be contained in the aforementioned footprint, they may also be detached and operated at considerable distances from the control electronics due to the integrated electronics and fiber optic coupling. Following characterization of the signal to noise levels and further demonstration of non-contact reflection measurements and THz phase-control, the system will be employed to characterize several compounds. The details of these measurements will be presented at the conference.

8032-24, Session 5

Compact remote Raman and LIBS system for detection of minerals, water, ices, and atmospheric gases for planetary exploration

A. K. Misra, S. K. Sharma, T. E. Acosta, D. E. Bates, Univ. of Hawai'i (United States)

At the University of Hawaii, we have developed a compact, portable remote Raman and Laser-Induced Breakdown Spectroscopy (LIBS) system with 532 nm pulsed laser for planetary explorations under NASA's Mars Instrument Development Program. The compact time-resolved remote Raman and LIBS system consists of (i) a regular 85 mm Nikon (F/1.8) camera lens with clear aperture of 50 mm as collection optics, (ii) a miniature spectrograph that is 1/14th in volume in comparison to commercial spectrograph from Kaiser Optical Systems Inc., (iii) a custom mini-ICCD detector, and (iv) a small frequency-doubled 532 nm Nd:YAG pulsed laser with a 10x beam expander (30 mJ/pulse, 20 Hz). In the standoff Raman mode the system is capable of measuring various minerals, water, ices, and atmospheric gases from a 50 meter range with a 10 s integration time. At shorter distances of 10 m or less, good quality Raman spectra can be obtained within 1 s. The time-gated system is capable of detecting both the target mineral as well as the atmospheric gases before the target using their Raman fingerprints. Various materials can easily be identified through glass, plastic, and water media. The time gating capability makes the system insensitive to window material which is highly desirable for future missions to Venus where instruments are expected to be within the lander. The standoff LIBS range is 10 m and LIBS spectra of various minerals can be obtained with single laser pulse excitation. The standoff LIBS capability provides additional elemental verification of the targeted material.

8032-25, Session 5

Combination optical and mass spectrometric technologies for detection of chemical and biological threats to the food supply

R. A. Lodder, Univ. of Kentucky (United States)

The Labeled Release (LR) technology is adapted from the Mars Viking mission. In the LR experiment, a sample of Martian soil was inoculated with a drop of very dilute aqueous nutrient solution. The nutrients (7 molecules that were Miller-Urey products) were tagged with radioactive14C. The air above the soil was monitored for the evolution of radioactive 14CO2 gas as evidence that microorganisms in the soil had metabolized one or more of the nutrients. The Quechers method [M. Anastassiades, S.J. Lehotay, D. Stajnbaher and F.J. Schenck, J AOAC Int 86 (2003) 412.] is now employed by many pesticide residue analysts. Some modifications to the original Quechers method have been applied to assure efficient extraction of pH dependent compounds (e.g. phenoxyalcanoic acids), to minimize degradation of susceptible compounds (e.g. base and acid labile pesticides) and to broaden the spectrum of matrices covered. Buffering with citrate salts has been instituted in the initial extraction/partitioning step to fine-tune the pH to a compromise value of 5 to 5.5, where most acid and base labile pesticides are satisfactorily stabilized. To improve stability of base-labile compounds in the sample extracts, a small amount of formic acid is added to the final extract following PSA cleanup, while acidic pesticides are analyzed from the raw extract before PSA cleanup. When using matrices with a high amount of chlorophylls, the cleanup procedure is enhanced by adding GCB to the PSA at amounts, where some residual chlorophyll remains in the final extract. Dry commodities such as cereals, dried fruits or teas necessitate the addition of water before extraction to weaken interactions of pesticides with the matrix and to assure sufficient partitioning. Even commodities with a high lipid load, such as avocados or plant oils, can be employed. However, due to a partition to the lipid phase, highly nonpolar pesticides give comparatively low but usually consistent recoveries. Co-extracted lipids in the extracts can be removed by a freezing-out step or a C18 cleanup.

8032-26, Session 6

Real-time smart fluorescence sensor platform

M. Ponstingl, Custom Sensors & Technology (United States)

Several process industries including pharmaceutical manufacturing require a high degree of measurement assurance and control. Therefore during PAT implementation consideration must be given to the sensor robustness. A novel sensor platform has been developed that provides various versatile and smart sensing features to meet this requirement allowing for effective real-time monitoring and process control. This small, self-contained design and multifaceted mechanical/automation attributes provide for a robust sensor that can be deployed across a wide range of manufacturing scenarios. The smart sensing features include communication interrupt store-forward, integrated thermal monitoring, dynamic referencing, intensity normalization, diagnostics, power management, and other supporting internal sensors. This provides the ability for real-time monitoring thereby reducing process upsets and manufacturing process time. This platform has been demonstrated with the GMP compliant light-induced fluorescence sensor in which an LED array is used allowing for a tailored analytical response. The resulting exceptional sensitivity, wide dynamic range, and extremely low detection limits create a desirable analytical solution. In addition to the smart sensing platform, analytical merits of the current LIF sensor derivative and future derivatives will be discussed.

8032-27, Session 6

TerraSpec Explorer real-time mineral analysis for economic mineral deposit exploration

B. Curtiss, ASD, Inc. (United States)

Reflectance spectroscopy is widely used in the mining industry to identify and map potential new economic deposits. Reflectance spectroscopy allows for rapid characterization of many individual minerals and alteration assemblages associated with economic mineral deposits. Since alteration often extends beyond an economic deposit, mapping of alteration zones provides a useful vector to the predicted mineralization. Deposit types such as epithermal gold, porphyry copper, diamonds, uranium, rare earths, and base metals all have diagnostic mineral signatures that define alteration assemblages associated with these deposits. A real-time mineral analysis software package has been developed that provides a flexible and easily extended environment for the real-time analysis of spectra collect with the ASD TerraSpec portable mineral analyzer. An experienced user is responsible for system calibration and configuration for a specific exploration project. This allows a less experienced users to focus on utilizing the system for analysis of geologic samples in the field without the need for that user to have in-depth reflectance spectroscopy expertise. While the system has been developed with a base set of real-time analysis applications, it also serves as a platform for the use of third-parties real-time analysis application modules.

8032-28, Session 6

Sensing of FWHM and peak wavelength for LEDs via a low-cost filter-based spectrum sensor and PSO optimization

C. Chang, C. Chen, N. Lin, National Taipei Univ. of Technology (Taiwan); U. Kurokawa, B. I. Choi, nanoLambda (United States)

LEDs are solid-state semiconductor light sources and are widely used in a variety of applications. For the measurement of LEDs, peak wavelength and full-width-half-maximum (FWHM) are the two key parameters to characterize the spectra of monotonic LED lights. Recently, spectrometers are increasingly being used for LED measurements. However, conventional spectrometers are often expensive, fragile and hard to implement into a portable device. Accordingly, a low-cost filter-array spectrum sensor for accurate LED measurement is proposed in this work. The sensing system is possible for rigid implementation in a chip-scale size.

To achieve a high quality measurement, it is critical to create a mapping criterion converting the data from sensor outputs to the measurement parameters of peak wavelength and FWHM. To facilitate the mapping process, Gaussian curves are introduced as the basis functions for the estimation. While a trivial solution is to place the Gaussian basis functions with evenly-spaced center-locations and a predetermined width for all Gaussian functions, we realized the transmittance characteristics of the spectral filters may not be optimal for the estimation of weightings for these evenly-spaced Gaussian functions. Notably, the center locations, the widths, as well as the numbers of Gaussian curves need to be optimized to deliver the best estimation result.

Since an exhaustive search for parameters of the Gaussian functions is not practical, Particle Swarm Optimization (PSO) is adopted to solve the problem. As a result, a low-cost filter-array spectrum sensor with measurement accuracy less than 1nm is demonstrated in this work.

8032-29, Session 6

A compact, fast, wide-field imaging spectrometer system

P. Mouroulis, B. van Gorp, V. White, J. M. Mumolo, R. G. Holm, Jet Propulsion Lab. (United States); D. Hebert, M. Feldman, Louisiana State Univ. (United States)

We present test results from a breadboard F/1.4 imaging spectrometer system with a 36 degree field of view, covering the spectral range 500-1650 nm (InGaAs detector array). The spectrometer incorporates an unobscured two-mirror aspheric telescope with snap-on assembly, and a Dyson spectrometer with a bilinear groove profile, steeply concave, extended-response diffraction grating made with gray scale x-ray lithography techniques.

8032-30, Session 6

High-speed resonant FTIR spectrometer

J. Rentz Dupuis, D. L. Carlson, D. J. Mansur, T. Evans, R. M. Vaillancourt, J. R. Engel, OPTRA, Inc. (United States); B. B. Engel, Nelson Air Corp. (United States)

OPTRA is developing a high speed resonant Fourier transform infrared (HSR-FTIR) spectrometer for surface contaminant measurements via time resolved thermal luminescence. This system incorporates a multipass reciprocating interferometer and a resonant mirror structure to accomplish the scanning. The resonant scanning approach significantly reduces the mirror drive power requirement relative to a non-resonant system. Because the spectral range is limited only by the spectral transmission and reflection properties of the components, this system can be made as broadband as a typical FTIR spectrometer system. For this application, the system will operate over the 700 - 1400 cm-1 spectral range with 8 cm-1 spectral resolution.

This paper presents a preliminary design of an HSR-FTIR prototype and includes the results from a series of breadboard tests of the resonant mirror assembly.

8032-31, Session 7

Compact high-resolution VIS/NIR hyperspectral sensor

T. Hyvärinen, E. Herrala, Specim Spectral Imaging Ltd. (Finland)

Current hyperspectral imagers are either bulky with good performance, or compact with only moderate performance. This paper presents a new hyperspectral technology which overcomes this drawback, and makes it possible to integrate extremely compact and high performance push-broom hyperspectral imagers for Unmanned Aerial Vehicles (UAV) and other demanding applications.

Hyperspectral imagers in VIS/NIR, SWIR, MWIR and LWIR spectral ranges have been implemented. This paper presents the measured performance attributes for a VIS/NIR imager which covers 380 to 1000 nm with spectral resolution of 2.5 nm. The key innovation is a new

imaging spectrograph design which employs both transmissive and reflective optics in order to achieve high light throughput and large spatial image size in an extremely compact format. High light throughput is created by numerical aperture of F/2.4 and high diffraction efficiency. Image distortions are negligible, keystone being 2 um and smile 0.1 nm across the full focal plane image size of 24 mm (spatially) x 6 m (spectrally). The spectrograph optics is integrated with an advanced camera which provides 1300 spatial pixels and image rate of 200 Hz. A higher resolution version with 2000 spatial pixels runs up to 120 images/s. The camera achieves, with spectral binning to 5 nm, an outstanding SNR of 800:1, orders of magnitude higher than any current compact VIS/NIR imager. The imager weighs only 1.4 kg, including fore optics, imaging spectrograph with shutter, and camera, in a format optimized for installation in small payload compartments and gimbals.

In addition to laboratory characterization, results from a field and UAV test mission are presented.

8032-32, Session 7

Advances in hyperspectral LWIR pushbroom imagers

H. Holma, A. Mattila, T. Hyvärinen, Specim Spectral Imaging Ltd. (Finland)

Two designs of hyperspectral imagers have been under extensive development: one utilizing a microbolometer and another with an MCT FPA. Both imagers employ pushbroom imaging spectrograph with transmission grating and on-axis optics.

The main emphasis has been on developing high performance instruments with good image quality and compact size for various industrial and remote sensing application requirements. A big challenge in realizing these goals without considerable cooling of the whole instrument is to control the instrument radiation. This applies especially in a hyperspectral instrument, where the optical signal from the target is spread spectrally over tens of pixels, but the instrument radiation is not dispersed. Without any suppression, the instrument radiation can overwhelm the radiation from the target even by 1000 times.

As a means to handle the instrument radiation and its variation, BMC-technique (background monitoring on-chip), background suppression and instrument temperature stabilization are employed with an MCT-detector. The design and implementation of this high performance, extremely compact imager with 8 to 12 um spectral range has now been completed. The performance with 84 spectral bands and 384 spatial samples has been experimentally verified and NESR of 18 mW/(m2srum) at 10 um wavelength for 300 K target has been achieved. This results to SNR of more than 500.

The first version of LWIR imager based on a microbolometer detector array was introduced in 2009. An improved design of this imager has now been finalized. The sensititvity of the imager has improved by a factor of 3 and SNR by 15%.

8032-33, Session 7

Near-infrared imaging spectroscopy for counterfeit drug detection

T. Arnold, M. De Biasio, R. Leitner, CTR Carinthian Tech Research AG (Austria)

Pharmaceutical counterfeiting is a significant issue in the healthcare community as well as for the pharmaceutical industry worldwide. The use of counterfeit medicines can result in treatment failure or even death. A rapid screening technique such as near infrared (NIR) spectroscopy could aid in the search for and identification of counterfeit drugs. This work presents a comparison of two laboratory NIR imaging systems and the chemo metric analysis of the acquired spectroscopic image data. The first imaging system utilizes a NIR liquid crystal tuneable filter and is designed for the investigation of stationary objects. The second imaging system utilizes a NIR imaging spectrograph and is designed for the fast analysis of moving objects on a conveyor belt. Several drugs in form of tablets and capsules were analyzed. Spectral unmixing techniques were applied to the mixed reflectance spectra to identify constituent parts of the investigated drugs. The results show that NIR spectroscopic imaging can be used for contactless detection and identification of a variety of counterfeit drugs.

8032-34, Session 7

Advanced algorithms for the identification of mixtures using condensed-phase FT-IR spectroscopy

J. Arnó, G. Andersson, D. Levy, C. A. Tomczyk, P. Zou, E. Zuidema, Smiths Detection (United States)

FT-IR spectroscopy is the technology of choice to identify solid and liquid phase unknown samples. Advances in instrument portability have made possible the use of FT-IR spectroscopy in emergency response and military field applications. The samples collected in those harsh environments are rarely pure and typically contain multiple chemical species in water, sand, or inorganic matrices. In such critical applications it is also desired that, in addition to broad chemical identification, the user is warned immediately if the sample contains a threat or target class material (i.e. biological, narcotic, explosive). The next generation HazMatID 360 combines the ruggedized design and functionality of the current HazMatID with advanced mixture analysis algorithms. The advanced FT-IR instrument allows effective chemical assessment of samples that may contain one or more interfering materials like water or dirt. The algorithm was the result of years of cumulative experience based on thousands of real-life spectra sent to our Reachback spectral analysis service by customers in the field. The HazMatID 360 combines mixture analysis with threat detection and chemical hazard classification capabilities to provide, in record time, crucial information to the user. This paper will provide an overview of the software and algorithm enhancements, in addition to examples of improved performance in mixture identification.

8032-35, Session 7

Development of simple algorithm for direct and rapid determination of cotton maturity from FT-IR spectroscopy

Y. Liu, G. R. Gamble, D. P. Thibodeaux, Agricultural Research Service (United States)

Immature fibers, which have little cell wall thickening relative to fiber perimeter, were found to be prone to entanglement formation during mechanical processing and also to alter the desired color appearance in dyed yarn and fabric products. Microscopic and instrumental devices have been developed to measure cotton fiber maturity in direct and indirect ways. In general, microscope based direct method can distinguish mature fibers from immature ones, but the degree of maturity is difficult to assess because the procedure is subjective and depends on one's judgment to assign the fibers into appropriate class. Indirect methods require a large number of samples (> 0.5 g), utilize air-flow measurements and a theoretical approach, and most notably, depend on direct methods' maturity references to calibrate the systems for the accuracy and performance. As a different approach, we collected FT-IR/ATR spectra of mature and immature cottons and discovered significant spectral differences between the two types of fibers. The characteristic IR bands were identified and further used to develop a simple three-band algorithm for determining fiber maturity. The result was validated by independent measurements of image analysis, AFIS, and HVI that are commonly practiced in cotton industry. This procedure has the potential to be a rapid, routine, accurate, and nondestructive measuring technique, because it needs minimal sample preparation and is based on the structural differences between immature and mature fibers.

Conference 8033: Advanced Photon Counting Techniques V

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8033-01, Session 1

Improving the performance of silicon single-photon avalanche diodes

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Many applications require high performance Single Photon Avalanche Diodes (SPAD) either as single pixels or as small arrays of detectors. Although currently available silicon devices reached remarkable performance, nevertheless further improvements are needed in order to meet the requirements of most demanding time-resolved techniques. In particular, one of the most significant challenges today is the development of a planar technology, compatible with the fabrication of arrays, capable of reaching a high Photon Detection Efficiency (PDE) in the near infrared region while maintaining a temporal resolution better than 100ps; moreover this target must be attained without a significant degradation in the other detector performance such as the Dark Counting Rate (DCR) and the Afterpulsing Probabiliy (AP).

In this paper we will discuss the influence of the device structure on its performance and the trade-offs that the device engineer must face. Then we will present a new structure aimed at overcoming these trade-offs and obtaining simultaneously good PDE and temporal response. Performance attainable with this structure will be discussed through device simulation and through experimental results.

8033-02, Session 1

Tau-SPAD: a new red sensitive single-photon counting module

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Single Photon Avalanche Diodes (SPADs) are valuable detectors in photon counting applications and used for numerous applications. They are typically used for detecting very low-light levels as they feature a much higher photon detection efficiency than photomultiplier tubes. Very often SPADs are combined with Time-Correlated Single Photon Counting (TCSPC) electronics for time-resolved data acquisition and the temporal resolution (“jitter”) of a SPAD is therefore one of the key parameters for selecting a detector.

In this presentation we will show technical data and first application results from a new type of red sensitive single photon counting module (“Tau-SPAD”), which is targeted at timing applications, most prominently in the area of Single Molecule Spectroscopy (SMS). The t-SPAD photon counting module combines Laser Components’ ultra-low noise VLoK silicon avalanche photodiode with specially developed quenching and readout electronics from PicoQuant. It features an extremely high photon detection efficiency of 75% at 670 nm and can be used to detect single photons over the 400 nm to 1100 nm wavelength range. The timing jitter of the output of the t-SPAD can be as low as 350ps, making it suitable for time-resolved fluorescence detection applications. We will show first application results including Fluorescence Lifetime Imaging (FLIM), Single Molecule Spectroscopy and Fluorescence Correlation Spectroscopy. First photon coincidence correlation measurements also show that the typical afterglow effect of SPADs is comparably low for these new SPADs.

8033-03, Session 1

Characterization of commercial single-photon counting modules in operational mode

T. Ferreira da Silva, Inmetro (Brazil) and Pontifícia Univ. Católica do Rio de Janeiro (Brazil); G. B. Xavier, J. P. von der Weid, Pontifícia Univ. Católica do Rio de Janeiro (Brazil)

The characterization of the main performance parameters of single-photon counting modules (SPCMs) is important for several applications in which high accuracy is desired. We present here a method based on the histogram analysis of the time interval between consecutive detection events at a gated avalanche photodiode-based SPCMs. Our analytical model allows the simultaneous extraction of the quantum efficiency, the dark count and the afterpulse probabilities parameters directly from the data acquired under normal operational conditions.

Two commercial SPCMs were characterized under several different settings. A continuous-wave laser was attenuated to achieve a low average number of photons per detection gate. A 100 MSamples/s acquisition board was used to acquire both the output detection and input trigger electrical signals. The number of gates opened between consecutive detections was arranged in a histogram. Our model was fit to the data and the parameters of interest were extracted. The optical source attenuation and the gating frequency were varied and the behavior of the detectors tracked. The frequency-dependent parameters (carrier detrapping lifetime and afterpulse probability) were analyzed at different gating conditions.

Our analytical model employed a second order approach for the afterpulse term, considering a single dominant type of carriers trap with an associated detrapping lifetime, and it was sufficient to fit the data and matched the histogram “knee”, a signature of this effect. The results show good agreement with the individually obtained parameters for both detectors.

8033-04, Session 1

Characterization of photon-counting detector responsivity for nonlinear two-photon absorption process

S. E. Sburlan, W. H. Farr, Jet Propulsion Lab. (United States)

A non-linear two-photon absorption process has been demonstrated and characterized on a Geiger mode detector array. A precisely focused beam from a 1550 nm source can trigger the two-photon process with 30 μW of power on a Si detector, which normally has no response at this wavelength for unfocused light. We present responsivity measurements and compare to the single-photon absorption mechanism. Such a system can provide more than 100 dB of isolation from sources at the bandgap wavelength of 1064 nm. One such application is deep space optical communication where it is desirable to track an uplink beam on the same detector array that monitors the downlink signal for feedback control. A flight transceiver for communication between Earth and Mars is being designed based on this principle, which will detect two wavelengths simultaneously using both single and two-photon absorption processes.

8033-05, Session 1

Frequency up-conversion single-photon detectors for quantum communication systems

L. Ma, O. T. Slattery, X. Tang, National Institute of Standards and Technology (United States)

In a quantum communication system, such as quantum key distribution, single photon detectors are key devices, whose detection efficiency, dark count rate and temporal resolution greatly influence the system speed and error rate, and further influence the security of the system. However, the performance of current commercially available single photon detectors for near infrared (NIR) is a bottleneck for high speed quantum communication systems. As an alternative, frequency upconversion technology can convert photons at NIR into the visible or near visible range for highly efficient detection using Si-APDs.

Recently, upconversion single photon detectors based on a periodically poled lithium niobate (PPLN) waveguide have been developed with high detection efficiency in the NIR, including the important telecommunication bands. The dark count rate, a major concern for upconversion detectors, can be significantly reduced by using a longer wavelength pump and proper filtration. In a quantum communication system equipped with an upconversion detector, the clock rate is normally determined by the temporal resolution of the Si-APD. By using a spectrally and temporally distinct pump pulse scheme, the temporal resolution of an upconversion detector can be improved to exceed the resolution of the Si-APD itself. Therefore the data transmission rate for the quantum communication system can be increased.

In this presentation, we present our research and development of upconversion single photon detectors based on PPLN waveguides with highly efficient, low dark count rate and high temporal resolution performance.. We also present their applications in quantum communication systems and single photon source characterization.

8033-06, Session 1

Geiger-mode operation of Ge on Si avalanche photodiodes

Z. Lu, Univ. of Virginia (United States); Y. Kang, Intel Corp. (United States); J. C. Campbell, Univ. of Virginia (United States)

Single photon detection is reported for Ge on Si separate-absorption-charge-multiplication (SACM) avalanche photodiodes. Single photon detection efficiency (SPDE) of 14%, 10^8 s-1 dark count rate and timing resolution of 117ps were achieved. Afterpulsing versus operating frequency is also analyzed.

8033-07, Session 2

CMOS SPAD: from fundamentals to single-photon imaging and applications

E. Charbon, M. W. Fishburn, Y. Maruyama, Technische Univ. Delft (Netherlands)

Single-photon avalanche diode (SPAD) technology has received significant attention in recent years, thanks to the growing number of applications where time-correlated and photon-starved imaging is required. Very recently, the emergence of CMOS SPADs and SPAD arrays has become a booster to SPAD based microscopy, nanoscopy, and bio-detection. The promise of CMOS SPAD devices is multifold and it includes miniaturization, speed, and massive parallelization. New functionality however comes at a price, namely higher noise, lower timing resolution, and low fill factor.

The paper is divided in two parts. In the first part we present an extensive theoretical analysis of a variety of structures built in CMOS and accurate models that show a very close match to measured results. Thanks to the proposed models, techniques are developed and successfully tested to reduce dark counts in SPADs and to add new functionality. Other important performance measures are analyzed, such time resolution, photon detection probability, and afterpulsing, as well as parameters important for arrays, such as crosstalk, and uniformity of noise and sensitivity across large arrays and batches.

In the second segment of the paper, we present designs based on SPAD technology that are aimed at advanced time-resolved imaging and detection of single molecules. The designs were tested for use as rangefinders, microscopy and nanoscopy cameras, and low-cost tools for point-of-care applications. The versatility and flexibility of the latter was demonstrated with in vitro experiments while in vivo experiments are underway.

8033-08, Session 2

MEGAFRAME: a fully integrated, time-resolved 160x128 SPAD pixel array with microconcentrators

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Time-resolved image sensors enabling picosecond resolutions over large formats are needed in many advanced imaging fields, from fluorescence lifetime imaging microscopy (FLIM) to fluorescence correlation spectroscopy, from optical rangefinding to positron emission tomography. Integrated single-photon avalanche diode (SPAD) technology embodies the new frontiers of time-resolved imaging, namely better instrument response function, increased throughput, and lower costs. SPADs have recently developed into large arrays with increasingly complex on-chip functionality. With larger array sizes however, the readout has become a serious bottleneck and thus several solutions have emerged, from hybrid designs to fully parallel pixel arrays.

In this paper we present a fully integrated deep-submicron CMOS sensor comprising an array of 160x128 pixels with on-pixel SPADs for single-photon detection and ultra-fast electronics for time-to-digital conversion. The sensor has a throughput of 50,000 symbols per pixel per second and it is capable of resolving events separated by 55 picoseconds over a range of 55 nanoseconds. The dark count rate of the sensor has a median of 50 Hertz, while the photon detection probability peaks at 465 nanometers, covering the entire visible range and parts of the near UV and IR spectra. The relatively low fill factor is partially reclaimed by an array of microconcentrators deposited directly on the sensor with a post-processing step.

The suitability of the sensor is shown through experimental use in a standard FLIM setup, where a two-dye system was used to enhance different features of an organism imaged in vitro in photon-starved regime.

8033-09, Session 2

Smart-pixel for 3D ranging imagers based on single-photon avalanche diode and time-to-digital converter

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We present a novel “smart-pixel” suitable for implementation of monolithic single-photon imaging arrays aimed at 3D ranging applications by means of the direct time-of-flight detection (like LIDAR systems), but also for photon timing applications (like FLIM, FCS, FRET). The pixel includes a Single-Photon Avalanche Diode (SPAD) and a Time-to-Digital Converter (TDC) monolithically designed and manufactured in the same chip, and it is able to detect single photons and to measure in-pixel the time delay between a START signal (e.g. laser excitation, LIDAR flash) and a photon detection (e.g. back reflection from a target object).

In order to provide both wide dynamic range, high time resolution and extreme linearity, we devised a TDC architecture based on an interpolation technique. A “coarse” counter counts the number of reference-clock rising-edges between START and STOP, while high resolution is achieved by means of two interpolators, which measure the time elapsed between START (and STOP) signal and a successive clock edge. In an array with many pixels, multiple STOP channels are needed while just one START channel is necessary if the START event is common to all channels. We report on the design and characterization of prototype circuits, fabricated in a 0.35 μm standard CMOS technology containing complete conversion channels (i.e. 20-μm active-area diameter SPAD, quenching circuitry, and TDC). With a 100-MHz reference clock, the TDC provides a time resolution of 10 ps, a dynamic range of 160 ns and very high conversion linearity.

8033-10, Session 2

Scaling trends of single-photon avalanche diode arrays in nanometer CMOS technology

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Time-resolved, single-photon image sensors with increasingly complex in-pixel and on-chip signal processing are emerging. These have been enabled by low-noise single photon avalanche diode structures (SPADs) compatible with standard digital nanometer CMOS technology. A host of applications from fluorescence lifetime imaging, time-of-flight imaging to positron emission tomography are being addressed. Current array sizes are in the 10’s of kilopixel range with pitch from 25-100um, limited by the SPAD device area, well-spacing and complex electronics. The large pixel pitch and generally small fill-factor, from 1-9%, has prevented access to wafer-scale microlens manufacturing developed for mainstream CMOS image sensors.

In this paper, we propose some approaches to reduce pixel pitch and improve fill-factor of SPAD arrays in nanometer CMOS technologies. A family of scaleable SPAD structures in 130nm and 90nm CMOS will be presented, with device active diameter down to 2um and dark count rate (DCR) as low as 9Hz. Performance trends such as DCR, jitter and photon detection efficiency are studied versus active diameter. To address pixel pitch we introduce a shared buried n-well approach allowing compact arrays containing both NMOS-transistor readout circuitry and SPAD devices. A pixel pitch of 5um has been achieved in 90nm CMOS technology, offering the potential for future megapixel single photon image sensors.

8033-11, Session 3

Resonant cavity silicon GPD arrays

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Silicon Geiger avalanche Photodiode (GPD) technology has seen tremendous development, mainly due to its capability of fabricating single-photon detectors. To realize the potential of the Geiger avalanche process, and capitalize on the silicon GPD technology and readout circuitry (ROIC) specifically developed for GPD operation we are working on extending the spectral range of the silicon to NIR and MWIR. We use the resonant cavity enhancement (RCE) to increase their quantum efficiency at 1030nm.

In this paper we review the performance of the silicon GPD array technology developed at aPeak, the expected performance enhancement in NIR, as well as the design and technological challenges to achieve uniform quantum efficiency response over large arrays. For manufacturability and processing cost reasons, we implement the RCE at the end of the GPD+ROIC array fabrication. Attention is paid to the thermal budget and chemistry processing limitations.

We have demonstrated the integration of readout with GPD sensors and RCE at the back end of the fabrication process. The challenge still remains in tuning the resonant cavity with nm resolution over large GPD arrays. We present some in-process methods to map and monitor the cavity resonance as well as their effectiveness in controlling the cavity performance.

8033-12, Session 3

MBE back-illuminated silicon Geiger-mode avalanche photodiodes for enhanced ultra-violet response

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A wafer-scale back-illumination process has been developed for silicon Geiger-mode avalanche photodiode arrays that use Molecular Beam Epitaxy (MBE) backside passivation. Critical to this fabrication is support of the thin (< 10 um) detector during the MBE growth by an oxide-bonded full-thickness silicon wafer. This back-illumination process enables low-dark-count-rate, single-photon detectors with MBE passivation, extending the detector’s high quantum efficiency in the visible to deep ultra-violet wavelengths. This paper reviews our process for fabricating MBE back-illuminated silicon Geiger-mode avalanche photodiode arrays and presents characterization of initial test devices.

8033-13, Session 3

Techniques for improved performances of direct-detection three-dimensional imaging laser radar system using Geiger-mode avalanche photodiode

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Direct-detection three-dimensional imaging laser radar system using Geiger-mode avalanche photodiode (GAPD) is investigated in order to acquire three-dimensional images of objects at a long distance (more than 100m). Due to extremely high sensitivity of the GAPD, a laser radar system using GAPD is not only advantageous in terms of ranging a distant object but also in detecting a target screened by a sparse obstacle located in front of it. Both laser radar systems using a single-pixel GAPD and 1x8-pixel GAPD focal plane array as detectors are built up and analyzed. Passively Q-switched microchip laser is used as a laser source and a compact peripheral component interconnect system, which includes a time-to-digital converter (TDC), is set up. With both the GAPD having short dead-time (45ns) and the TDC functioning multi-stop acquisition, the system operates in a multi-hit mode. Three-dimensional images taken by the laser radar systems are shown. The theoretical model of the laser radar system using GAPD is also established with Poisson statistics and proved experimentally. Both the single-shot precision and the dependence of the precision on the effective number of laser pulses are shown. Range walk reduction and autofocus techniques are proposed and demonstrated experimentally; they improve the accuracy and transverse spatial resolution of the laser radar system, respectively.

8033-14, Session 3

Design considerations for high-altitude altimetry and lidar systems incorporating single-photon avalanche diode detectors

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The weak pulse energies detected in compact high-altitude altimeters and lidar systems, particularly those with small sized apertures, suggests that single photon avalanche diode (SPAD) detectors are candidates for use in such applications. However, the statistical nature of the photon-counting process; the long dead-times typical of some SPADs after a detection event and the restriction that these detectors can only detect a maximum of one photon in a single return pulse have often precluded their use. The high pulse energy lasers typically used in such long range applications often have a low repetition rate which conflicts with the requirement for high data acquisition rates.

Lidar systems incorporating scanning optics and a single SPAD have been reported in literature. In a push-broom configuration a platform moving at high velocity requires a rapid scan. It is probable that for a point detector-based scanning system where the average number of photons per return pulse is low and/or the repetition rate of the laser is low, that there will be insufficient data per measurement point to determine range. Recently, 2d-arrays of silicon and InGaAs(P)/InP SPAD detectors have been developed and are now commercially available. Each pixel is essentially independent from the other pixels in the array (except for some cross-talk) and each pixel has its own quench and timing circuitry. These features make these arrays attractive candidates for high altitude lidar applications.

This paper will report on the simulated performance of a high altitude altimeter and lidar system containing a 2d-array of SPAD detectors and will discuss the trade-off between using high pulse energy-low repetition rate periodic laser pulses against lower pulse energy-high clock rate optical waveform. The results from of a long range, dual-wavelength, ground-based range-finder incorporating a silicon SPAD detector will be presented.

8033-15, Session 3

Geiger-mode avalanche photodiode focal plane arrays for 3D imaging ladar

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We describe the performance of focal plane arrays (FPAs) with a 32 x 128 format based on Geiger-mode avalanche diodes (GmAPD) for 3 D LADAR imaging applications requiring single photon sensitivity. These FPAs incorporate InP/InGaAsP GmAPDs within each pixel for the detection of single photons at 1.06 um with high efficiency and low dark count rates. GmAPD arrays are hybridized to CMOS read-out integrated circuits (ROICs) that provide independent pixel-level time-of-flight measurements and have been designed to operate at frame rates exceeding 100 kHz. The per-pixel dark count rate (DCR) is ~20 kHz with modest Peltier cooling to 253 K at a pixel-level photon detection efficiency (PDE) of 40% (excluding microlens array fill factor losses). These FPAs have been demonstrated with 100% pixel operability and excellent DCR uniformity, with < 0.1% of the 4096 pixels exhibiting elevated DCR values between 100 and 175 kHz. These arrays represent a migration to 50 um pitch from our earlier 32 x 32 GmAPD FPA format with 100 um pitch. Crosstalk is largest between nearest neighbor pixels, and crosstalk mitigation features have limited this near-neighbor crosstalk to ~1% under typical operating conditions. For an average pixel-level PDE of 35%, the total cumulative crosstalk probability per detected photon is ~15%. As expected, crosstalk probability exhibits - on average - a decrease for larger distances between pixels, but as in our 32 x 32 arrays, local maxima in this crosstalk probability vs. distance relationship are observed for certain specific inter-pixel geometries.

8033-16, Session 4

Compact eight-channel SPAD module for photon timing applications

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Multi-dimensional Time Correlated Single Photon Counting has nowadays reached a prominent position among analytical techniques employed in the medical and biological fields. The development of instruments able to perform simultaneously temporal and spectral fluorescence analysis (sFLIM) is limited by the performances of single-photon detector; in fact currently available arrays cannot satisfy simultaneously all the requirements.

To face this rising quest, a fully-parallel eight channel module, based on a monolithic Single Photon Avalanche Diode (SPAD) array with great temporal resolution, high Photon Detection Efficiency (PDE) and low Dark Counting Rate (DCR), has been designed and fabricated.

The system relies on a novel architecture of the single pixel, based on the integration of the timing pick-up circuit next to the photodetector, making the negative effects of electrical and optical crosstalk on photon timing performances negligible. To this aim, the custom technological process used to fabricate the SPAD has been modified, allowing the integration of MOS transistors without impairing the structure and the performances of the detector. The single channel is complemented by an external Active Quenching Circuit, fabricated in a standard CMOS technology, that ensures high maximum counting rate (> 5 MHz) and low afterpulsing (< 1.5%). Finally, the output timing signals are read and conditioned by a proper CMOS electronics. The complete pixel shows a very good temporal resolution of about 55 ps (FWHM).

The module also includes a double-stage Peltier, driven by a closed loop controller that allows a minimum operation temperature of about -15°C, and a liquid cooling system.

8033-18, Session 4

A technique to measure afterpulse probabilities in InGaAs SPADs at nanosecond time scales with sub-pico Coulomb avalanche charge

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While recent advances in InGaAs SPADs have resulted in devices with improved detection efficiency at telecom wavelengths, afterpulsing remains a significant issue limiting performance. It is well known that afterpulsing can be reduced by reducing the avalanche current, which can be achieved by applying bias gates of duration less than 1 ns. In this

operating regime the avalanche signal becomes difficult to discriminate from the large capacitive transient created by the applied bias pulse. We present a technique for accurate cancellation of the capacitive transient at short (nanosecond) time scales, for the purpose of making afterpulse measurements. We use the previously reported technique of taking the difference between an applied bias pulse and a reference pulse. We find that careful impedance matching can significantly suppress reflections, allowing the system to operate with only 2 ns between the bias and reference pulses. This allows us to apply a second bias/reference pulse pair only 4.8 ns after the first. The capacitive transient is canceled well enough so that avalanche events with total charge below 100 fC can be discriminated. In this manner, we can make afterpulse measurements in a biasing regime comparable to that of the self-differencing technique, a measurement not heretofore made. We present preliminary results supporting counting at rates above 100 MHz with low afterpulse probabilities.

8033-19, Session 4

High-speed characterization of quantum systems in the near infrared

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We experimentally investigate the operation and applications of high-speed single photon detection in the near-infrared with indium gallium arsenide avalanche photodiodes (InGaAs APDs). We discuss our design of detectors based on the self-differencing electronic post-processing technique, and how they operate at repetition rates of 200 MHz and greater. The design shows promise for miniaturization; it features fully integrated components that are all home-made or commercially available on printed circuit boards. We also report progress on implementing these detectors in several quantum optics experiments. First, our detector is used to characterize a spontaneous parametric downconversion (SPDC) source of photon pairs. Photons at 811 and 1531 nm wavelengths are created by 530 nm laser pulses that propagate at a 50 MHz repetition rate into a nonlinear, periodically-poled lithium niobate (PPLN) crystal. We collect correlation statistics stemming from detections of the 811 nm photons with a commercial APD, and the 1531 nm photons with our self-differencing detector. As well, we use the detectors in our 100 MHz clocked quantum key distribution (QKD) system, thereby removing a major bottleneck towards high secret key rates. Our QKD system generates qubits with attenuated laser pulses, utilizes the BB84 protocol supplemented by decoy states and quantum frames, and is implemented over a 12 km real-world fibre-optic link.

8033-20, Session 4

InGaAs/InP negative feedback avalanche diodes (NFADs)

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In recent years substantial effort has been made in material growth, device design and fabrication, and driving circuitry to improve the performance of InGaAs/InP single photon avalanche diodes (SPADs) operated in Geiger mode. Despite these efforts, InGaAs/InP SPADs are constrained by certain performance limitations due to the inherent positive feedback involved in the avalanche process. With the goal of overcoming some of these performance limitations, we have successfully designed and implemented thin film resistors monolithically integrated with InGaAs/InP SPADs to provide a negative feedback mechanism to regulate the avalanche sizes. The monolithic integration scheme ensures very small parasitic effects, results in fast quenching of avalanches, and allows for wafer level integration which facilitates the fabrication of array structures. We will discuss the design and operation of NFAD devices and performance characterization of these devices. Basic characteristics of NFADs such as pulse response, quenching and recovery dynamics will be described. We will also present device performance parameters such as photon detection efficiency (PDE), dark count rate (DCR) and afterpulsing probability (Pap). InGaAs/InP negative feedback avalanche diodes with different device sizes and quenching resistances have been designed and fabricated. Devices with ~10% PDE and acceptable Pap has been realized, which provides a simple, practical solution for a range of photon counting applications.

8033-21, Session 4

Active hold-off characterization of negative avalanche feedback single-photon detectors

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InGaAs avalanche photodiodes employing internal negative avalanche feedback are an interesting new class of semiconductor single photon detector that operate similar to classic Geiger-mode avalanche photodiodes, but are self-quenching and self-resetting. They exhibit output pulse widths on the order of one to a few nanoseconds with excess noise factors near one at typical gains above 10^5, and can even generate a photon number response in some configurations, similar to the photon number response of an Intensified Photodiode (IPD) or Visible Light Photon Counter (VLPC) detector.

A significant issue with this new technology class has been large after-pulsing rates, as even though the charge through the avalanche junction is much lower than a classic Geiger mode detector, there is no fixed hold-off time for trapped charge to detrap without creating a new avalanche pulse with high probability. Thus we have found it useful to compare NAF detectors performance in both their native free-running regimes and in a controlled hold-off regime using a passive-quench, active-reset circuit and shall present comparison characterization data of single photon detection efficiency, dark count rate, and after-pulsing rate in the two regimes of devices from multiple vendors.

8033-22, Session 5

HgCdTe APD-based linear-mode photon counting components and ladar receivers

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No abstract available

8033-23, Session 5

Linear-mode photon counting with the noiseless gain HgCdTe e-APD

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In the linear photon counting APD, photons and dark events are counted without disruption such that very closely spaced temporal avalanche events can be distinguished. This feature is an advantage over existing Geiger Mode photon counters that require a recovery time after an event is registered. The MWIR cutoff HgCdTe electron avalanche photodiode (e-APD) is capable of achieving gains high enough to allow the detection of single photons in the linear mode of operation. In addition, the lack of excess noise in the HgCdTe e-APD (excess noise factor near 1.0) implies a high probability of detect with a low false alarm rate. A semi-empirical end-to-end model for a linear mode photon counting (LMPC) system has been developed which includes the HgCdTe e-APD and a very high gain-bandwidth RTIA and comparator circuit. The two key empirical aspects

of the model are (1) the gain versus bias voltage curve and (2) the dark current versus bias curves. Using the model, we develop key operational parameters of interest to users of LMPC detectors. In addition preliminary APD dark current vs. bias data will be presented that indicate an input dark current dark count rate of < 20,000 count/s at an APD gain of 500. Extrapolation of this data to a gain of 1000 predicts a dark count rate of < 100,000 count/s. A 2x8 photon counting FPA (vertically integrated eAPD detector array and readout) has been designed, fabricated, and operated. Initial characterization results will be presented.

8033-24, Session 5

Application of an end-to-end linear mode photon-counting (LMPC) model to noiseless-gain HgCdTe APDs

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Linear-Mode Photon Counting (LMPC) detection requires a combined system consisting of a semiconductor avalanche photodiode (APD), a high-gain low-noise amplifier, and a comparator circuit. Modeling these aspects of the system requires a combination of semiconductor detector theory, electronics circuit modeling, and classic decision theory. Because of the disparate skills involved, it is difficult to both model and build such devices. In this paper, we present an end-to-end model of the LMPC detector that contains all the required theory. As part of the decision theory aspect of LMPC technology, we present a three-dimensional Receiver Optimization Characteristic (ROC) curve that contains the key performance aspects of the LMPC as a function of the comparator threshold setting. We present nomenclature and specification methods that provide for unambiguous definitions of the combined-system detector performance for both the fabricators and users of LMPC technology. Finally, we apply the model to a noiseless-gain HgCdTe APD, ROIC, and comparator device being developed by DRS and GEOST in order to demonstrate the photon counting end result, as well as several key intermediate values in the signal chain.

8033-25, Session 5

New developments in nano-injection-based imagers

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Since our demonstration of the first nano-injector photodetector in 2007, and subsequent achievements of low jitter, high internal gain, and low excess noise, we have developed the necessary processing steps towards realization of nano-injector based imagers. We present our results for the first and second generations of these imagers that working at room and TE achievable temperatures. These imagers show much improved sensitivity and speed compared with conventional imagers at SWIR wavelengths. For example, we achieve an overall system noise of 28e- rms at 0.5 ms integration time (1,950 frames/sec) and negligible excess noise, while using an off-the-shelf readout integrated circuit (ROIC) with ~700e- rms noise. Despite the dramatic noise level improvement, the device performance is severely limited by the architecture of the conventional ROIC, especially at longer integration times. In order to solve this problem, we are working on optimizing the device layers and geometry to lower the current to improve the compatibility with existing ROICs designed for unity gain devices.
In parallel, we are working on novel ROIC designs. Since the imager performance is almost independent of the ROIC noise levels, new ROICs with very small pixel pitch and high dynamic range are expected.

8033-26, Session 5

Opportunities for single-photon detection using visible light photon counters

J. Kim, Duke Univ. (United States)

Visible light photon counters (VLPCs) are solid-state devices providing high quantum efficiency (QE) photon detection (>88%) with photon number resolving capability and low timing jitter (~250 ps). VLPC features high QE in the 400-1,000 nm wavelength range, as the main photon absorption mechanism is provided by electron-hole pair generation across the silicon bandgap. The QE in the UV is reduced since the photon is predominantly absorbed in the top contact layer. The thickness of the top contact layer can be reduced to dramatically increase the QE of the VLPC in the 300-400 nm range, which is crucial for ion trap quantum computing applications. The QE of VLPC drops dramatically for photons with wavelengths above 1 μm due to lack of photon absorption across the silicon bandgap. The direct photo-ionization of arsenic impurities used in the gain region of VLPCs allows single photon detection for photons with wavelengths up to 28 μm, but the absorption coefficient of this photo-ionization process is low in the 1-2μm range. We describe a strategy for engineering an infrared photon counter that features high QE photon detection (potentially over 90%) in the telecom wavelength range using novel illumination geometry. In this paper, we will discuss the optical and electrical operating principles of VLPCs, and propose a range of device optimization paths that improves various aspects of VLPC for advanced quantum optics and quantum information processing experiments.

8033-27, Session 6

CMOS solid state photomultipliers for ultra-low light levels

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Detection of single photons is crucial for a number of applications. Though the dark current is present, Geiger photodiodes (GPD) provide large gains (106) with an insignificant amount of multiplication noise. When the GPD is operated above the reverse bias breakdown, the diode can breakdown due to charged pairs induced from random noise (typically thermal) or incident photons. The GPD is built in a similar manner as an avalanche photodiode with guard rings but requires some external quenching circuit. The avalanche process in a GPD is self-sustained, and a resistor in series with the GPD drops the voltage across the diode to stop the avalanche. The GPD is a binary device, as only one photon is needed to trigger an avalanche, regardless of the number of incident photons. A solid-state photomultiplier (SSPM) is an array of GPDs, and the output of the SSPM is proportional to the incident light intensity, providing a replacement for photomultiplier tubes.

We have developed CMOS SSPMs using a commercial fabrication process for applications within the fields of science, medicine, and the military. We present results on the operation of these devices for low-light levels, discussing all of the signal and noise considerations associated with SSPMs. Single photon detection from the level of a GPD to small SSPMs to larger SSPMs is shown. Advances in the technology consists of an integrated comparator at the diode level of the device, providing a discrete response for the number of photons detected out to hundreds of GPDs triggered.

8033-28, Session 7

High-performance HPD for photon counting

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We have developed a new Hybrid Photo-Detector (HPD) with fast time response and high timing resolution. GaAsP, GaAs and Bialkali are available for the photocathode material. GaAsP photocathode type has high quantum efficiency of about 45% around the wavelength of 500 nm. GaAs photocathode has wide spectral response from 380 nm to 890 nm. The size of the effective area is 3 mm in diameter for GaAsP and GaAs photocathode, 6 mm in diameter for Bialkali photocathode. They are much wider than that of a SPAD. The emitted photoelectrons from photocathode are multiplied by a total of 1E5 by electron bombardment and succeeding avalanche multiplication process in avalanche diode. The pulse height for single photon is approximately 2 mV with 50 ohm load impedance, and they can be easily observed by a fast-response oscilloscope. The rise and fall times for the impulse light are approximately 400 ps, much faster than the conventional PMTs. The timing resolution for single photon for GaAsP photocathode type was evaluated with a constant fraction discriminator and a time to amplitude converter, the results was 110 ps FWHM. Since the pulse width of laser in this measurement were evaluated to be 77 ps, the timing resolution of the GaAsP HPD was calculated to be approximately 80 ps. The developed hybrid photodetector has very simple structure, it means good vacuum quality. And the multiplication process for photoelectrons is done only inside of avalanche diode, leading to very little probability of ion feedback. These advantages make possible the achievement of extremely low afterpulse characteristics.

8033-29, Session 7

Multichannel intensified photodiode at near infrared

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The Intevac Intensified Photodiode (IPD) combines state-of-the-art solid state and vacuum technology to circumvent many of the difficulties of other NIR photon counting detectors. The IPD utilizes a high quantum efficiency transferred electron (TE) InGaAsP or InGaAs photocathode for high optical sensitivity in the 920-1300nm or 920nm-1650nm wavelength range, respectively. Electrons emitted into vacuum from the TE photocathode are accelerated and focused onto an electron bombarded APD anode biased below breakdown in non-Geiger mode operation. This combination of TE-photocathode and APD anode separated by a vacuum gap provides high counting efficiency of 0.30, extremely low noise for multiple photon discrimination, large active area, and counting rates approaching 1GHz with little or no after-pulsing. This paper will present recent results on an InGaAsP photocathode IPD optimized for use at 1060nm that utilizes imaging electron optics and a 4x4 APD anode array.

8033-30, Session 8

Development of large area fast microchannel plate photo-detectors from Argonne National Laboratory

K. Byrum, Argonne National Lab. (United States)

We report on a cross-disciplined, multi-institutional effort to develop large-scale ‘frugal’ photo-detectors capable of mm-scale space resolution and psec-range time resolution. This new R&D effort is being led by the High Energy Physics branch within DOE. The large-area fast photodetectors being developed would have applications in many fields, including particle physics, astrophysics, nuclear sciences, and medical imaging. The basic approach uses novel inexpensive micro channel pores (MCP). Two MCP substrates have been studied. Anodic Aluminum oxide which is a self-ordering fabrication of pore structure in aluminum by anodization and glass capillary substrates. The borosilicate glass capillary MCPs appear to be the most easily scalable to large areas. The MCPs are functionalized using a technique called atomic layer deposition (ALD) which is a process that deposits materials in an atomic layer by layer fashion. A custom anode readout and fast sampling (GHz) ASIC is being developed as part of the large area fast photodetector project. High quantum efficiency photocathodes are being explored along with traditional multi-alkali photocathodes. Two parallel packaging designs are being pursued. A conventional more expensive ceramic design which uses a single brazed joint for sealing the ceramic tube walls compared to previous commercial tube methods which use many brazes. The alternative higher risk, but potentially more economical method uses inexpensive glass and bonding methods. The R&D program includes detailed testing and end to end simulations.

8033-31, Session 8

Microchannel plate imaging photon counters for ultraviolet through NIR detection with high time resolution

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The topic of this paper is on photon counting microchannel plate (MCP) imaging detectors using the cross strip anodes (XS) and cross delay line (XDL) anodes. Both types have been implemented in open face devices for UV, soft X-ray and particle detection, and as sealed tube detectors with visible/NIR photocathodes. Our development of the XS anode scheme has been demonstrated with open face laboratory detector formats of 22mm and 40mm using pairs of microchannel plates. These demonstrate good spatial resolution (better than 20um FWHM) using low MCP gain (5 x 105) and encode photons at greater than 5 MHz rates. We have also made sealed tubes with supergen-II photocathodes for coverage of a wide range of wavelengths and peak efficiencies approaching 20%. XS tubes with 18mm active area and XDL tubes with 25mm active area have also been built and tested. Typical results show spatial resolution of ~30um, and individual photon events can be time stamped with ~1 ns timing accuracy. One of these systems is now installed on the SALT 10m optical telescope in South Africa. Such detector systems have applications in many fields including, airborne and space situational awareness, high-speed adaptive optics, astronomy of transient and time-variable sources, optical metrology, three-dimensional imaging, biological single-molecule fluorescence lifetime microscopy, optical and infrared tomography, and hybrid mass spectrometry.

8033-32, Session 9

Fast superconducting IR single-photon detectors with a microwave reflectometry readout

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We are developing nanoscale superconducting transition edge sensors (TESs) for IR single-photon detection. The significantly reduced volume compared to traditional TESs allows for similar energy resolution to be achieved at higher operating temperatures and with faster response times [1]. Coupling of the incident photon is achieved by integrating the nanoscale TES in a planar antenna. Mid-IR detectors are based on a superconducting titanium (Ti) nanobridge with an operating temperature of 0.3 K and microsecond response times. For near-IR detection, the Ti is replaced by niobium, which is operated at 4 K with sub-ns response times.

The speed and sensitivity of these detectors require a readout with large bandwidth and negligible backaction. We have implemented such a readout using microwave reflectometry [2]. The resistance of the detector, designed to be close to 50 ohms, is modified by the detection of a photon. This change in impedance is measured by the change in the reflection of a microwave tone. This technique has the advantage of utilizing available low-noise, broadband microwave amplifiers and cryogenic microwave isolators. Additionally, this readout technique is amenable to frequency-division multiplexing of a large-format detector array.

[1] J. Wei, D. Olaya, B.S. Karasik, S.V. Pereverzev, A.V. Sergeev, and M.E. Gershenson, Nature Nanotech. 3, 496 (2008)

[2] D.F. Santavicca, B. Reulet, B.S. Karasik, S.V. Pereverzev, D. Olaya, M.E. Gershenson, L. Frunzio, and D.E. Prober, Appl. Phys. Lett. 96, 083505 (2010)

8033-33, Session 9

Photon-number resolving transition edge sensors and superconducting nanowire single-photon detectors for optical Schrödinger cat state generation

T. Gerrits, National Institute of Standards and Technology (United States)

We have generated and measured an approximation of an optical Schrödinger cat state by photon subtraction from squeezed vacuum. Using the photon-number resolving transition edge sensors (TES), we were able to subtract up to three photons from a squeezed light pulse and generate an optical Schrödinger cat state with fidelity of 0.59 and a size of 2.75 photons. These promising results show that high efficiency detectors with photon number resolving capabilities are the route to perform quantum information experiments with high generation rates and cat states with mean photon number greater than 2. However, the fidelity of the generated state is still low when using it for quantum information applications. Increasing the purity of the squeezer is the key to generating high fidelity cat states. We present our recent results on engineering a squeezing source designed to produce a pure squeezed state. The second-order correlation data (g(2)), joint spectral distribution and Hong-Ou-Mandel (HOM) interference data points towards a highly pure squeezed output state. The characterization of this source was done using the photon-number resolving TES. This detector allowed us to measure the photon number statistics of the output state in the HOM experiment, as well as the determination of the g(2) values from the photon-number statistics. A superconducting nanowire single photon detector was used to determine the joint spectral distribution of our squeezer. The fast response time and the low dark count rate of this detector allowed directly measuring the joint spectral distribution.

8033-35, Session 9

Performance of large-area superconducting nanowire single-photon detectors

V. Anant, Photon Spot Inc. (United States) and Massachusetts Institute of Technology (United States)

For many applications, such as free-space optical communication and quantum key distribution, superconducting nanowire detectors offer the unique advantage of simultaneously providing high efficiencies at near-infrared frequencies, fast nanosecond-scale dead-times, sub-100 picosecond jitter, and low dark-counts. In other applications, having a few nanosecond dead-time is not critical, but instead other performance criteria such as efficiency and timing resolution are more important. By trading-off nanosecond dead-times, large-area single-element detectors promise more efficient and robust optical coupling over smaller area detectors without the complexities involved with multielement detectors. However, it is challenging to fabricate large-area detectors that do not suffer from critical current-suppression due to film defects or fabrication imperfections (constrictions). We report on the performance of large-area superconducting nanowire detectors.

8033-36, Session 9

Developments in efficiency, timing, and implementations of superconducting nanowire single-photon detectors

M. G. Tanner, J. A. O'Connor, C. M. Natarajan, R. H. Hadfield, Heriot-Watt Univ. (United Kingdom)

We describe progress on Superconducting Nanowire Single Photon Detectors (SNSPDs) operating at telecommunications wavelengths whilst exploiting low dark count rates and picosecond timing resolution.

With a 225nm thermally grown SiO2 layer below the detector to provide cavity enhancement of the photon absorption probability, we demonstrate significantly increased system efficiency for NbTiN SNSPDs fabricated on silicon substrates. Practical fibre-coupled efficiencies in excess of 20% at 1310 nm are achieved with dark count rates ~1 kHz. We report on the extension of this technique towards higher quality cavities, and describe progress on integration of SNSPDs with optical waveguides as an alternative approach to efficient photon coupling.

Uniformity of the patterned superconducting nanowire is key to obtaining an output pulse when a photon has been absorbed. We present both electrical characterisation of device uniformity, and results of nano-optical studies performed with a miniaturised confocal microscope of large-area meander wire structures. This technique also yields information about variation in the timing response across non-uniform devices.

We discuss examples of practical uses of SNSPDs' favourable characteristics, including a distributed fibre raman sensor which exploits the ~100ps timing accuracy to yield centimetre resolution temperature-sensing along an optic fibre. Such a distributed fibre sensor is an attractive alternative to point sensors, where a single flexible fibre line could replace thousands of individual sensors, simplifying the installation and readout in long structures, wide areas, or 3D constructions.

The authors acknowledge the collaboration of the research groups of S.W. Nam at NIST (USA), T. M. Klapwijk and V. Zwiller at TU Delft (The Netherlands), Z. Wang and M Sasaki at NICT (Japan), Z. Barber and M. Blamire at the University of Cambridge (UK) and funding support from the EPSRC and The Royal Society (UK).

8033-37, Session 9

Putting superconducting nanowire detectors to use

V. Zwiller, S. N. Dorenbos, E. Bermudez-Urena, R. Heeres, M. Witteveen, H. Azzouz, P. Forndiaz, T. Fuse, T. Zijlstra, T. Klapwijk, Technische Univ. Delft (Netherlands)

We fabricate and implement superconducting single photon detectors in a range of quantum optics experiments. We follow several routes to boost the detection efficiency: integration into resonant cavities, implementation of plasmonic waveguides and coupling to planar waveguides. We illustrate the advantages with measurements performed on single quantum dots emitting in the IR.

Integration of our detectors allows for on-chip quantum optics experiments where emitters, waveguides and detectors are integrated to perform quantum plasmonics experiments at the single plasmon level. We demonstrate single plasmon detection.

To access other detection ranges in the mid-IR, we have fabricated detectors based on superconducting materials with lower gap. A NbSi detector will be presented. We will also show that our detectors have potential applications beyond photon detection: single beta particle detection shows that this new type of detector might find additional uses in radioactive decay detection at the nanometer scale.

8033-38, Session 10

Single-photon emission from artificial atoms in diamond

H. Fedder, F. Jelezko, J. Wrachtrup, Univ. Stuttgart (Germany)

Diamond does not only shine as the hardest known material, and the material with the largest thermal conductivity known, in recent years it also became a big player in single photon applications and quantum information processing. I will highlight some of the recent results on diamond photonics and spintronics including tailored single photon emission, coherent spin manipulation, as well as nano scale sensing using nano diamonds. The focus will be on engineering of the single photon emission through resonant optical cavities, plasmonic structures and integrated diamond photonics. I will pay special attention to the achieved single photon characteristics relevant to transform limited operation, spectral stability and photon-spin entanglement. Future perspectives of diamond based single photon sources for quantum information science and stable markers for fluorescence microscopy and nano scale sensing will be given.

8033-39, Session 10

Efficient narrow-band PDC source for quantum interfaces

S. V. Polyakov, A. Muller, A. Ling, N. Borjemscaia, E. B. Flagg, A. L. Migdall, G. S. Solomon, National Institute of Standards and Technology (United States)

We report on a parametric down-conversion (PDC) single photon source that is capable of producing heralded single photons that are compatible with quantum dot (QD) photons. Highly dissimilar photon sources will not generally produce indistinguishable photons. However, due to flexibility of PDC sources it is possible to manipulate a photon wavefunction without loss of quantum coherence. Here, we engineer the PDC process to yield high spectral brightness, narrow band output. Recent progress in quantum information has added practical interest to this fundamental problem. Establishing quantum networks requires interconnects between dissimilar nodes that are unlikely to be made from the same physical systems.

Our PDC source is a periodically-poled KTP quasi-phase matched (type-II) crystal with a pump at 410 nm. Detection of a photon at 740 nm heralds the presence of a photon at 918 nm. To match the spectral linewidths of the 918 nm PDC photon to that of QD, we use a tunable spectral filter made of a volume Bragg grating (VBG) and a Fabry-Perot cavity. The transmission peak of the filter is overlapped with the emission of the QD by sending the QD light through the filter and optimizing its transmittance and then locking the cavity to a reference laser. Another VBG is used to increase the heralding probability by rejecting heralds whose conjugates are far from the target wavelength. This source creates 1000 heralded single photons per second that are compatible with a QD. The detected coincidence-to-accidentals ratio for our source is >60.

8033-40, Session 11

Quantum information with photon-number-resolved measurements of continuous-wave quantum sources

O. Pfister, Univ. of Virginia (United States)

Experimental quantum optical measurements are not yet routinely conducted in the photon number (Fock-state) basis. Until very recently, only two other options were available: the first one is to use single-photon sensitive, but inefficient detectors such as avalanche photodiodes and photomultipliers, which, when used along coincidence detection, can yield good quantum signals. The other approach is to measure the quantum fields by use of near-unity quantum efficiency PIN photodiodes that do not, however, have single-photon resolution, due to their dark-current noise. The latter approach forms the basis for squeezed and Einstein-Podolsky-Rosen (EPR), a.k.a. continuous-variable, quantum measurements. Recently, photodetection at both single-photon resolution and near-unity quantum efficiency has been demonstrated with superconducting transition-edge sensor (TES) detectors by Sae Woo Nam's group at NIST. Because such detectors enable Fock-state measurement (and preparation), they usher in a novel regime of "quantum-only" optics, beyond non-classical optics. This is epitomized by the negativity of the Wigner function of Fock states, negativity which is a prerequisite for Bell inequality violation and universal quantum computing. We report here on the preliminary implementation of photon-number-resolved detection of continuous-wave, continuous-variable-entangled optical beams, by use of NIST TES detectors. The optical beams have sub-picowatt power and are emitted by mode-filtered parametric downconversion. They are weakly entangled in the EPR sense but are nonetheless strongly photon-number correlated and clearly nonclassical photon-number correlations were evidenced.

8033-41, Session 11

Improved correlation determination for intensity correlation interferometers

P. D. Dao, P. J. McNicholl, Air Force Research Lab. (United States)

To image astronomical objects with an intensity interferometer, the classical Hanbury Brown technique involves multiplying the photocurrents fluctuations recorded with two telescopes separated by a variable distance. The correlation of the intensity fluctuations is a measure of the magnitude of the coherence or mutual intensity and can be used to retrieve the intensity distribution of the source using the Van Cittert-Zernike theorem. In low light observations, it has been proposed by others that coincidence counting can improve the effective bandwidth of the measurement, hence improving the SNR if the photon arrival times can be estimated with high accuracy. In the second case, count fluctuations are measured instead of intensity fluctuations. Those are the two measurement techniques currently reported in the literature. Since the successful width measurements of bright stars by HB in the 70's, advances in photodetectors have created opportunities to apply intensity interferometry to dimmer and more challenging man-made objects. However to overcome inherently low SNRs, more work is required to take advantage of the high speed photodetectors. We propose a new technique of measuring correlation in the low light regime that ensures maximum bandwidth allowed by the reproducibility of the photoelectron pulse. Theory and tests based on simulated signals will be discussed.

The object's radiance distribution can be retrieved from correlation coefficients measured at all baselines since they are the square of the magnitude of the Fourier transform of the radiance. While coincidence counting improves correlation SNR, it's not optimum. Hard binning the photon pulses and choosing the smallest bin width allowed by the uncertainty of photon arrival times turn out to be not optimum and too conservative. We propose a soft binning process that automatically maximizes SNR. Also, in support the use of counting sensors in ICI, the effect of dead time on correlation statistics will be studied with Monte Carlo technique. The overall theme of the paper is a new ICI technique based on direct processing of high speed detectors. Demonstration of phase retrieval and object recovery will be performed on simulated correlation data.

8033-42, Session 11

Photon correlation spectroscopy in ophthalmology

L. L. Rovati, Univ. degli Studi di Modena e Reggio Emilia (Italy)

On the basis of the theory of light scattering, photon correlation spectroscopy has been used for more than three decades to study ocular tissues. From first in-vitro experiments to study cataractogenesis, this

approach has been extended to characterize semiquantitatively in-vivo all the ocular tissues from cornea to retina and choroid. This non-invasive method is emerging not only as a diagnostic tool in ophthalmology but measurements performed on the ocular tissues can be useful also in the diagnostic process of systemic pathologies such as Alzheimer and diabetes. Photon correlation technique is used to analyze light scattered from ocular tissue. When analyzing ocular refractive tissue, the single Rayleigh scattering approximation allows us to use the theory of dynamic light scattering (also known as quasi-elastic light scattering) whereas in the case of turbid tissues like sclera, retina and choroid, multiple scattering should be considered and thus diffusion wave spectroscopy theory is used.

In order to acquire high quality measurement data for the experiments, serious attention has to be paid to the detection and processing system. Detector noise, sensitivity, dead time and afterpulsing lead to a direct or indirect corruption of the acquired correlation function whereas counting range and resolution should be optimized to take into account the wide variability of the ocular tissue optical characteristics. As an example, note as the intensity of the light scattered backward, and thus the photon count rate, form crystalline lens increases approximately exponentially with age.

8033-43, Session 12

A SPAD-based hybrid system for time-gated fluorescence measurements

A. Gola, L. Pancheri, C. Piemonte, D. Stoppa, Fondazione Bruno Kessler (Italy)

In the paper we propose a hybrid approach to Single photon counting with Single-Photon Avalanche Diodes (SPAD), in which the detector is built in dedicated technology and is read by a CMOS ASIC. This solution allows for an independent optimization of both detector and readout channels, while maintaining all the benefits of an integrated readout electronics. This system should be considered as a prototype for a larger system composed of an array of detectors coupled to a multi-channel ASIC. Potential application are in the fields of Fluorescence Lifetime Imaging Microscopy and Time of Flight 3D Imaging. The SPADs under test have been fabricated at the Fondazione Bruno Kessler (FBK) and have two different sizes, with an active area of 310 um2 and 2830 um2. The ASIC, designed at FBK too, is built in 0.35 um CMOS technology and has 16 channels, each one featuring an active quenching circuit and four time-gated 8-bit counters, with programmable gate duration ranging from 0.8 ns up to 10 ns. In the paper we will discuss the performances of the two detectors, in terms of Dark Count Rate, Gain and Afterpulsing Probability, with respect to relevant system parameters, such as Overvoltage, Off Time and Precharge Time. We will also discuss the results of the experimental characterization of the prototype in FLIM measurements. Preliminary results show low dark count rate, in the order of 100 Hz at room temperature for the smaller devices.

8033-44, Session 12

New photon-counting detectors for single-molecule fluorescence spectroscopy and imaging

X. Michalet, R. A. Colyer, G. Scalia, S. Weiss, Univ. of California, Los Angeles (United States); O. H. Siegmund, A. S. Tremsin, J. V. Vallerga, Univ. of California, Berkeley (United States); F. A. Villa, F. Guerrieri, I. Rech, S. Tisa, A. Gulinatti, F. Zappa, M. Ghioni, S. Cova, Politecnico di Milano (Italy)

Solution-based single-molecule fluorescence spectroscopy is a powerful new experimental approach with applications in all fields of natural sciences. Two typical geometries can be used for these experiments: point and wide-field excitation and detection.

In point-like geometries, the basic concept is to excite and collect light from a very small volume (typically femtoliter) and work in a concentration regime resulting in rare burst-like events corresponding to the transit of a single-molecule. Those events are accumulated over time to achieve proper statistical accuracy. Therefore the advantage of extreme sensitivity is somewhat counterbalanced by a very long acquisition time. One way to speed up data acquisition is parallelization. Here we will discuss a general approach to address this issue, using a multispot excitation and detection geometry that can accommodate different types of novel highly-parallel detector arrays. We will illustrate the potential of this approach with fluorescence correlation spectroscopy (FCS) and single-molecule fluorescence measurements obtained with different novel multipixel single-photon counting detectors.

In wide-field geometries, the same issues of background reduction and single-molecule concentration apply, but the duration of the experiment is fixed by the time scale of the studied process and the survival time of the fluorescent probe. Temporal resolution on the other hand, is limited by signal-to-noise and/or detector resolution. The latter is easily reached in current experiments, which calls for new detector concepts. We will briefly present our recent results in this domain.

8033-45, Session 12

Single-photon detectors for ultra-low-voltage time-resolved emission measurements of VLSI circuits

F. Stellari, P. Song, A. J. Weger, IBM Thomas J. Watson Research Ctr. (United States)

Time Resolved Emission (TRE), also known as Picosecond Imaging Circuit Analysis (PICA), technique, based on the collection of near infrared light emitted by hot carriers in the transistor channel, is an invaluable method for detecting timing related faults in VLSI circuits. However, the trend of the semiconductor industry towards smaller devices and lower supply voltages caused significant decrease in detectable light, thus challenging the conventional PICA detectors.

Alternative detectors with significantly better Quantum Efficiency (QE) started to be adopted by several tool vendors: the Superconducting Single Photon Detector (SSPD) and the InGaAs Single Photon Avalanche Diode (SPAD). Although both detectors offer only single-point detection capability, they allow a significant reduction of the acquisition time. IBM was an early adopter of the SSPD technology in both its prototype and commercial version showing very promising performance and results. However, optical tool limitations, chip cooling technology, vendor consolidations, and cost favored the adoption of the InGaAs SPAD for the larger test and failure analysis community. In more recent years, the InGaAs SPAD technology has also started to run out of steam. At the same time, the SSPD has continued to improve from its early stage, thanks to the attention from other scientific communities.

In this paper we summarize the best performance results with both types detector and present the first direct comparison of the performance of the two detectors using the same test vehicle and the same microscope optics to collect the hot-carrier emission.

Conference 8034: Photonic Microdevices/ Microstructures for Sensing III

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8034-01, Session 1

Photonic crystal microarray nanopatform for high-throughput detection of biomolecules for diagnostic assays

S. Chakravarty, Omega Optics, Inc. (United States); W. Lai, The Univ. of Texas at Austin (United States); X. A. Wang, Omega Optics, Inc. (United States); C. Lin, R. T. Chen, The Univ. of Texas at Austin (United States)

We experimentally demonstrate a compact label-free biomolecule microarray for personalized and specific diagnostic assays of various cancers and allergies using two-dimensional photonic crystal microcavity devices. Defect engineered photonic crystals, with sub-micron dimensions have already demonstrated high sensitivity to trace volumes of analyte. While bio-sensing has been demonstrated in these devices with single biomolecules, no previous effort has been made to extend device capability to microarrays. Particularly, patterning of multiple biomolecules on a few micron scales has faced challenges of binding exclusivity and binding specificity. Our device consists of an array of photonic crystal microcavity resonators coupled to a single photonic crystal waveguide that give rise to minima in the photonic crystal waveguide transmission spectrum at the resonance frequency of the microcavity. When a probe biomolecule binds specifically to a target biomolecule, coated exclusively on the microcavity, shift in microcavity resonance translates to corresponding shift in photonic crystal waveguide transmission minimum. The method eliminates labeling for analyte identification. The impact of our novel and robust multi-analyte sensing technique can reach much further than the field of biomolecular science and diagnostics. Our research will lead to highly parallel detection of multiple diseases and thus a low-cost personalized diagnostic assay.

8034-02, Session 1

Identification of biological agents using surface-enhanced Raman scattering

T. L. Paxon, F. J. Mondello, R. S. Duthie, C. Renko, A. A. Burns, GE Global Research (United States); M. Lesaicherre, Morpho Detection (United States)

GE Global Research Center, in collaboration with Morpho Detection, Inc has developed an assay scheme for the identification of biological agents using Surface Enhanced Raman Scattering (SERS). Specifically, unique spectroscopic signatures are generated using SERS tags consisting of individual glass-encapsulated gold nanoparticles and surface-bound reporter molecules. These SERS tags are modified with a capture moiety specific to the antigen of interest, and serve as a spectroscopic label in a bead-based sandwich assay. Assays are being developed for a variety of pathogens, and this presentation will focus on aspects of assay development, optimization, stabilization and validation.

8034-03, Session 1

A new generation of mid-infrared sensors based on quantum cascade laser

H. Mohseni, Northwestern Univ. (United States)

The mid-infrared (mid-IR) spectral region is of great importance in biosensing because of its specific sensitivity to a large number of molecular building blocks. Chip scale biosensor operating in the mid-infrared region of the optical spectrum has remained out of reach until the recent development of highly efficient semiconductor light source known as quantum cascade laser (QCL). We show our new results towards a chip-scale label-fee biosensor, using integrated plasmonic structures and microfluidics directly on the QCL lasers.

8034-04, Session 1

Immobilization of aptamers onto unmodified glass surfaces for affordable biosensors

R. Chen, C. Surman, R. A. Potyrailo, A. Pris, GE Global Research (United States); E. A. Holwit, V. K. Sorola, J. L. Kiel, Air Force Research Lab. (United States)

Silicon dioxide (SiO2) surfaces are commonly used in photonic biological microsensors for bioreceptor attachment. Immobilization methodologies that provide a reproducible, robust, and highly active performance of attached bioreceptors are critical for the device performance in the field. Functionalization of sensor surface with aptamer receptors provides the opportunity to develop low cost, robust, field deployable sensors. Most aptamer sensors are constructed by covalently linking 5'-modified aptamer probes to a derivatized surface such as amino-silane or streptavidin on top of silane coated surfaces. Both modification of aptamer probes and surface functionalization add cost and variability to sensor development. There have been reports of using UV crosslinking to directly immobilize DNAs with poly(T)10-poly(C)10 tails on an unmodified glass surface for hybridization. We have expanded this strategy using thrombin-binding aptamers with three different tail modifications. They all showed specific binding to fluorescently labeled thrombin compared to the control sequence. PolyT20 and polyT40 modified aptamer behaved similarly and both had more binding than poly poly(T)10-poly(C)10 modified aptamer, which may be due to that the interactions between the C bases and G-quardruplex affect polyTC modified aptamers target binding capability. The aptamer microarrays prepared using this method also showed stronger and more reproducible results with shorter incubation periods than biotinylated aptamer immobilized on commercial streptavidin slides. In conclusion, our results show that using PolyT-tagged aptamer probes immobilized on an unmodified glass surface is a robust, very straightforward, and inexpensive method for preparing chem/bio sensors.

8034-05, Session 1

Integrated photonic structures for parallel fluorescence and refractive index biosensing

M. M. Lee, T. D. O'Sullivan, A. Cerruto, V. Liu, Stanford Univ. (United States); J. Zhang, The Univ. of New Mexico (United States); O. Levi, Univ. of Toronto (Canada); H. Lee, Korea Univ. (Korea, Republic of); S. R. J. Brueck, The Univ. of New Mexico (United States); S. Fan, J. S. Harris, Stanford Univ. (United States)

Although there is a pressing global need for widely deployable disease detection and monitoring systems, today's solutions for biochemical analysis are often bulky, slow, and expensive. The miniaturization and integration of devices based on micro-arrays of sources, detectors, and active or passive sensing surfaces provides a means to achieve handheld diagnostic capabilities.

In this work, we present a multi-modality optical sensing platform employing integrated Vertical Cavity Surface Emitting Lasers (VCSELs), photodetectors, and filters suitable for portable, real-time analyte detection in aqueous environments. Semiconductor processing

Return to Contents

technology and nano-imprint lithography techniques allow these photonic components to be low-cost and scalable into arrays, with packaged device footprints less than 1 cm2. Fluorescence and refractive index sensors designed to utilize visible and near-infrared VCSELs for low background absorption from analyte delivery fluids are described. We demonstrate in vitro fluorescence sensing of Cy5.5 dye with a detection sensitivity of 5-10nM and photonic crystal slab refractive index sensing with temperature-tunable GaAs-based 670nm-850nm VCSELs. Effects of VCSEL beam polarization, divergence, and packaging geometries are shown. This compact, parallel sensor architecture enables multiplexed, cost-effective on-chip biosensing.

8034-06, Session 2

Fiber-optic intrinsic Fabry-Perot interferometric sensors fabricated by femtosecond lasers

T. Wang, Shanghai Univ. (China)

A recent development in near-IR femtosecond (fs) laser technology has stimulated interest in its application for photonic devices production. Various fiber-optic devices were realized by fs laser with different interaction mechanisms of induced refractive index (RI) change or direct laser ablation machining. In this talk, we will report our latest progress in using fs lasers to fabricate intrinsic Fabry-Perot (F-P) micro-cavity interferometric sensors in silica fiber. The fs lasers are directly focused into the fiber core of the conventional single mode fiber to form an in-core mirror, which is due to the laser induced relative RI difference. Then the F-P micro-cavity is formed with a pair of in-core mirrors and the fiber between them. We will discuss the different writing methods and their relations with the sensor properties. Because the reflection of the in-core mirror is very weak, the insert loss of the F-P micro-cavity sensor is quite low, generally around 0.2 dB. This enables the sensor to have a good multiplexing capability. However, the fringe visibility of this F-P micro-cavity interferometer is still not low. In the experiments, we achieved a high contrast up to ~10 dB, which meets the requirements of most sensing case. We have roundly studied the temperature sensing characteristics of the fs laser fabricated F-P micro-cavity. And the experimental results show that the reflection spectrum shifts linearly against the temperature with the sensitivity of 10.6 pm/ .

8034-07, Session 2

Micro-structured sapphire fiber sensor for measurement of high-temperature in harsh environments

X. Fang, T. Wei, Y. Han, B. Cheng, X. Lan, H. Xiao, Missouri Univ. of Science and Technology (United States)

Optical fiber sensors are very attractive for application in harsh environment due to their proven advantages of compact size, immunity to EMI and resistance to adverse environments. However, the silica-based sensors are no longer practical in the harsh environment with temperature up to about 1100 oC for the relative low softening point compared with the melting point of sapphire fiber. In this paper, we present a novel, assembly-free hybrid extrinsic/intrinsic Fabry-Perot interferometer (HEIFPI) fabricated by femtosecond laser micromachining on sapphire fiber. Due to the inherent high melting point (up to about 2053oC) of single-crystal sapphire fiber, this micro-structure can survive and maintain operational in high-temperature up to 1575 oC with effective and repeatable sensitivity. This paper describes the operating principle, fabrication and evaluation results of the sapphire fiber HEIFPI sensor. The integrated micro-structure provides good long-term stability in extremely high temperature, and possibility to be deployed into the hot zones of advanced power and fuel systems as a temperature sensor.

8034-08, Session 2

Thinned fiber Bragg grating magnetic field sensor with nano-magnetic fluid

C. Zhou, L. Ding, D. Wang, D. Jiang, Wuhan Univ. of Technology (China)

Nano-magnetic fluid is a stable colloidal system where strong magnetic nano-particles are highly dispersed among certain liquids. The refractive index of nano-magnetic fluid may be changed by the external magnetic field. Therefore, through measuring its refractive index, the intensity of the magnetic field can be obtained. Fiber Bragg grating (FBG) is also sensitive to the refractive index surrounding its cladding after the cladding is thinned well. In order to prove the sensitivity of the thinned fiber Bragg grating, series of experiments, such as the fabrication of thinned FBG, precise tuning magnetic field and obtaining spectral characterizations, are carried out. The cladding diameter of FBG is reduced as a thinned FBG by the erosion of hydrofluoric acid solution. The thinned FBG is installed in a capillary tube with nano-magnetic fluid. Using a tunable magnetic field which is produced by a controllable high-current source, the refractive index of magnetic fluid is changed and the Bragg wavelength of FBG is shifted corresponding. Several thinned FBGs have been applied to the measurement of magnetic field. The obtained results show that the thinned FBG sensor with nano-magnetic fluid could be applicable for magnetic field and current sensing.

8034-10, Session 3

Passive infrared sensing using plasmonic resonant dust particles

M. S. Mirotznik, Univ. of Delaware (United States); W. A. Beck, K. Olver, J. W. Little, U.S. Army Research Lab. (United States)

Natural materials reflect and emit infrared radiation in a relatively smooth spectrum. However, by applying resonant structures to the surface of those materials, the reflection and emission spectra can be enhanced or reduced at particular wavelengths. Moreover, by mixing small resonant particles (<50 microns) designed for several different wavelengths we can create an infrared (IR) dust that reflects or emits with a characteristic spectral signature. Such material-by-design particles would be useful for a variety of remote atmospheric sensing applications. In this presentation we will present computational and experimental results of dust particles that can be tuned to preferentially reflect or emit IR radiation within the 8-14 micron band. The particles consist of thin metallic subwavelength gratings patterned on the surface of a simple quarter wavelength cavity. This design creates distinct IR absorption resonances by combining the plasmonic resonance of the grating with the natural resonance of the cavity. We will show that the resonance peaks are easily tuned by either varying the geometry of the grating or thickness of the cavity. We will present a computational design algorithm along with experimental results that validate the design methodology.

8034-11, Session 3

Lithography free fabrication of high-aspect-ratio silver-coated silicon nanopillars as Raman-enhancing substrates for explosives detection

M. S. Schmidt, J. Hübner, A. Boisen, Technical Univ. of Denmark (Denmark)

Surface enhanced Raman scattering (SERS) has been in the spotlight of the chemical and biological sensing community since its discovery. However, the lack of cost effective substrates which provide the necessary Raman enhancement has been a limiting factor in the deployment of mobile SERS based sensors. We have previously

presented a reproducible two-step cleanroom process for producing large areas of SERS active substrates which provide exceptionally large Raman enhancements [1].

Now the fabrication process has been optimized further to fabricate densely packed arrays of high aspect ratio silver nanopillars with large surface area and hence large numbers of electromagnetic “hot spots” which are responsible for the large Raman enhancement. The metalization process has also been optimized for complete coverage of the silicon nanopillars. Using these substrates we demonstrate the capability to detect trace amounts of explosives in the gas phase. As these substrates have superior chemical sensing performance in addition to a more cost effective fabrication process compared to existing commercial substrates it is believed that these novel substrates will be able to make SERS more applicable in mobile explosives detection systems as being carried out in the Xsense project to be deployed in for example landmine clearance actions.

[1] M. S. Schmidt, A. Boisen, “Metal-coated silicon nanopillars with large Raman enhancement for explosives detection”, Advanced Environmental, Chemical, and Biological Sensing Technologies VII, edited by Tuan Vo-Dinh, Robert A. Lieberman, Günter Gauglitz, Proc. of SPIE Vol. 7673, 767303, 2010, doi: 10.1117/12.850198

8034-12, Session 3

On-chip plasmonic systems for ultrasensitive nanospectroscopy

H. Altug, A. A. Yanik, R. Adato, S. Aksu, A. E. Cetin, A. Artar, M. Turkmen, Boston Univ. (United States)

Plasmonics, by localizing light to the sub-wavelength volumes and dramatically enhancing local fields, is enabling myriad of exciting possibilities in bio-detection field . In this talk, I will present integrated on-chip plasmonic systems for ultrasensitive vibrational nanospectroscopy and biodetection.

Infrared spectroscopy, which directly accesses vibrational fingerprints of the biomolecular/chemicals in mid-IR frequencies , is an important identification and analysis tool. Its low sensitivity, however, limits the technique in single molecule/monolayer studies. By engineering plasmonic nano-antenna arrays, we demonstrate an ultra-sensitive surface-enhanced spectroscopy with zepto-mole level sensitivities . Our arrays, supporting collective plasmonic resonances, give much strong near-field intensities than what is achievable with individual antennas . Using such fields, we will show 100,000-fold enhancements of amide band signatures of proteins and detect absorption signals from 145 proteins per antenna.

Finally, we will introduce a low-cost fabrication technique for high-throughput fabrication of engineered infrared plasmonic antenna arrays . The optical response of arrays fabricated by our method is comparable to that of the arrays fabricated by electron-beam lithography. We will show that our method could be used to pattern nanostructures on variety of substrates and surfaces. We will also show nanostencils can be reused multiple times to create series of nanoantenna arrays having identical optical responses.

8034-13, Session 3

Ultra-fast and ultra-sensitive 2,4-dinitrotoluene vapor sensing using gold nanoparticle assembled SERS probes

M. K. Khaing Oo, C. Chang, X. Fan, Univ. of Michigan (United States)

Surface enhanced Raman scattering (SERS) amplifies the small Raman scattering cross section of molecules toward distinguishable signal. It has been advanced into an influential label-free nondestructive method to measure vibrational fingerprints of molecular structures directly. We report here the demonstration of vapor detection of 2,4-dinitrotoluene (2,4-DNT), a typical manufacturing impurity of TNT-based explosives, using reproducible ultra-sensitive SERS substrates, i.e., assembled gold nanoparticles (GNPs) synthesized by a UV photoreduction method. The detection was achieved down to only a few 2,4-DNT molecules in the detection region within a minute of exposure to the DNT vapor at room temperature. The detection time was as short as only 2 seconds with 12 mW 785 nm laser excitation at the SERS substrate. Our study shows that larger GNPs (~ 125 nm in diameter) with higher density exhibit the high sensitivity and the fast detection response, as compared to smaller and lower density GNPs. Dynamic depletion by laser heating indicates that our GNP based sensor is capable of detecting 2,4-DNT on the order of 1 ppb.

8034-14, Session 3

Toward development of nanostructured-integrated optical waveguide sensors with tunable dual-output capacity

M. M. Aslan, TÜBITAK Marmara Research Ctr. (Turkey) and Univ. of Louisville (United States); S. B. Mendes, Univ. of Louisville (United States); K. Allakhverdiev, TÜBITAK Marmara Research Ctr. (Turkey) and Institute of Physics ANAS (Azerbaijan); T. Baykara, TÜBITAK Marmara Research Ctr. (Turkey)

Nanostructured-integrated optical waveguide (n-IOW) sensors are capable to detect molecular interactions at lower concentrations with higher sensitivity comparing with conventional waveguide sensors. In this study, the fabrication and characterization of IOWs with nanostructured surface is presented. The fabrication of n-IOWs includes the fabrication of grating couplers, deposition of alumina film waveguides, and nanostructuring the waveguide surface. The engraving of 75x25x1mm soda-lime glass substrates is done by deep reactive-ion etching to produce grating couplers with spatial period of 332 nm. The light is confined into waveguides by either fabricated gratings or prisms couplers. Single-mode planar waveguides are produced by depositing 135, 232, and 307 nm thick films of Alumina (Al_2O_3) using an atomic layer deposition. Surfaces of the waveguides are modified at nano-level with pillars formation by simply introducing the uniform alumina waveguide to the hot deionized water in a controlled environment. Characterization of the n-IOWs are done by spectroscopy, atomic force microscope, scanning electron microscopy and coupling measurements. The promising results show that fabrication of alumina IOW sensors with surface nano-pillars is viable. The surface nano-pillars act like nano-antennas and the average height of the nano-pillars enhances the radiative component of the confined light. The formation of nano-pillars on the surface improves the transmittance and controls the ratio of the sensor’s output namely surface scattering and total internal reflection (TIR) to each other. Development of the tunable dual-output sensor will provide significant advantages, allowing the study of both the concentration and the organization of biological and chemical molecules via surface enhanced Raman scattering and TIR measurements.

8034-15, Session 4

Fully distributed fiber-optic sensing based on acoustically induced long-period grating

D. Y. Wang, Virginia Polytechnic Institute and State Univ. (United States)

We proposed a fully-distributed fiber-optic sensing platform based on a transient and traveling long-period grating (LPG) in an optical single-mode fiber. The LPG is generated by pulsed acoustic waves that propagate along the fiber. Based on this platform, first we demonstrate the fully-distributed temperature measurement in a 2.5m fiber. Then by coating the fiber with functional coatings, we demonstrated fully-distributed biological and chemical sensing. In the biological sensing experiment, immunoglobulin G (IgG) was immobilized onto the fiber surface via ionic self-assembly, and we show that only specific antigen-antibody binding can introduce a measurable shift in the transmission optical spectrum of the traveling LPG when it passes through the pretreated fiber segment. It is also shown that non-specific binding to other unintended IgG can be avoided by the application of a standard binding block in the sensor fabrication. In the hydrogen sensing experiment, the fiber was coated with a platinum (Pt) catalyst layer, which is heated by the thermal energy released from Pt-assisted combustion of H2 and O2, and the resulted temperature change gives rise to a measurable LPG wavelength shift when the traveling LPG passes through. Hydrogen concentration from 1% to 3.8% was detected in the experiment. This technique may also permit measurement of other quantities by changing the functional coating on the fiber; therefore it is expected to be capable of other fully-distributed sensing applications.

8034-16, Session 4

Polarimetric heterodyning fiber grating laser sensors

B. Guan, Jinan Univ. (China)

Fiber grating laser sensors have been attracting interest because of their high signal-to-noise ratio and narrow linewidth that permit high resolution sensing. According to the working principle, fiber grating laser sensors can be classified into two types: wavelength encoding sensor and polarimetric heterodyning sensor. The former converts measurrand into shift in the operation wavelength of the fiber laser, which is similar to that of fiber grating sensor. The latter converts measurrant into change in beat frequency between the two orthogonal polarization modes from the laser. Because the beat frequency is in radio frequency (RF) range, the polarimetric heterodyning sensor has distinctive advantages of ease of interrogation and avoidance of expensive wavelength measurement that is required for wavelength encoding sensors. In this paper, we report some of our recent works in fabrication of dual-polarization fiber grating lasers and development of polarimetric heterodyning fiber grating laser sensors for measurement of acoustic wave, acceleration, lateral force, electric current and hydrostatic pressure.

8034-17, Session 4

U-shaped nano-apertures for enhanced optical transmission and resolution

M. Turkmen, Boston Univ. (United States) and Erciyes Univ. (Turkey); S. Aksu, A. E. Cetin, A. Artar, A. A. Yanik, H. Altug, Boston Univ. (United States)

The subject of light transmission through optically thin metal films perforated with arrays of subwavelength nanoholes has recently attracted significant attention. In this talk, we will present experimental and calculated results on optical transmission/reflection of the U-shaped nanoapertures for enhanced optical transmission and resolution. We will propose different structure designs in order to prove the effect of geometry on resonance and enhanced fields. Theoretical calculations of transmission/reflection spectra and field distributions of U-shaped nano-apertures are performed by using three-dimensional finite-difference time-domain method. The results of these numerical calculations show that transmission through the apertures is indeed concentrated in the gap region. Added to theoretical calculations we also performed a lift-off free plasmonic device fabrication technique based on positive resist electron beam lithography and reactive ion etching in order to fabricate U shaped nanostructures. After transferring nanopattern on 80 nm thick suspended SiNx membrane using EBL followed by dry etching, a directional metal deposition processes is used to deposit 5 nm thick Ti and 30 nm thick Au layers. Theoretical calculations are supported with experimental results to prove the tunability of resonances with the geometry at the mid-infrared wavelengths which could be used for infrared detection of biomolecules.

8034-18, Session 5

Nanoscale optics with negative metamaterials

S. Sridhar, Northeastern Univ. (United States)

Nanoscale optical elements offer the potential of entirely new modalities of superresolution imaging, superfocussing and slow light utilizing the unique properties of negative metamaterials.

We present an experimental demonstration of superresolution imaging by a low-loss three-dimensional metamaterial nanolens consisting of aligned gold nanowires embedded in a porous alumina matrix. This composite medium possesses strongly anisotropic optical properties with negative permittivity in the nanowire axis direction, which enables the transport of both far-field and near-field components with low-loss over significant distances, and over a broad spectral range. We demonstrate the imaging of large objects, having subwavelength features, with a resolution of at least wavelength/4 at near-infrared wavelengths. The results are in good agreement with a theoretical model of wave propagation in anisotropic media. The results have potential applications in metamaterials imaging components for military and civilian telecommunication systems.

Controlling the speed of light, in addition to the direction, is a fundamental challenge that can lead to new physical phenomena and applications. We have proposed new concepts to stop and trap light pulses that utilize anomalous wave propagation in waveguides in semiconductor heterostructures with negative index metamaterial core or cladding. These nanoscale metamaterial waveguides offer the prospect of on-chip slow light devices where light speeds are reduced by orders of magnitude, enabling ultra-compact optical delay lines and buffers.

For further details see sagar.physics.neu.edu.

In collaboration with B.D.F.Casse, W.T.Lu, Y.Huang, S.Savo, L.Menon, D.Heiman, D.Xiao, O.Yavuzcetin and B.Ozturk. Supported by the National Science Foundation and the Air Force Research Laboratories.

8034-19, Session 5

High-sensitivity temperature sensing by employing an on-chip high-Q PDMS-coated toroidal microcavity

B. Li, X. Jiang, Q. Gong, Y. Xiao, Peking Univ. (China)

Whispering-gallery-mode (WGM) optical microresonators with high Q factors and small mode volumes open a myriad of lab-on-chip applications ranging from fundamental physics to various photonic applications, such as nonlinear optics, cavity quantum electrodynamics, low-threshold microlasing, and bio/chemical sensing. In real applications of WGM-based photonic devices, the temperature fluctuations, caused either by the ambient temperature variation or the probe light field, are inevitably involved in the measurement. On the other hand, the ultrahigh sensitive response of the WGMs to the surrounding temperature variation can be employed for high-sensitivity thermal sensing. In this paper, a high-sensitivity temperature sensor is demonstrated by coating a layer of polydimethylsiloxane (PDMS) on the surface of a silica toroidal microresonator on a silicon chip. Combining both the advantages of the WGM microcavity (with ultrahigh Q factor) and PDMS (with large thermal effect), the PDMS-coated microresonator is highly sensitive to the temperature change of the surroundings. We find that, when the PDMS layer becomes thicker, the fundamental WGM experiences a transition from red- to blue-shift with temperature increasing due to the negative thermal-optic coefficient of PDMS. The measured sensitivity (0.151 nm/K) is one order of magnitude higher than pure silica microcavity sensors. The ultra-high resolution of the temperature sensor is also analyzed to reach 10-4 K. With both high sensitivity and resolution, the thermal sensor can be employed to monitor a slight temperature variation which cannot be realized with conventional temperature sensor. Its on-chip feature can also fulfill the demand for integration and miniaturization in optics.

8034-20, Session 5

Resonant cavity enhancement of polycrystalline PbTe films for IR detectors on Si-ROICs

T. W. C. Zens, Massachusetts Institute of Technology (United States) and U.S. Air Force (United States); J. Wang, P. Becla, A. M. Agarwal, L. C. Kimerling, Massachusetts Institute of Technology (United States)

The target of the Multi-Spectral Infrared Detector Arrays (MIDAS) project is to explore a novel way to realize infrared (IR) multi-band (at least two) detection on a single pixel. MIDAS also opens the way to integrate the IR pixel/pixel arrays with Si read-out integrated circuits (Si ROIC) to further reduce the cost and improve the reliability of the system. A single waveband (3.6 µm) resonant-cavity-enhanced (RCE) mid-IR photodetectors on a silicon platform has been demonstrated. Single waveband RCE photodetectors can serve as building blocks for multiple wavebands RCE photodetectors. We demonstrate high quantum efficiency (90%) and a peak responsivity of 100 V/W at the resonant wavelength of 3.5 µm, 13.4 times higher compared to blanket PbTe film of the same thickness. Detectivity as high as 0.72x10^9 cmHz^1/2W^-1 has been obtained. The fabrication process is low temperature (< 160 °C), this demonstration shows promise for monolithic integration of RCE photodetectors with Si readout integrated circuits (Si ROIC). Finally, a rigorous analysis of detectivity versus power consumption tradeoff has been presented. We have fabricated, integrated, and tested Single-Wavelength Infrared Detector Arrays (SIDAS) devices. The pixel was fabricated based on the processing parameters developed for small size Si ROIC dies (3 mm × 5 mm). The testing of the integrated SIDAS-on-ROIC, has been successful and data relating bias current and output voltage are obtained. This data unambiguously depicts that a SIDAS-on-ROIC is indeed feasible.

8034-21, Session 5

Frequency tunable nonlinear-optical negative-index metamirror for sensing applications

A. K. Popov, Univ. of Wisconsin-Stevens Point (United States)

Optical negative-index metamaterials (NIMs) form a novel class of artificial electromagnetic media that promises revolutionary breakthroughs in photonics. Unlike ordinary materials, the energy flow and wave vector are counter-directed in NIMs, which determines their extraordinary linear and nonlinear optical (NLO) properties. In this talk, three- and four-wave mixing processes in NIMs are discussed, which enable coherent, NLO energy transfer from the control optical field(s) to the negative-phase wave and incident signal through optical parametric amplification. Uncommon phenomenon of generating of a contra-propagating wave at appreciably different frequency in the direction of reflection is investigated. The feasibility and extraordinary features of such energy transfer are shown, which stem from the unusual fact that the energy flows of the coupled electromagnetic waves are contra-directed, whereas their wave-vectors remain parallel. Such opportunity makes phase matching of counter-propagating waves much easier. Consequently, distributed feedback features become possible while antiparallel orientation of wave vectors of the coupled waves is not required anymore. Ultimately, the possibility to implement originally strongly absorbing microscopic samples of plasmonic nanostructured metal-dielectric composites for the remote all-optical tailoring of transparency and reflectivity of the metamaterial films as well as for creation of unique ultracompact photonic devices is demonstrated through numerical simulations. Such microscopic devices can be used as sensors with enhanced functionalities for weak electromagnetic radiation due to amplification of signals and conversion of their frequencies to the range of maximum detector's sensitivity.

This work has been funded by the National Science Foundation under award #1028353.

8034-23, Session 5

Sapphire tube waveguide as a potential basis for high-temperature Raman spectroscopy

M. J. Fraser, E. M. Lally, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

Raman spectroscopy has become an established method for determining the composition of gaseous samples at low temperatures (<1000°C). However, the design of a Raman sensor which operates at high temperatures (>1000°C) remains elusive. This work investigates the feasibility of high temperature Raman spectroscopy utilizing a monolithic sapphire tube as a sample cell and signal collection optic. The insertion loss of small-diameter, single-crystal sapphire tubing is measured to be 0.26-0.40dB/cm, proving its potential for use as a short-distance waveguide. Relevant system losses are characterized for a fiber-based, reflection mode Raman sensor, and expected Raman signal powers are predicted by simulation for the gaseous combustion products of ethylene: N2, CO, CO2, H2, and H2O. The successful implementation of a Raman sensor as described by this research could enable real-time analysis of exhaust gasses from a hydrocarbon combustor. Furthermore, the extension of Raman spectroscopy to high temperatures would be a critical step towards more precisely controlled, fuel-efficient technologies.

8034-22, Poster Session

Fiber Bragg grating high-current sensor based on magnetic coupling

C. Zhou, D. Wang, W. Zhang, L. Wu, Y. Yao, Wuhan Univ. of Technology (China)

Current sensors always play a very important role in the power industry. For example, current sensors can provide the key information for measurement, control and relay protection. However, when the economic further develops and the level of current increases year by year, it is very difficultly to meet the demand for current sensors based on conventional technology which is still the main stream. Novel current sensors always are pursued. A research focusing on the current sensor is the technology of fiber optic current sensor, because there is high resistance to electromagnetic interference in fiber optic sensors. Fiber Bragg grating (FBG) sensors have been applied in many fields and have gained great achievements. It is of great help to the current measurement if FBG current sensors are realized. In this paper, a novel FBG high-current sensor is developed based on magnetic coupling. The principle is described, such as the magnetic coupling, the structure of the sensor and the sensing data processing. Experiments are carried out, and the results indicate that the FBG wavelength is high sensitive to current and the sensor is capable of measuring both dc and ac current.

Return to Contents

Conference 8035: Energy Harvesting and Storage: Materials, Devices, and Applications II

Monday-Thursday 25-28 April 2011

Part of Proceedings of SPIE Vol. 8035 Energy Harvesting and Storage: Materials, Devices, and Applications II

8035-01, Session 1

Emergence of power and energy as a driver in the modern army

J. M. Pellegrino, U.S. Army Research Lab. (United States)

Power and energy are critical enablers across the spectrum of Army operations with ever increasing demands on the technology. In part as a result of global energy conservation measures and restricted resources, power and energy is identified as one of the top five technology needs and focus areas within the Army, for both operational energy and infrastructure. Research and development in this area are focused on increasing power and energy density of a variety of energy technologies and on increasing demand side energy efficiency. Current operations highlight the logistics burden of supplying both fuel and materiel to the battlefield, leading to the evaluation of using energy harvesting devices as part of a holistic approach to supplying current and future operational energy needs. Photovoltaics, vibrational energy harvesting and thermoelectric devices are all being developed to meet the increasing demand for power and energy on the battlefield. Army electronic device and component advancements, such as low power electronics, flexible displays and long-lived autonomous sensors will benefit from energy harvesting. The increasingly energy-intensive nature of battlefield systems require these novel solutions to energy supplies to ensure that today's Army remains in the forefront of military technology and capability.

8035-02, Session 1

Mesoporous electrode materials for lithium battery applications

P. Balaya, National Univ. of Singapore (Singapore)

We present our recent results on lithium storage using nanostructured mesoporous electrode materials highlighting their advantages compared to nanopowders and nanoplates. In addition we also discuss the importance of thermodynamics at nano-size on the storage performance.

(a) $LiFePO_4$ nanoplates (b-axis 30 nm a-c plane 500 nm) with ~ 5 nm thick carbon coating synthesized using solvo-thermal methods could store Li-ions comparable to theoretical capacity at C/10, while at 30C, they exhibit storage capacity up to 45 mAh/g. On the other hand, mesoporous $LiFePO_4$ (20-25 nm diameter organized within 25 nm thick nanoplates) synthesized using soft-template method has superior storage performance close to 60 mAh/g at 30C with a clear voltage plateau compared to $LiFePO_4$ nanoplates cited above. Analysis will be made based on two dimensional Li-ion transports along b and c - axes.

(b) Mesporous-TiO_2 with high surface area (137 m2/g) synthesized using soft-template method exhibits superior reversible storage capacity of 288 mAh/g and 107 mAh/g at C/5 and 30C respectively. The packing density of meso-TiO_2 is found to be about 6.6 times higher than commercial TiO_2 nanopowders favoring high volumetric storage capacity. The enhanced storage performance is attributed due to excellent electronic transport across the nanograins (15-20 nm) of micron sized mesoporous TiO_2.

(c) We also report on the lithium storage performance of α- and -Fe_2O_3, undergoing conversion reaction at C/10 and 2C rates. Both α- and -Fe_2O_3 transform to nanostructured Fe/Li_2O composite during the first discharge, while the first charge results in the formation of nano-sized -Fe_2O_3. Such a transition from alpha-Fe_2O_3 to gamma-Fe_2O_3 is attributed to its thermodynamics at nano-size. Better storage performance of -Fe_2O_3 at 2C compared to α-Fe_2O_3, is attributed to the formation of highly crystalline nano-sized -Fe_2O_3.

8035-03, Session 1

Search for greener Li-ion batteries: an alternative offered by organic electroactive materials

F. Dolhem, P. Poizot, Univ. de Picardie Jules Verne (France)

The threats of climate change and the issues of secure energy supply are among the fundamental challenges of the 21st century that push humanity to adopt a sustainable model of development. Changes need to be made in our energy management favoring the use and development of renewable sources of energy. By powering the next ZE vehicles and stabilizing the future smart grid Li-ion batteries (LIBs) will be key players in these areas, in addition of their historical use as power sources for "nomadic" devices. Thus the world production of Li-ion batteries is expected to keep on growing during the foreseeable years. However, these large-scale perspectives induce to consider, as for other goods, the environmental impact of current LIBs, near exclusively based on inorganic compounds (non-renewables) basically synthesized from high temperature reactions, making also difficult and energy-greedy their recycling process.. Such a huge economical and industrial foreseeable demand on these inorganic electrode materials already results in speculation on metals price quotation while the question of their recycling is on the road. In parallel of regular inorganic-based LIBs and as a proposed alternative, we have recently pinpointed the interest in developing "low emission batteries" by searching for redox-active organic materials, which are easier to discard, and can derive from biomass and so be considered as CO_2 neutral. Our latest progresses in designing the next organic electrodes by computational studies and a structure electrochemical activity relationship study will be presented.

8035-04, Session 1

Sustainable nanostructured materials for energy storage

J. Cho, Ulsan National Institute of Science and Technology (Korea, Democratic Peoples Republic of)

Synthesis and electrochemical properties of the nanostructured anode and cathode materials with 0, 1, 2 and 3 dimensions will be presented, in addition to suggestion of new electrode material and new nanoscale coating method. Although bulk electrode materials should be used in their application under the only consideration of volumetric energy density, nanoscaled engineering and nanochemistry for the electrode materials is essential to overcome rate capability, cycling stability, structural stability at elevated temperatures at higher cut-off voltages. The 0, 1, 2 and 3D cathode and anode materials with mesopore, nanowire, nanoparticles, nanosheet, core-shell nanoparticles can be materialized by way of surface modification, particle size and morphology controls. These materials showed significantly improved the rate capabilities at higher C rates, compared to bulk counterparts. In the case of the metallic anode nanomaterials, there has been growing researches for reducing the critical volume changes by phase transition during lithium reaction. The nanoscaled synthetic methods for carbon-metal core-shell, mesopores, and hollow structures demonstrated some meaningful solutions for the control of the volume expansion. Nevertheless, the minimization of the side reactions of the nanostructured electrode materials with the electrolytes should be more studied in order to reduce the irreversible capacity and gas evolution during cycling or elevated temperature storage. There are also more needs for lower polarization, high capacity, low working voltage, capacity retention and above all simple lithiation mechanism without structure change. Here, lithium intercalating metal phosphide nanomaterials can be the best candidates, considering all requirements for much higher anode characteristics. On the other hand, nanoscaled metal oxide coating can be used onto various bulk layered $LiCoO_2$, $LiNi_{1-x}M_xO_2$ and spinel $LiMn_2O_4$ cathodes, which look forward to solve fatal metal-ion dissolution occurred in the higher cut-off voltage, elevated temperature storage and to improve the cycling stability than the bare materials. Nanowire and nanoplate lithium rich cathode materials also demonstrated much improved the rate capability, compared with the bulk counterparts.

8035-05, Session 2

Recent advances in nanocrystalline intermetallic tin compounds for the negative electrode of lithium ion batteries

J. L. Tirado, R. Alcantara, U. Nwokeke, F. Nacimiento, P. Lavela, Univ. de Córdoba (Spain)

Intermetallic compounds of tin and first-row transition metals have been considered as potential anode materials for Li-ion batteries that could improve the performance of pure tin. Particularly, the solids dispersed at the nano scale provide interesting behaviour. Thus CoSn, $FeSn_2$ and $CoSn_3$ nanocrystalline samples have been obtained at low temperatures. As compared with micrometric particles of CoSn, significantly higher reversible capacities are found for the nanocrystalline CoSn. For nanocrystalline $CoSn_3$ maximum reversible capacities of 690 mAh g^{-1} were observed in lithium test cells. Nanocrystalline products in the series $CoSn_2$-$FeSn_2$ could be prepared by chemical reduction in polyol solvents using a "one-pot" method. Superparamagnetic nanocrystalline $FeSn_2$ delivers reversible capacities of about 600 mAhg-1 by the formation of Li_xSn phases and superparamagnetic iron nanoparticles. A comparison between the properties of nano-$FeSn_2$ and micro-$FeSn_2$ shows a significantly better electrochemical behavior and electrode stability for the nanocrystalline material. For $Fe_{1-x}Co_xSn_2$ solid solutions with x= 0.25, 0.3, 0.5, 0.6 and 0.8, particle diameters of about 20 nm and different morphologies were obtained. The substitution of iron by cobalt induces a contraction of the unit cell volume and the hyperfine parameters of the ^{57}Fe Mössbauer spectra reveal a superparamagnetic behaviour. The intermediate compositions exhibit better electrochemical performance than the limit compositions $CoSn_2$ and $FeSn_2$. To improve the performance of $CoSn_x$ intermetallics, composites in which the nanocrystalline intermetallic material is embedded in an amorphous layer based on the polyacrylonitrile (PAN) polymer were used. The PAN shell contributes to stabilize the intermetallic phases upon electrochemical cycling.

8035-06, Session 2

Green energy storage materials: advanced nanostructured materials for lithium-ion batteries

S. Mitra, Indian Institute of Technology Bombay (India)

The projected doubling of world energy consumption in the next fifty years requires certain measures to meet this demand. The ideal energy provider is reliable, efficient, with low emissions source- wind, solar etc. The low carbon footprint of renewables is an added benefit, which makes them especially attractive during this era of environmental consciousness. Unfortunately, the intermittent nature of energy from these renewables is not suitable for the commercial and residential grid application, unless the power delivery is 24/7, with minimum fluctuation. This requires intervention of efficient electrical energy storage technology to make power generation from renewables practical.

The progress to higher energy and power density especially for battery technology will push material to the edge of stability, and yet these materials must be rendered safe, stable and with reliable operation throughout their long life. A major challenge for chemical energy storage is developing the ability to store more energy while maintaining stable electrode-electrolyte interface. A structural transformation occurs during charge-discharge cycle, accompanied by a volume change, degrading the microstructure over time. The need to mitigate this volume and structural change accompanying charge-discharge cycle necessitates going to nanostructured and multifunctional materials, has the potential of dramatically enhance the energy density and power density. This talk will focus on the recent developments of nanostructured materials for Lithium-ion battery applications.

8035-07, Session 2

Micro- and nanostructural design approaches for improved Li-ion batteries

S. J. Dillon, Univ. of Illinois at Urbana-Champaign (United States)

For the foreseeable future lithium ion batteries will likely be the dominant energy storage technology for applications ranging from microelectronics to automobiles. Unfortunately, fundamental thermodynamics ultimately limit the energy density of the active electrode materials to levels that are not significantly higher than today's commercial technology. However, novel engineering and design on the micro and nano-scale still provide opportunities for significant increases in the energy and power density of battery systems. Our recent efforts in this realm will be discussed with respect to technologies, such as; structural batteries, nano-scale surficial films for enhanced power, and direct writing of high energy density microbatteries.

The energy densities of traditional lithium ion battery electrodes suffer from the fact that the electrodes contain about 30-40 volume percent active material and the over all system contains about half that amount. Traditional fabrication processes do not allow for significant improvements and they often lead to reduced rate capability. New electrode designs based on all-oxide and metal-oxide composites are being fabricated by high temperature processing and direct writing. Power improvements in these systems are being achieved through the use of nano-scale lithium rich surficial films. A new mechanism for the markedly enhance power will be described based on the results of electrochemical and microscopic characterization. The discussion will highlight future directions of research for continued improvements.

8035-08, Session 2

Computational design of high-performance lithium ion battery cathodes

S. N. Adams, R. P. Rao, National Univ. of Singapore (Singapore)

It is still a major challenge in lithium ion battery research to design cathodes that combine high energy density with high power density. To systematically find ways of enhancing the power performance of safe low cost materials we employ atomistic Molecular Dynamics simulations with a novel consistent force-field that we developed based on our softBV bond valence parameters in combination with ab-initio simulations. Thereby a fast screening of candidate materials, their homogeneous aliovalent doping, as well as the effects of tailoring the concentration of disorder (antisite defects), and interface engineering (heterogeneous doping in cathode:electrolyte nanocomposites) can be analysed efficiently.

1D Li conductor $LiFePO_4$ and quasi-1D amblygonite-type "high voltage" cathode materials tavorite $LiVPO_4F$ and $LiFeSO_4F$ as well as $LiFeBO_3$ are used as examples for investigating the effects of aliovalent dopants and antisite disorder on the Lithium pathways and hence on the power performance, as the amblygonite-type structure exhibits channels for one-dimensional low-energy migration in combination with moderate energy thresholds for pathways in the perpendicular directions (0.9 eV) mitigating the effects of channel blocking in other mixed conductors with strictly one-dimensional Li^+ motion. The interplay of Fe^{2+} on Li sites blocking Li^+ pathways and Li^+ or Na^+ on iron sites connecting parallel pathways has a complex influence on the value and anisotropy of Li^+ ion mobility. Li^+ ion conductivity in the Li_xFePO_4 phase of

LixFePO4:Li4P2O7 nanocomposites is discussed as a model for the drastic power performance enhancement by interface engineering.

8035-10, Session 3

Enabling organosilicon-based electrolytes for lithium ion batteries

Z. Zhang, Argonne National Lab. (United States)

Fenton et. al.1 reported in 1973 that PEO showed ionic conductivity when complexed with alkali salt. With a number of advantages over the liquid electrolyte currently in use, polymeric electrolytes have particularly interesting properties for application in high energy lithium ion batteries.2 Considering a conductivity of 10-3 Scm-1 or higher is sufficient for commercial viability, PEO/LiX complex has far too low ambient conductivity.

However, the pursuit of polymer electrolyte never ceased. Polysiloxanes, due to their highly flexible skeleton, good thermal stability and largely amorphous compositions, are promising candidates for polymer-based electrolytes.3-5 We have found that conductivity gradually increases with decreasing Si-O repeating unit of the polysiloxane backbone.

In this report, synthesis, conductivity and electrochemical cell performance of Si-based electrolyte are summarized. The story originated from the evaluation of a polymeric siloxane material. It was found that conductivity gradually increases with decreasing Si-O repeat unit of the polysiloxane backbone, which leads us to a new class of electrolytes based on tetra-, tri-, and disiloxanes and monomeric silanes containing oligo(ethylene glycol) substituents, as shown in Scheme 1.6-7 Their viscosity, cyclic voltammetry and thermal properties are also described. These properties and the results of electrochemical testing in lithium ion battery indicate that these oligomeric siloxane derivatives are ideal alternative to conventional organic carbonate- based electrolytes.

8035-11, Session 3

Soft matter electrolytes for Li-ion batteries

A. J. Bhattacharyya, Indian Institute of Science, Bangalore (India)

Demand for safe lithium-ion batteries (LiBs) for varied applications such as portable electronics, transportation, space technologies have lead to significant emphasis on development of new materials and concepts. This talk will focus on prospective soft matter electrolytes which have been synthesized from liquids e.g. molecular solvents and low melting point solvents (ionic liquids) as the starting medium. Although conversion from liquid to the soft matter state constrains intrinsic spatial and temporal disorder of the liquid solvent, the materials properties in the soft matter state however, are far more interesting and beneficial than the liquid state. Assembly of various soft matter electrolytes in cells containing in-house synthesized nanostructured (nanotubes/sheets, mesoporous) non-carbonaceous anode and cathode materials show improved battery performance compared to the liquid electrolytes. The talk will also discuss mechanistics of ion transport in the electrolytes.

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8035-12, Session 3

All solid state rechargeable lithium batteries with three-dimensionally ordered macroporous ceramic electrolyte

K. Kanamura, R. Osone, H. Munakata, Tokyo Metropolitan Univ. (Japan)

Rechargeable lithium ion battery has been widely investigated to realize an effective energy storage and utilization with high energy and power densities. However, some of issues should be solved, such as cost, safety, energy densities and so on. One of solution for these problems is a construction of bipolar type cell. For this purpose, solid electrolyte has to be utilized. At a mean time, high capacity materials should be applied. So far, all solid-state rechargeable lithium ion battery with ceramic electrolyte has been extensively studied. In this study, a unique structural design for all solid-state battery based on ordered porous materials was prepared and applied to all solid-state battery. The structure included two types of porous structure in order to obtain high electrochemical interface area and adequate mechanical strength of solid electrolyte. The first one is "Three Dimensionally Ordered Macroporous" (3DOM) ceramic electrolyte, and the second one is the conductive ceramic plate with hole-array structure. 3DOM structure was constructed in holes and then active material was injected into macropores to create an electrochemical interface. Many solid electrolytes with Li+ ion conduction have been developed. In this study, active materials with high capacity should be applied to anode material, such as Li metal and Si. However, most of solid electrolytes are not stable against a reduction by Li metal or lithiated Si. Recently, Li7La3Zr2O12 has been proposed as new solid electrolyte with high Li+ ion conductivity and stability against Li metal. In this study, we employed this new solid electrolyte construct all solid-state rechargeable lithium ion battery.

8035-13, Session 3

An external sensor for instantaneous measurement of the internal temperature in lithium-ion rechargeable cells

R. Srinivasan, B. G. Carkhuff, M. E. Butler, A. C. Baisden, The Johns Hopkins Univ. Applied Physics Lab. (United States)

We demonstrate, in several different rechargeable lithium-ion cells ranging in capacity from 2- to 50-Ah, the existence of an intrinsic relationship between a cell's internal temperature and a readily measurable electrical parameter. Today, container rupture and fire are the most detrimental consequences of thermal runaway in rechargeable Li-ion cells. Although storing or operating Li-ion cells in high-temperature environments is not advisable, high internal temperature has a greater potential to initiate catastrophic events. Measuring the environmental temperature at any proximity to the surface of the cell is insufficient to know or intervene with fast-rising internal heat. For example, monitoring internal temperature in real time has direct relevance to the thermal runaway caused by external and internal short circuits that may have no relevance to the external temperature. Yet, until now, there has been no simple technique to monitor the internal temperature of a single cell or multiple cells in Li-ion batteries. A miniature instrument developed by the Johns Hopkins University Applied Physics Laboratory has demonstrated capability to measure and report internal temperature of individual cells in a multi-cell battery pack at the rate of 200-ms/cell.

8035-14, Session 3

All-solid-state thin film microbatteries fabricated by rf sputtering

L. Lu, National Univ. of Singapore (Singapore)

Recent development in miniatures of microelectronic devices and systems on chips requires to develop compact power sources with small size in order to integrate the power sources with microelectronic devices. Different processes and materials have therefore developed.

This research studies the fabrication of full thin film microbattery cells (Pt/anode/electrolyte/cathode/Pt) in the thickness of several tens of micrometers which are fabricated by rf sputtering. Different types of materials are tested as cathodes and anodes. The electrochemical

characterization has been demonstrated that the thin film electrodes and full microbatteries not only have good capacity but also have fast charge/discharge rates. One of key layers for the thin film microbattery cells is the electrolyte which controls Li ion transportation as well as leakage of current. Various processing parameters are studied to ensure the highest ionic conductivity and lowest electronic conductivity for the electrolyte.

8035-15, Session 4

Pseudo-capacitive reactions based on imidazolium ion

M. Egashira, T. Tanaka, Y. Matsuno, N. Yoshimoto, M. Morita, Yamaguchi Univ. (Japan)

The present study contains two of new electrochemical processes provided by substituted imidazolium cation in non-aqueous electrolyte. First one is a pseudo-capacitive reaction of ruthenium oxide in non-aqueous electrolyte containing 1-ethyl-3-methyl imidazolium (EMI) tetrafluoroborate salt. By the comparison with electrode behavior in tetraalkylammonium salt, we have clarified the existence of a pseudo-capasitive reaction based on the reversible adsorption of EMI cation on ruthenium oxide surface. We have also made attempts to design ruthenium oxide/activated carbon composite electrodes in order to obain applicable capacitance value based on this reaction. The other reaction is an intercalation of EMI cation in various carbon electrodes having different graphitizabilities. EMI cation intercalates only in the interlayer space of graphite, while there are no sign for the intercalation of EMI in hard carbon.

8035-16, Session 4

Advances in solid polymer electrochemical capacitors and hybrid energy systems

K. K. Lian, Univ. of Toronto (Canada)

An electrochemical Capacitor (EC), also known as supercapacitor or ultracapacitor, is an electrochemical energy storage system that has important applications in renewable energies. Possessing higher power density, faster charge/discharge rate, and longer cycle life than conventional batteries, on the one hand, and higher energy density than conventional capacitors on the other, ECs can fill the performance gap between these conventional technologies.

Research on ECs has been focusing on increasing their energy densities with a) high performance nano materials or pseudocapacitive electrodes, b) novel electrolytes to expand the voltage operation windows and, c) various cell configurations (i.e. symmetric vs. asymmetric). Recently, more attention has been shifted towards the high rate and power aspects of the ECs, which could further extend their applications. In this presentation, areas of ECs with respect to the portable, flexible and integrated energy source/storage will be reviewed. Specifically, we will discuss our efforts in developing solid polymer electrolytes to minimize the packaging weight and volume and to enable safe operation and flexible form factors for portable devices. We will also present some results on battery-EC hybrid energy storage systems with high pulse current to demonstrate the effectiveness of hybrid energy systems under high rate and high load conditions.

8035-17, Session 4

Carbon nanotube and 1-Ethyl-3methylimidazolium tetrafluoroborate-based electrochemical double layer capacitors

W. J. Ready, Georgia Tech Research Institute (United States)

A design of experiments (DOE) approach was taken to create a selection of supercapacitor coin cells for manufacture. The variables studied are type and amount of single wall carbon nanotubes (SWCNTs) and room temperature ionic liquid (RTIL) electrolyte. Electrical tests consisted of constant current and constant voltage characterizations. In addition, impedance spectroscopy was used to obtain complex plane and Bode plots. The resulting data was used to create Ragone plots showing specific power versus specific energy. Additional electrical characterizations consist of cyclic voltammetry and equivalent circuit modeling that help elucidate the material origins to the variability and electrical performance traits.

8035-18, Session 4

In-situ preparation of PEDOT/V2O5 nanocomposite and its synergism for enhanced capacitive behavior

P. Ragupathy, H. N. Vasan, N. Munichandraiah, N. Vasanthacharya, Indian Institute of Science (India)

Synthesis of poly (3,4-ethylenedioxythiophene) /V2O5 (PEDOT/V2O5) by in-situ oxidation of monomer (3,4-ethylenedioxythiophene) of different compositions into crystalline nanostrip V2O5 using microwave hydrothermal technique is reported. The synthesized compounds are characterized by powder X-rd, IR spectra, four probe conductivity and thermal analysis (TGA/DTA). The morphological changes of the compound are further investigated using FE-SEM. The electrochemical behavior of PEDOT/V2O5 nanocomposites is studied by CV and galvanostatic charge-discharge cycling.

8035-19, Session 4

Design, fabrication, and evaluation 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. Electrically conducting polymers, such as polyaniline (PANI), polypyrrole (Ppy) and their derivatives and transition metal oxides, such as RuO2 and MnO2 are promising electro-active materials for supercapacitors. In this work, we are aiming to develop on-chip supercapacitors based on interdigitated C-MEMS electrode microarrays, which are employed both as electrode material for electric double layer capacitor (EDLC) or as three dimensional (3D) current collectors of pseudo-capacitive materials. Fabrication of C-MEMS structures involves a two-step photolithography on silicon oxide wafer followed by a pyrolysis step. 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). Detailed results will be presented at the conference.

8035-20, Session 5

Photovoltaic commercialization potential in the U.S.

M. Symko-Davies, National Renewable Energy Lab. (United States)

The primary objective of the PV Technology Incubator project is to shorten the timeline for small businesses to transition PV technologies into pilot and full-scale manufacturing. The PV Technology Incubator project targets innovative R&D on PV cell and module prototypes and emphasizes activities focused on the barriers to manufacturing

Return to Contents

scale up and 2012 commercialization. It also provides significant opportunities for collaboration between NREL and industry to develop and improve disruptive solar energy technologies. Companies selected are diverse and able to meet the objectives set out by Solar Energy Technology Program.It is anticipated that these companies will have the commercialization potential of 100's-1000's of MW.

8035-21, Session 5

Simulation of novel energy harvesting devices

V. Parameshwaran, R. Olah, A. Dutta, Banpil Photonics, Inc. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States)

Energy harvesting and scavenging has ignored a large potential source of energy. Ignored is energy harvesting from surrounding environment that is 500 W/sq.meter at 25C. A difficulty in harvesting this energy is that this energy is at long infrared wavelengths centered at 9 m. Previously we worked on the device structures based on nanostructures to improve shorter wavelength solar harvesting. This work is the extension of our previous work to extend the wavelengths to longer wavelengths, especially to long infrared wavelengths regions using the standard material systems. We have investigated the potential use of novel and new device structures to infrared harvesting using the mercury cadmium telluride (HgCdTe, herein after mentioned as MCT) material systems. A device simulation tool, named MCT-SIM, was developed in order to obtain the photovoltaic characteristics of MCT P+/N-/N+ diodes exposed to blackbody radiation and an applied voltage bias. These characteristics include quantum efficiency, current-voltage curves, and dynamic resistance. This tool consists of two components; the One Stack Model simulates the electrical characteristics of one P+/N-/N+ device, and the Multi Stack Model simulates the electrical characteristics of a superlattice series configuration of P+/N-/N+ devices. MCT-SIM's results show agreement with recently published work on long-wavelength infrared HgCdTe devices. An example thermal energy harvesting system is designed and characterized through the use of our device Model. This work demonstrates that MCT-SIM is a tool that can be utilized in developing thermal energy harvesting systems that incorporate HgCdTe P+/N-/N+ based devices. Details of the modeling and simulation of novel harvesting device will be presented.

8035-22, Session 5

Nanoscale engineering: optimized electron-hole kinetics of quantum dot solar cells

K. A. Sablon, U.S. Army Research Lab. (United States)

Although heterostructure solar cells are presently dominating the market of concentrator solar cells with a record conversion efficiency of greater than 40%, the efficiency remains below the theoretical limit of 56% and is mainly limited by two factors: thermalization losses and recombination losses. While self-assembled quantum dots are great candidates for minimizing the thermalization loss and providing multiple energy levels that can accommodate the mismatch between the solar spectrum and two-level transitions, they can simultaneously increase the recombination loss. Therefore, we have developed a novel approach to effectively control of photoelectron capture into the dots by potential barriers around the dots. This reduces recombination losses in quantum dot solar cells without increasing the thermalization loss thus enhancing the maximum power output.

8035-23, Session 5

Low-cost, chemical-etched black silicon solar cells

H. Yuan, A. C. Goodrich, J. Oh, F. Toor, V. E. Yost, M. R. Page, H. M. Branz, National Renewable Energy Lab. (United States)

We developed an one-step, all chemical etch that creates nanoporous, density-graded black silicon surface on crystalline silicon substrates and is capable of suppressing reflectivity from around 35% on a planar silicon surface down to below 2% over broad spectrum. This etch chemistry consists of 0.4 mM $HAuCl_4$ and mixes with $HF/H_2O_2/H_2O$ mixture. Au nanoparticles with diameter less than 10 nm form upon mixture and catalyze silicon nanoporous etching. Very high throughput of black silicon anti-reflection (AR) etch is possible; it takes 3 minute to get below 2% reflectivity when etching bath is at room temperature and the etch time can be further reduced to 30 seconds at 50°C. In addition to low reflectivity and high throughput, our measurement shows black silicon is better AR at both near- and off-normal incident angles than the conventional dielectric AR coating. This result suggests PV modules made from black silicon solar cells could have higher kWh/kWp rating. Our cost analysis shows Au accounts for more than 60% of the black silicon AR cost. We have recently reduced $HAuCl_4$ concentration from 0.4 mM to 0.07 mM and found similar nanoporous structure, low reflectivity, and solar cell performance. In the early report we replaced the conventional vacuum-based dielectric AR coating with black silicon and achieved 16.8% confirmed energy conversion efficiency on mono-crystalline diffused-junction silicon solar cell. In this presentation recent development in cell efficiency improvement will be discussed.

8035-24, Session 5

Nano-photocatalysts for solar fuels applications

S. E. Hunyadi Murph, Savannah River National Lab. (United States)

To design a better photocatalyst nanostructure for solar fuels applications, one needs to engineer the bandgap of the photocatalytic materials and light absorption in the UV/Vis region, and maximize the reaction channels for the conversion. This requires one to reduce the bandgap of catalysts through nanofabrication and broaden the absorbance with multiple bandgap materials under careful design.

Titania has been considered the most appropriate candidate for photocatalytic processes due to its powerful oxidation capability, superior charge transport, and corrosion resistance. Despite these attributes, the efficiency of TiO_2 for photovoltaic and photocatalytic applications is severely limited by its large bandgap (~3.2 eV) and rapid charge carrier recombination dynamics which means that anatase titania can use less than 1% of the solar spectrum. However, Au, Ag and Pt nanoparticles and CdS quantum dots can be utilized to sensitize TiO_2 and extend its photo-response to the visible region of the solar spectrum.

This presentation highlights work from its authors' laboratories on the synthesis, growth mechanism, properties and solar fuels applications of noble metals (Au, Ag, Pt)-oxides (titania, silica) and CdS-titania nano-photocatalysts. This includes nano-photocatalysts with various designs, geometries and compositions prepared by wet chemical synthesis approaches and electron-beam lithography. Materials are characterized by electron microscopy (SEM, TEM, HRTEM), UV-Vis spectroscopy, energy dispersive X-ray analysis (EDX), dynamic light scattering, UV-visible spectroscopy, inductively coupled plasma emission spectroscopy (ICP-MS), and atomic force microscope (AFM).

8035-25, Session 5

Metal-black scattering centers to enhance light harvesting by thin film solar cells

C. J. Fredricksen, LRC Engineering Inc. (United States) and Univ. of Central Florida (United States); R. E. Peale, D. Panjwani, Univ. of Central Florida (United States); I. Oladeji, SISOM Thin Films, LLC (United States); K. M. Beck, Pacific Northwest National Lab. (United States); F. K. Rezaie, Univ. of Central Florida (United

States)

Small metal particles in proximity to the absorbing layers of thin-film solar cells have the potential to improve light harvesting by scattering normally incident radiation into the plane, thus increasing the effective path length in the absorber. Scattering is particularly strong near plasmon resonances of the particles. While present art emphasizes lithographic metal structures of pattern suggested by electrodynamic theory, we have adopted an approach more suitable for low-cost large-scale manufacturing, namely deposition of so-called “gold-black” by thermal evaporation in inert gas at ~1 Torr pressures. Such nano-structured metal particles have a broad size distribution, potentially resulting in high scattering efficiency over the entire solar spectrum. Optimization of the deposition with regard to solar cell performance is determined by direct experimentation. The design of the experiment is based on the two-level full factorial protocol. The statistically significant results consist of response surfaces plotted as a function of pairs of the variable parameters, which were pressure, mass of gold, and evaporation-boat current. Maxima indicate the optimal parameter values. Response considered was solar-cell efficiency as measured under a simulated solar spectrum using a Xe arc lamp and appropriate filters. Correlations of this response with characteristics of the deposited layers were also made. These characteristics include percent coverage and particle size distribution, as determined from SEM images, and the spatial-spectral distribution of plasmon resonances as observed by Photoelectron Emission Microscopy (PEEM). Standard thick crystalline silicon, thin film amorphous silicon, and spray deposited thin-film CuInS solar cells were investigated.

8035-26, Session 5

Fabrication of dye sensitized solar cells using sol-gel coated nanostructured metal oxide thin films

A. H. Jayatissa, The Univ. of Toledo (United States)

Fabrication of dye sensitized solar cells using sol-gel coated NiO and ZnO was investigated. The primary focus of this investigation was to understand the surface modification effect on energy conversion efficiency of dye sensitized solar cells. Surface modification was carried out by UV irradiation of sol-gel coated nanostructure metal oxide films. The Conversion efficiency of solar cells before and after UV irradiation was compared. The investigations were also carried out to understand the change of crystallinity, electrical conductivity, and optical properties. The paper will include experimental as well as theoretical analysis of these results.

8035-27, Session 6

Embeddable miniature solid oxide fuel cells

S. Ramanathan, Harvard School of Engineering and Applied Sciences (United States)

I will discuss on-going efforts in our laboratory to create embeddable solid oxide fuel cells utilizing thin film components. Challenges in device fabrication and measurements will be addressed. Microstructural instability during thermal treatments and their influence on power output will be considered. Replacing precious metal electrodes with inexpensive low temperature catalytic oxides will be discussed in detail. Finally, examples of prototype thin film oxide fuel cells, their performance/power metrics and furture directions will be considered.

8035-28, Session 6

Interfacial effects on the ionic conductivity of thin film electrolytes for micro-solid oxide fuel cells (μ-SOFCs)

E. Traversa, National Institute for Materials Science (Japan)

The development of micro-solid oxide fuel cells (μ-SOFCs) is very attractive because μ-SOFCs are expected to produce energy densities per volume and specific energy per weight up to four times larger than state-of-the-art batteries. A further advantage is the continuous SOFC operation when fed with fuel and oxidant, compared to the charge-discharge cycling operating mode of batteries. Reducing the operating temperature is a prerequisite for developing portable devices. Electrolytes in thin-film form are needed for μ-SOFCs since electrolyte ohmic losses can be reduced by decreasing their thickness. Pulsed laser deposition (PLD) is a suitable technique for the fabrication of tailored oxide thin films, because it allows obtaining single crystal or polycrystalline films and it is compatible with microfabrication technology. The choice of the substrates affects the orientation and crystalline order of PLD oxide films. This talk will present some example of how the interfacial effect of the substrate and crystalline order influence the oxygen-ion conductivity in the case of samaria-doped ceria (SDC) films or proton conducting Y-doped barium zirconate (BZY) films. The use of epitaxially ordered electrolyte films was particularly beneficial to boost the proton conductivity of highly textured thin films of BZY grown by PLD, which showed a conductivity of 0.01 S/cm at about 350°C. The very limited extension of the grain boundary region allowed such a high conductivity. Superlattices made of yttria-stabilized zirconia and SDC were also prepared having different modulation length. The effect of interfaces was significant on superlattices, being larger when individual layers were thinner.

8035-29, Session 6

Development of reversible solid oxide fuel cell for power generation and hydrogen production

G. B. Jung, J. Y. Chen, S. H. Chan, Yuan Ze Univ. (Taiwan)

A reversible solid oxide fuel cell (RSOFC) provides a dual function of performing energy storage and power generation, all in one unit. When function as an energy storage device, RSOFC acts like an electrolyzer in water electrolysis mode wherby the electric energy is stored in its electrolyzied hydrogen and oxygen gases. While hydrogen can then be useful for transportation fuel and other industrial applications, the RSOFC can also acts as a fuel cell in power generation mode to produce electricity when in need. The RSOFC would be a competitive technology in the upcoming hydrogen economy on the basis of low cost, simple structure, and high efficiency advantages. This paper reports the design and manufacturing of its membrane electrode assembly using commercially available materials. Also reported are the resulting performance, both in electrolysis and fuel cell modes, as a function of its operating parameters, such as temperature, inlet gas composition (humidity) and current density. The RSOFC is shown to have a better performance in fuel cell than in electrolysis mode.

8035-31, Session 6

Recent development of miniatured enzymatic biofuel cell

Y. Song, Florida International Univ. (United States)

Enzymatic biofuel cells involving oxidizing biological fuels by enzyme-modified electrodes attracted considerable attention. It is also considered to be a promising candidate for implantable power sources. However, there are still challenges to be overcome before biofuel cells become

Return to Contents

competitive in practical application. Short lifetime and poor power density are the most critical issues in developing biofuel cells. In this talk, we will review recent development of biofuel cells and highlight out recent progress in C-MEMS based micro biofuel cells. Our computational modeling study based on finite element analysis is to study the design rule and scaling law of the micro-electrodes arrays, mass transport of enzyme, enzymatic reaction rate and power density. In the experimental work, we performed the individually addressable functionalization of carbon surfaces and immobilization of enzymes on the interdigited electrode array. Our effort on developing reliable covalent bonding, increasing the enzyme loading and improving the power density of device will be discussed in this talk.

8035-32, Session 7

Multimodal vibration energy harvesting

S. Priya, Virginia Polytechnic Institute and State Univ. (United States)

In this presentation, we will provide an overview of various reported devices and prototypes covering broad spectrum of energy conversion mechanisms. The prime goal of this review being identification of the current stage of energy conversion devices and evaluation in terms of magnitude of output power and specific power density, detailing the spread of technology over varying dimensions. Based on this review, we will identify the progress made in the area of vibration energy harvesting in comparison to other harvesting technologies. Next, we describe our results in the area of vibration energy harvesting covering piezoelectric, inductive, and magnetoelectric transduction mechanism. The focus of discussion will be on design and implementation of broadband piezoelectric transducer structure and four-bar inductive harvester. Relevant details from micro-mechanics based models and FEM analysis will be provided to elaborate the relevance of experimental prototypes. Next, we present concepts that combine multiple modalities into unified broadband energy harvesting structures. Analytical modeling and FEM results will be presented to illustrate the concept of multimodal conversion. Experimental results based on bulk-structures will be used to validate the models which will then be used to make scaling predictions. Once the multimodal energy conversion structures have been designed, there remains challenge in printing heterogeneous materials on the same platform with nanometer precision in complex configurations. These challenges include embedding the ceramic with metal layers, rapid-annealing of the printed materials in real-time to achieve desired microstructure, and fabrication of large arrays with in-phase response. We provide our ideas on addressing these issues and show preliminary results.

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8035-33, Session 7

Perpetual harvesting device electronics

R. Olah, G. Mizuno, A. Dutta, Banpil Photonics, Inc. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States)

As harvesting energy methods have been developed for perpetual powering of electronics, power management, storage control and regulation electronics need to match the voltage and current characteristics of the different harvested energy levels. Besides being able to harvest relatively small and large amounts of energy efficiently, the harvesting electronics must also consume very low power. The harvesting electronics storage and output must also match the power output demand. In our work to harvest solar and thermal energy, we have evaluated what electronics would be necessary to efficiently harvest, store and regulate these diverse energy sources. Expected energy levels from thermal harvest and from solar harvest will be discussed in relation to the harvesting electronics. Electronics to efficiently harvest thermal and solar energy at low and high energy levels will be discussed. During our development of thermal and solar energy harvesting, a demonstration vehicle was developed to further understand the needs of harvesting. We will detail the energy harvest demonstration vehicle learning and the details of the final integrated harvesting-storage-regulator structure with electronics.

8035-34, Session 7

Development of MEMS-based pyroelectric thermal energy harvesters

S. R. Hunter, T. Bannuru, Oak Ridge National Lab. (United States); S. Mostafa, The Univ. of Tennessee (United States); N. V. Lavrik, S. Rajic, P. G. C. Datskos, Oak Ridge National Lab. (United States)

Our group at the Oak Ridge National Laboratory (ORNL) is developing a new type of high efficiency, low grade thermal waste heat energy converter that can be used to actively cool electronic devices, concentrated photovoltaic solar cells, computers and larger waste heat producing systems, while generating electricity that can be used to power monitoring sensor systems, or recycled to provide electrical power. The energy harvester is a temperature cycled pyroelectric thermal-to-electrical energy generator that can be used to generate 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 goals of this effort are to demonstrate the feasibility of fabricating high conversion efficiency MEMS based pyroelectric energy converters that can be fabricated into scalable arrays using well known microscale fabrication techniques and materials. These fabrication efforts are supported by detailed modeling studies of the pyroelectric energy converter structures to demonstrate the energy conversion efficiencies and electrical energy generation capabilities of these energy converters. 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.

8035-35, Session 7

Innovative microbial fuel cell design for energy harvesting and corrosion protection

C. Kung, X. Yu, Case Western Reserve Univ. (United States)

Microbial Fuel Cell produces electricity by collecting the electrons released during the metabolism of bacteria. By using special electrodes design, the energy contained in the natural environment is harvested. MFC has advantages as energy source for sensors in unfavorable conditions such as marsh and marine environment. This paper descrives an innovative method for corrosion protection using MFC principles. It is based on emulating the principles of using sacrificial anode for corrosion protection. The electrons released by bacteria while digesting food were collected and serve as a current source and electron donors on the protected metal structure. Consequently, the corrosion potential on the protected structure is reduced. A special energy storage device helps to save the energy and serve for longer term protection purpose. This method is especially attractive for remote area, marsh and other marine environment

8035-36, Session 7

Ultra-high transmittance through nanostructure-coated glass for solar cell applications

R. E. Welser, A. W. Sood, Magnolia Solar, Inc. (United States); A. K. Sood, Magnolia Optical Technologies, Inc. (United States); D. J. Poxson, S. Chhajed, J. Cho, E. F. Schubert, Rensselaer Polytechnic Institute (United States); D. L. Polla, Defense Advanced Research Projects Agency (United States); N. K. Dhar, Defense Advanced Researech Projects Agency (United States)

Ultra-high, broadband transmittance through coated glass windows is demonstrated over a wide range of incident angles. The measured improvements in transmittance result from coating the windows with a new class of materials consisting of porous nanorods.

Energy harvesting photovoltaic devices frequently employ a protective glass cover on their topmost surface. Optical transmittance through the cover glass is typically limited by reflection losses. In particular, Fresnel reflection losses in optical windows arise because of the difference in index of refraction between air (n ~ 1) and the window material (n ~ 1.5). Although Fresnel reflection losses can be relatively low at normal incidence, they can become quite substantial for off-angle light incidence. For example, Fresnel reflection from uncoated glass generally varies from over 4% at normal incidence to over 40% at an incident angle of 75o. By employing a step graded antireflection coating consisting of SiO2 layers of varying porosity on both sides of a glass slide, we have achieved near perfect 100% transmittance over select spectral bands. Moreover, we have demonstrated broadband, omni-directional average transmittance of greater than 97% between 0 o and 75 o and between 400 nm and 1600 nm, which represents a tremendous increase over the 86% average transmittance of the uncoated reference sample.

8035-37, Session 7

Challenges and opportunities in polycrystalline CdTe thin-film solar cells

R. G. Dhere, D. S. Albin, J. Duenow, T. A. Gessert, National Renewable Energy Lab. (United States)

No abstract available

8035-45, Poster Session

Energy harvesting from mortar tube firing impulse to supplement fire-control electronics battery

J. S. Rastegar, R. T. Murray, Omnitek Partners, LLC (United States); R. Tillinghast, C. M. Pereira, H. Nguyen, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

Novel designs are presented for piezoelectric-based energy-harvesting power sources that are attached to mortar tubes to harvest energy from the firing impulse. The power sources are constructed with innovative mass-spring unit with in-series piezoelectric elements. The power sources generate electrical energy by storing mechanical potential energy in spring elements as a result of the firing impulse during the firing. The mass-spring unit of the power source will then begin to vibrate, thereby applying a cyclic force to the piezoelectric elements. The mechanical energy of vibration is thereby converted to electrical energy during each cycle of vibration. The electrical energy is then harvested over a relatively long period of time and stored in electrical energy storage elements such as capacitors.

The power sources are shown to provide a significant portion of the required electrical energy of the fire control system. The primary design parameters of the present energy harvesting power sources are the spring rate and the effective mass of the system's vibrating mass-spring units. The natural frequency of the mass-spring unit can be readily adjusted to match the firing impulse profile for optimal energy transfer to the spring elements and to achieve the desired electrical energy generation rate.

Previously developed power sources were shown to produce enough electrical energy for many gun-fired munitions applications such as artillery and mortar fuzing, e.g., on the order of 250 - 500 mJ in a packaging that is 0.75 inch diameter and 1.25 inches long. In certain fuzing applications, the developed power sources have been shown to be capable of completely eliminating the need for chemical batteries. In fuzing applications, the developed power sources have the added advantage of providing additional safety, since with such power sources the fuzing electronics are powered only after the munitions have exited the barrel and have traveled a safe distance from the weapon platform. In addition, the power source piezoelectric stacks may also be used to detect events such as firing setback and se-forward, barrel exit time and the time and level of terminal impact for fuzing purposes (U. S. Patents number 7,231,874; 7,312,557; 7,701,120; 7,762,191; 7,762,192; 7,777,396 and several pending).

The basic construction and mode of operation of the piezoelectric-based energy harvesting power sources are described in detail. The results of extensive analytical modeling, computer simulation and prototype testing are presented. Methods to design mass-spring units and package the power source together with the piezoelectric elements to protect the latter elements and minimize losses due to friction and internal damping of the spring elements are presented. The power source components are packaged to withstand high-G firing shock loading while maximizing the amount of mechanical potential energy that can be stored in their elastic elements. It is shown that electrical energy of 1-3 Joules can be readily harvested from each firing event using a relatively small power source.

The developed energy harvesting power sources can be readily be adapted for use on many weapon platforms and machinery that subject their structure or components to shock/impulsive loading during their operation.

8035-46, Poster Session

Piezoelectric energy harvesting power sources for gun-fired munitions

J. S. Rastegar, R. T. Murray, Omnitek Partners, LLC (United States); C. M. Pereira, H. Nguyen, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

A novel class of piezoelectric-based energy-harvesting power sources has been developed for gun-fired munitions and similar high-G applications. The power sources are designed to harvest energy primarily from the firing acceleration, but from in-flight vibratory motions as well. During the firing, a spring-mass element reacts to the axial acceleration, deforming and storing mechanical potential energy. After the projectile has exited the muzzle, the spring-mass element is free to vibrate, and the energy of the vibration is harvested using piezoelectric materials.

These piezoelectric-based devices have been shown to produce enough electrical energy for many applications such as fuzing, and are able to eliminate the need for chemical batteries in many applications. When employed in fuzing applications, the developed power sources have the added advantage of providing augmented safety, since the fuzing electronics are powered only after the projectile has exited the muzzle and traveled a safe distance from the weapon platform.

An overview of the development of these novel power sources is provided, especially designing and packaging for the high-G environment. Extensive laboratory and field testing has been performed on various prototypes; the methods and results of these experiments are presented. In addition to presenting the development and validation of this technology, methods for integrating the generators into different classes of projectiles are discussed along with strategies for manufacturing and a side-by-side comparison with competing

technologies. This technology is currently at DoD Technology Readiness Level 7, and strategies for elevating through the final two levels and transitioning to commercialization are discussed.

8035-48, Poster Session

Design and optimization of a fiber-based luminescent solar concentrator

E. Banaei, A. F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Luminescent Solar Concentrators (LSC's) are a class of solar concentrators that have proven to be cost-efficient for solar energy conversion. Planar LSC's in particular have attracted attention within the last few years. The usual design involves a thin luminescent organic film coating on the top of an optical slab waveguide and photovoltaic cells attached to the slab edges.

With the advance in organic luminescent materials and multi-material fiber production, fabrication of LSC's in cylindrical geometry with the luminescent materials doping the fiber core appears feasible. In this work, we report on the design of a fiber-based LSC. We also present numerical optimization of the performance of such fiber-based luminescent solar concentrators (FLSC's) over a wide range of parameters such as fiber structure, shape and dimensions, as well as potential luminescent materials properties and their concentration in the fiber. Fiber structures for optimum capture of the solar light are studied with ray tracing. We also consider the properties of the active fiber dopants, finite self-absorption, and the effect of optical losses.

As a first step towards fabrication of FLSCs, doping techniques are developed for the fiber cores. Results of this study show the possibility of fabricating FLSC's with reasonably high efficiency and low cost. These all-polymer FLSC's can be potentially light-weight and flexible devices suitable for new application areas where the existing technologies fail due to weight constraints and limitations on substrate flexibility.

8035-49, Poster Session

Energy harvesting roads via pyroelectric effect: a possible approach

A. K. Batra, S. Bhatacharjee, A. K. Chilvery, Alabama A&M Univ. (United States)

Thermal energy in the environment is a potential and possible source of electric energy for low-power electronics. The ambient temperature variation can be converted into electrical current or voltage via pyroelectric effect. The possibility of the utilizing pyroelectric materials in energy harvesting from roads warrants systematic exploration to take advantage of heat absorbed by the pavements. The simulated performances, in terms of power generated, of a few important pyroelectric materials, including fabricated in our laboratory by employing real pavement temperature data obtained from climatic database of MEPDG shall be described. Results show that triglycine selenate(TGSe) crystals are also attractive for energy harvesting applications.

*The partial financial support for this work through NSF-RISE grant ID 0927644 is gratefully acknowledged.

8035-50, Poster Session

Investigation on solution processed films for organic photovoltaic cells

A. K. Batra, A. K. Chilvery, P. Guggilla, M. D. Aggarwal, M. E. Edwards, Alabama A&M Univ. (United States)

Organic solar cells (OSC) hold the potential of low-cost production and a high throughput as compared to inorganic solar cells besides the increase in efficiency. To realize these possibilities, objective should be to fabricate most of functional films in OSC structure via solution-process technologies: spin; spray; dip and other coating methods. Spray coating is a high-rate, large-area deposition technique that ensures an ideal coating on a variety of surfaces with different morphologies and topographies.. Systematic efforts are being made to fabricate various films of important efficient OSC materials such as ZnO, TiO2, P3HT, PCBM, and others by solution-processed techniques. The results obtained in regard to their microstructures, dark- and photo-electric transport and junction characteristics shall be presented. The 'process-property' relations shall be described in order to obtain best-set of performance characteristics.

* work supported by NSF-RISE grant: 0927644.

8035-51, Poster Session

Ligand-engineered optical performance of nanocrystal photovoltaics and photodetectors

G. M. Williams, Jr., Voxtel, Inc. (United States)

There has been much interest in solution-processed nanocrystal (NC) quantum dot photodetectors and photovoltaics with response to optical radiation in the visible and short wavelength infrared (SWIR) spectral regions. Much interest has also been paid to harvesting the signal gain available through multiple exciton generation. However, despite their promise, high-performance detectors using nanostructured materials have not been achieved. It will be shown how engineering the properties of the ligands can lead to improved performance, while retaining the benefits of solution processing. It will be shown how ligand engineering can enable multiple exciton capture (MEC) in photovoltaic and photodetector devices.

8035-52, Poster Session

Quantum well and quantum dot energy harvesting devices

R. E. Welser, Magnolia Solar, Inc. (United States); A. K. Sood, Magnolia Optical Technologies, Inc. (United States); O. A. Laboutin, Kopin Corp. (United States); L. J. Guido, Virginia Polytechnic Institute and State Univ. (United States); N. K. Dhar, Defense Advanced Researech Projects Agency (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

Quantum structured solar cells seek to harness a wide spectrum of photons at high voltages by embedding low energy-gap wells or dots within a high energy-gap matrix in a single-junction device. Quantum well and quantum dot solar cells have the potential to deliver ultra-high power conversion efficiencies in single junction devices, efficiencies that in theory can approach 45% in un-concentrated sunlight over a wide range of environmental conditions. In this paper, we will review the theoretical underpinnings of quantum well and quantum dot photovoltaic devices, and summarize recent experimental efforts on quantum solar cell devices.

Magnolia and its team members have been developing quantum well structures in a variety of different material systems for energy harvesting applications. In one specific example, test devices employing radiation-hard, III-V nitride materials have been built using both bulk and multiple quantum well (MQW) structures. In this case, devices utilizing a MQW structure are shown to outperform devices utilizing a thicker, bulk InGaN layer. In a separate experimental effort, we have demonstrated that both the current and the voltage output of a GaAs-based photovoltaic device can be increased by employing a novel III-V material structure with an InGaAs well layer. These results are consistent with a suppressed radiative recombination rate, and provide direct experimental evidence that quantum well structures can enhance the performance of photovoltaic devices for a variety of defense applications.

8035-53, Poster Session

A high-temperature acoustic-electric system for power delivery and data communication through thick metallic barriers

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In many sensing applications that monitor extreme environmental conditions within sealed metallic vessels, penetrating vessel walls in order to feed through power and data cables is impractical, as this may compromise a vessel's structural integrity and its environmental isolation. Frequent servicing of sensing equipment within these environments is costly, so the use of batteries is strongly undesired and power harvesting techniques are preferred. Traditional electromagnetic power delivery and communication techniques, however, are highly ineffective in these applications, due to Faraday shielding effects from the metallic vessel walls. A viable, non-destructive alternative is to use piezoelectric materials to transmit power through thick metallic barriers acoustically. We present critical elements of a high-temperature battery-less sensor system prototype, including power harvesting, voltage regulation, and data communication circuitry able to operate up to 260ºC. Power transmission is achieved by aligning a pair of high-temperature piezoelectric transducers axially, on opposite sides of a thick steel barrier. Continuous-wave excitation of the outside transducer creates an acoustic beam that is captured by the opposite transducer, forming an acoustic-electric link for power harvesting circuitry. Simultaneously, sensor data can be transmitted out of the high-temperature environment by switching the electrical impedance placed across the leads of the inside transducer, creating a reflection-based amplitude modulation on the outside transducer. Transducer housing, loading, and alternatives for acoustic couplants are discussed. Measurement results are presented, and it was found that the system can harvest up to 1 watt of power and communicate sensor data up to 50 kbps, while operating at 260ºC.

8035-38, Session 8

Wearable thermoelectric generators

K. Settaluri, K. Lo, R. J. Ram, Massachusetts Institute of Technology (United States)

Wearable thermoelectrics harvest the thermal energy generated by the body to generate useful electricity. The performance of these systems is limited by (1) the small working temperature differential between the body and ambient, (2) the desire to use natural air convection cooling on the cold-side of the generator, and (3) the requirement for thin, light-weight systems that are comfortable for long-term use. Our work has focused on the co-design of the heat transfer system and thermoelectric materials as part of the overall thermoelectric system. In particular, the small heat-transfer coefficient for natural air convection results in a module thermal impedance that is smaller than the heatsink. In this heatsink limited regime, the generator performance no longer scales with Seebeck coefficient, electrical conductivity, and thermal conductivity as described by ZT (the typical figure of merit for thermoelectrics). We show that new materials with low ZT but high thermal resistivity will be optimal for the wearable thermoelectric application.

In addition to co-optimizing the material for wearable applications, we have designed flat (1-1.5 mm thickness) heatspreaders to realize performance surpassing splayed pin heatsinks. 2-D heat spreading exploits the large available surface area for wearable applications. Body heat is constrained to pass through the module by a thin ceramic felt. A commercial sub-100mV DC/DC converter is integrated on the band. The resulting system generates 28 microWatts/cm2 with a converter output of 4.5 V and an overall thickness less than 5 mm.

8035-39, Session 8

Progress in Bi2Te3-based superlattice thermoelectric materials

G. E. Bulman, D. Stokes, R. Venkatasubramanian, RTI International (United States)

Thin film superlattice (SL) based thermoelectric (TE) devices offer the potential for improved efficiency and high heat flux cooling over conventional bulk materials. We have demonstrated external cooling of 55K and heat pumping capacity of 128 W/cm2 in single couples and temperature differences as high a 102K in three stage cascade structures. The high heat flux pumping capacity of these in thin film devices are also attractive for hot-spot cooling in electronics. These same materials have also been successfully employed in power generation and energy harvesting applications. In this presentation, will present recent advances at RTI in the cooling and energy harvesting performance of Bi2Te3-based SL devices.

8035-40, Session 8

Isothermal method for rapid, steady-state measurement of thermoelectric materials and devices

P. J. Taylor, J. R. Maddux, U.S. Army Research Lab. (United States); S. B. Trivedi, Brimrose Corp. of America (United States)

Energy Harvesting using thermoelectrics requires highly accurate measurements. A simple, highly accurate method for characterizing thermoelectric materials, partially assembled devices and full devices is presented. In this work, we introduce non-contact radiative heat as a new, independently controlled heat flow that can be used to force isothermal conditions during thermoelectric measurements. Under isothermal conditions, the steady-state heat flows can be determined with high accuracy because parasitic heat flows (e.g., that along the sensing thermocouples, Thomson heat) become negligible and that enables accurate determination of thermoelectric properties such as thermal conductivity. This method applies to bulk and thin-film materials, and can also be extended to determine device performance metrics including coefficient of performance. To validate the method, samples of (Bi,Sb)2(Se,Te)3 alloy bulk materials were prepared by a vertical Bridgman technique.1 The samples typically had an area-to-length ratio of 0.405 cm2/cm. The Seebeck coefficient was found to be +178 microvolts/Kelvin, the electrical resistivity was determined to be 0.74 milliohm-cm, and the thermal conductivity was determined to be 14.9 mWatt/cm-K. The thermal conductivity was determined by the comparison method and that was compared to that measured using the new technique.

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8035-41, Session 8

Thin film thermoelectric energy harvesting for security and sensing applications

D. A. Koester, Nextreme Thermal Solutions, Inc. (United States)

The past decade has seen significant advances in distributed sensors and sensor networks. Many of these advances have been driven by programs that support national intelligence and security interests. With these advances have come an increased interest energy harvesting to provide continuous power sources to replace or augment existing power storage systems. The use of waste heat is an attractive source of energy for many applications where uW-mW power is required. The implementation of a thermoelectric power conversion system requires several basic elements in addition to an assumed heat source. These elements are: 1) a thermoelectric device, 2) a heat sink, 3) voltage regulation, 4) an energy storage device and 5) load management. The

design and optimization of the system (and each element within the system) is highly dependent on the thermal boundary conditions and the power load. This presentation will review the key performance factors and considerations required to optimize each element of the system to achieve the required I-V characteristics for output power.

8035-42, Session 8

Demonstration of 15-mW electrical power using 2-cc thermoelectric generators with radioisotope heat

N. G. Baldasaro, R. Venkatasubramanian, D. Stokes, J. Posthill, P. Thomas, R. Wiitala, RTI International (United States)

RTI has demonstrated steady, 14.6 mW electrical output from an experimental, micro-scale radioisotope thermoelectric generator (RTG) designed with a radiation shield, for the DARPA MIPS program. Results were demonstrated in a radioisotope-fueled laboratory test, in a 2.2 c.c. volume and with predicted radiation emissions close to 500 mrem/yr, which is lower than occupational regulation limits demand. A load voltage of 107 mV was produced, which could be upconverted at high conversion efficiency. Less than 610 mW of radioisotope heat was used to make this power. We have developed ruggedization ideas for field deployment of micro-RTGs. Our results translate to a power density of 6.6 W/Liter and an energy density >290 KW-hr/Liter over a 5-year lifetime. These represent high energy density options for deployable power converters using limited radioisotope heat; the low radiation leakage and favorable form factor would allow further developed units to be useful for a variety of unattended DoD/DoE sensors, both in defense/intelligence and in infrastructure maintainance (bridges, power plants, nuclear waste, etc.). We will also present analytical comparisons of relevant design parameters (volume, dose, curies) under choices of several different “ideal” but attainable radioisotope fuels, and give rough comparisons for unit price and lifetime electrical output.

8035-43, Session 8

Nanoparticle-based thin-film thermoelectric materials

G. M. Williams, Jr., Voxtel, Inc. (United States)

Solid-state thermoelectric (TE) materials are highly reliable, have no moving parts, and may be scaled to small sizes for targeted applications, providing an attractive approach for waste heat recovery and for direct conversion of thermal energy to electrical power. This class of material is also appealing for solid-state cooling applications. However, widespread use of TE materials for power generation and cooling applications will require improvements of device efficiency. Low-cost methods of configuring low-dimensional materials into energy-scavenging films with high coefficient of performance (COP) will be discussed, and the low-cost deposition methods used to fabricate them will be described.

8035-44, Session 8

High figure of merit bulk thermoelectric nanomaterials from directed synthesis and assembly of sculpted chalcogenide and oxide nanocrystals

T. Borca-Tasciuc, G. Ramanath, Rensselaer Polytechnic Institute (United States)

Thermoelectrics materials offer promise for realizing transformative solid-state refrigeration and power harvesting technologies. The fruition of these possibilities requires factorial enhancements in the figure of merit ZT, necessitating high Seebeck coefficient α, high electrical conductivity σ and low thermal conductivity κ. Here, we report a surfactant-mediated microwave-stimulated bottom-up synthesis approach to scalably sculpt large quantities (>10g/minute) of nanocrystals with controllable shapes and sizes, and assemble them into bulk samples to obtain both high power factors as well as unprecedentedly low thermal conductivity through tunable doping and nanostructuring. Using our method, we can selectively obtain both n- and p-typed pnictogen chalcogenide (Bi2Te3, Sb2Te3, Bi2Se3) nanoplates and nanowires that can be sintered to obtain 25-250 % increases in ZT compared to their non-nanostructured and undoped counterparts. We show that nanostructuring diminishes the lattice thermal conductivity κL to ultralow values of 0.2-0.5 W/mK. Sub-atomic-percent sulfur doping induced through mercaptan-terminated organic surfactants used in the synthesis result in large Seebeck coefficients between $-240 < \alpha < 298$ µV/K and high σ between 0.2-2.5 × 105 Ω-1m-1. The high power factors are shown to arise due to hot-electron filtering heterostructured interfaces in the nanoplates and changes in the electronic structure near the Fermi level. These correlations are verified by Hall measurements of carrier concentrations and mobility and photoemission measurements unveiling the electronic structure near the band edges. These effects can be accentuated by creating nanocomposites by mixing nanoplates of different materials (e.g., S-doped Sb2Te3 and Bi2Te3). We show that controlling the fraction of the nanoplates of the different materials in the nanocomposite can result in factorially higher ZTs than bulk nanostructured samples of each pure material, pointing to non-linear effects on the power factor and nanostructuring. We will then illustrate the extendability of our synthesis approach to tailor the thermoelectric properties of In- and Bi-doped ZnO for power harvesting from heat.

8035-54, Session 9

Thermoelectric energy conversion using nanostructured materials

C. G. Chen, A. Muto, D. Kramer, K. McEnaney, H. Feng, Massachusetts Institute of Technology (United States); W. S. Liu, Q. Zhang, B. Yu, Z. Ren, Boston College (United States)

Seebeck effect can be exploited to generate power when there is a temperature difference. The efficiency of thermoelectric power generation systems depends on the materials’ thermoelectric figure-of-merits, heat source temperatures, and heat transfer in and out of the devices. This paper reports recent progresses in improving materials’ figure-of-merits based on nanostructured bulk materials and discuss their potential applications. Although there are many available heat sources, the key for the application of thermoelectric generators are to create a temperature difference across thermoelectric devices. Examples will be given on current and future applications of thermoelectric generators in sensors, waste heat recovery, and renewable energy.

8035-55, Session 9

Engineering carbon nanomaterials for future applications: energy and sensor

W. Choi, Florida International Univ. (United States)

We present engineering of carbon nanomaterials for various applications: (i) A novel binder-free multi-wall carbon nanotube (MWCNT) structure as anode in Li-ion batteries. The interface-controlled MWCNT structure, synthesized through a two-step process of catalyst deposition and chemical vapor deposition (CVD) and directly grown on copper current collector, showed very high specific capacity - almost three times as that of graphite, excellent rate capability - even at a charging/discharging rate of 3C and nil capacity degradation up to 50 cycles. (ii) A large graphene film on flexible substrate. Graphene film was grown on Cu foil by thermal chemical vapor deposition and transferred to various substrates including PET, glass and silicon by using hot press lamination and etching process. The graphene/PET film shows high quality, flexible transparent conductive structure with unique electrical-mechanical properties; ~88.80 % light transmittance and ~ 100 Ω/sq sheet resistance. We

demonstrate application of graphene/PET film as flexible and transparent electrode for solar cell and field emission displays. (iii) Application of individual carbon nanotube as nanoelectrode for high sensitivity electrochemical sensor and device miniaturization. An individual CNT is split into a pair of nanoelectrodes with a gap between them. Using a quasi-Ag/AgCl reference electrode, the nanoelectrodes were subject to cyclic voltammetry. An excellent electrocatalytic behavior was found: The observed detection limit was as low as 10 pM dopamine. Another scheme was for electronic detection of DNA hybridization at the single molecule level. Hybridization of the probe with its complementary strand results in an appreciable change in the electrical output signal.

8035-56, Session 9

Developments in MEMS scale printable alkaline and Li-ion technology

K. Littau, C. L. Cobb, Palo Alto Research Center, Inc. (United States)

Two technologies for MEMS scale cell formation are discussed. First, the fabrication of planar alkaline cell batteries compatible with MEMS scale power storage applications is shown. Both mm scale and sub mm scale individual cells and batteries have been constructed. The chosen coplanar electrode geometry allows for easy fabrication of series connected cells enabling higher voltage while simplifying the cell sealing and electrode formation. The Zn/Ag alkaline system is used due to the large operating voltage, inherent charge capacity, long shelf life, and ease of fabrication. Several cells have been constructed using both plated and spun-on silver. The plated cells are shown to be limited in performance due to inadequate surface area and porosity; however, the cells made from spun-on colloidal silver show reasonable charge capacity and power performance with current densities of up to 200 uA/mm2 and charge capacities of up to 18 mA-s/mm2. Three-cell series connected batteries have been fabricated capable of cell potentials up to 4.5V. Second, a new printing method for interdigitated 3-D cells is introduced. A microfluidic printhead capable of dispensing multiple materials at high resolution and aspect ratio is described and used to form features as small as 5 um in width and aspect ratios of greater than 10:1. Various structures enabled by this method are modeled electrochemically, and the energy and power density improvements are reported.

8035-57, Session 9

Further studies in the electrochemical/ mechanical strength of printed microbatteries

D. A. Steingart, The City College of New York (United States)

Flexible electronics require flexible energy storage, and electrochemical batteries are currently the strongest option for such devices. In this talk we further our previous investigation, beginning to add quantitative analysis to the composite mechanical/electrochemical performance of printed electrodes. The presented work will explain the principles of microfluidic stress analysis and how it provides insight into the operating conditions of real microbatteries. channels are formed around printed battery electrodes, allow in-situ measurement of electrode cycling behavior (color change, volume change, erosion, etc) by varying electrolyte flow rate and composition. Electrodes over silver, silver-oxide, zinc (both plated and printed) and manganese oxide will be demonstrated. Flow rate will be correlated with electrode shear strength and cell cycle life.

8035-58, Session 9

Energy and size-scalable 3D battery architecutres

J. W. Long, U.S. Naval Research Lab. (United States)

Battery architectures comprising electrochemical interfaces that are interpenetrated in three dimensions (3D) offer major gains in energy and power density as compared to conventional 2D battery designs, particularly with respect to the limitations imposed by many devices on the footprint available for the power source. We are developing 3D solid-state Li-ion batteries that are sequentially assembled from interpenetrating and tricontinuous networks of anode, cathode, and electrolyte/separator materials. Fiber-paper-supported carbon nanofoams are an ideal base platform for 3D battery architectures because of their through-connected networks of porosity with readily tunable pore sizes (nanometers to micrometers), a conductive carbon framework, and scalability in area (to hundreds of square centimeters) and thickness (70 to 300 m). To functionalize carbon nanofoams we use simple, scalable electroless deposition methods to incorporate conformal nanoscale (~10 nm) coatings of either manganese or iron oxides that ultimately serve as one of the two active electrodes in a 3D Li-ion battery configuration. In the next fabrication step, the metal oxide-coated nanofoam electrode must be passivated with a film that is ultrathin, conformal, pinhole-free, electronically insulating, and Li-ion conductive, which we achieve via the self-limiting electrodeposition of phenol-based polymer coatings. Self-wired RuO2 nanoparticle networks, deposited via solution-based reactions using RuO4 as precursor, can then serve as the opposing charge-storage electrode when incorporated into the remaining void volume of the polymer-coated metal oxide-carbon nanoarchitecture. At each step en route to the ultimate 3D battery architecture, we characterize the individual components using electron microscopy, X-ray photoelectron spectroscopy, electroanalytical methods, and impedance spectroscopy.

8035-59, Session 9

Ultrathin, microscale epitaxial compound semiconductor solar cells

J. A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Compound semiconductors like gallium arsenide provide advantages over silicon for photovolatics, due to strong absorption and high energy conversion efficiencies. Difficulties in growing large, high quality wafers of these materials, and in intimately integrating them on substrates such as glass or plastic restrict their use. Here we describe the use of functional films in multilayer epitaxial assemblies formed in a single deposition sequence on a growth wafer. Release and separation of the individual active layers yields large quantities of high quality material for subsequent device integration in large area formats, in a manner that also allows the wafer to be reused for additional growths. Demonstrations in photovoltaic modules on sheets of plastic, illustrate some capabilities.

8035-60, Session 10

Little Robeep: miniature power sources for autonomous systems

S. Ramanathan, Harvard School of Engineering and Applied Sciences (United States)

We will discuss our recent progress in fabricating micro-solid oxide fuel cells devices and stacks for autonomous systems. Approaches to fabricate large area power skins will be presented. A detailed study on the structure-composition-electrochemical property relations in oxide fuel cell materials will be discussed along with novel experimental techniques being developed to understand rate limiting processes. The role of stresses in affecting fuel cell membrane morphology and their evolution with temperature will be discussed.

8035-61, Session 10

Self-powered nanosystems: nanogenerators, piezotronics, and piezo-phototronics

Z. L. Wang, Georgia Institute of Technology (United States)

Developing wireless nanodevices and nanosystems is of critical importance for sensing, medical science, environmental/infrastructure monitoring, defense technology and even personal electronics. It is highly desirable for wireless devices to be self-powered without using battery. This is a new initiative in today's energy research for mico/nano-systems in searching for sustainable self-sufficient power sources [1]. It is essential to explore innovative nanotechnologies for converting mechanical energy, vibration energy, and hydraulic energy into electric energy that will be used to power nanodevices. We have invented an innovative approach for converting nano-scale mechanical energy into electric energy by piezoelectric zinc oxide nanowire arrays [2]. The operation mechanism of the nanogenerator relies on the piezoelectric potential created by an external strain; a dynamic straining of the nanowire results in a transient flow of the electrons in the external load due to the driving force of the piezopotential. We have developed the nanogenerator from fundamental science, to engineering integration and to technological scale-up [3-6]. As today, a gentle straining can output 1-3 V from an integrated nanogenerator [6], using which a self-powered nanosensor has been demonstrated [6]. A commercial LED has been lid up [7]. This is a key step for developing a totally nanowire-based nanosystem [6]. Alternatively, by substituting the gate voltage in a field effect transistor (FET) with the piezopotential creating by an external strain, we have fabricated a series of devices that rely on a coupling between semiconductor and piezoelectric properties and are controlled/tuned by externally applied force/pressure, such as diode, strain sensor and strain-gated logic unites, which are a new field called piezotronics [8]. A three way coupling among piezoelectricity, semiconductor and photonic excitation has demonstrated the piezo-phototronic effect [9].

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8035-62, Session 10

Nanotechnology enabled flexible energy harvesting

M. C. McAlpine, Princeton Univ. (United States)

The development of a method for integrating highly efficient energy conversion materials onto stretchable, biocompatible rubbers could yield breakthroughs in implantable or wearable energy harvesting systems. Piezoelectric crystals represent particularly interesting smart materials which function as energy converters. Here, we present a scalable and parallel process for transferring piezoelectric nanoribbons (NR) of PZT from host substrates onto flexible rubbers over macroscopic areas. The nanoribbons are fabricated via the recently developed PENCiL approach, which allows for location-determinant PZT NR arrays hierarchically patterned over wafer scales. Fundamental characterization of the ribbons by piezo-force microscopy (PFM) indicates that their electromechanical energy conversion metrics are among the highest reported on a flexible medium. Finally, integration into energy harvesting devices reveals the ability to harvest energy from common body movements such as finger tapping.

Conference 8036: Scanning Microscopies 2011: Advanced Microscopy Technologies for Defense, Homeland Security, Forensic, Life, Environmental, and Industrial Sciences

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8036-01, Session 1

Is scanning electron microscopy/energy dispersive x-ray microanalysis (SEM/EDS) quantitative?

D. E. Newbury, N. W. M. Ritchie, National Institute of Standards and Technology (United States)

Spatially-resolved analysis at the micrometer lateral scale performed in a scanning electron microscope (SEM) equipped with energy dispersive x-ray spectrometry (EDS) is applied in a wide range of science, engineering, and technological applications. Despite this extensive use and familiarity, a critical question is still heard: is SEM/EDS capable of quantitative results? That is, are the concentration results obtained with an error budget that is sufficiently small to make the values useful for characterizing the excited volume in question and comparing it within the specimen to other areas of interest as well as to other specimens? The answer to this question is emphatically yes and it has been so for many years, but the exciting news is that the accuracy and precision are actually getting better as a result of the emergence of the silicon drift detector (SDD-EDS). SDD-EDS provides much faster throughput, a factor of 10 to 50 or more, for the same spectral resolution as compared to Si(Li)-EDS. By increasing the measured x-ray count with SDD-EDS, quantitative results can be obtained in a reasonable measure time, e.g., 30 seconds, with an accuracy that is nearly indistinguishable from those obtained with wavelength dispersive x-ray spectrometry (WDS), which is taken as the “gold standard” of quantitative electron-excited x-ray microanalysis. It must, however, be noted that there are real limits imposed on the accuracy of SEM/EDS (and WDS) microanalysis by the geometric nature of the specimen (e.g., particles and rough surfaces), and by remote x-radiation produced by gas scattering in variable pressure SEMs.

8036-02, Session 1

Scanning microscopies in forensic science: classic and new applications

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Since the early days of manually “scanning” a handheld magnifier over a questioned object for “clues” scanning microscopes have been and still are valuable tools in forensic science. Today there are a myriad of scanning microscopes using a variety of probes (electrons, photons, physical probes, etc.) to collect physical, compositional and/or chemical information from large objects to submicron size particles. The area has evolved from the classic use of high vacuum scanning electron microscopy (SEM) for conductive specimens to the more recently developed environmental / variable pressure SEM’s used on wet tissues, non-conductive specimens and even liquids. Even though SEM and energy dispersive x-ray spectrometry (EDS) are now used around the world the semi-automated particle analyses such as gun shot residue analyses still require confirmatory individual particle morphology and chemistry evaluation by the analyst. Scanning photon profilometers are now being used in forensics in a variety of applications including performing unique measurements in the analysis of counterfeit pharmaceuticals. In this presentation we will illustrate a number of the classic applications as well as improved, new and potential applications of several types of scanning microscopy in forensic science.

8036-04, Session 2

Probative value of gunshot residue on victims of shootings and comparison of gunshot residue results with modern technology versus older testing of samples

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Many laboratories take the position that gunshot residue samples collected from persons that are victims of gunshot wounds will not be examined by their laboratories. Some have stated that the results are meaningless and are not probative. I shall discuss the importance of these results in specific cases to illustrated their value. The results of gunshot residue on samples from victims of shootings will be either positive (gunshot residue was present) or negative. (it was not present). This presentation shall discuss cases in which the results are important and are probative by both positive results and also negative results. A case shall show that the value of a man’s life depends on the results of samples from the victim of a shooting. Another shall show the importance and probative value of an Army General, who was the victim of a shooting. Also discussed will be cases in which victims were shooters and being shot at by other persons to prove the importance of finding gunshot residue on them. The technology today in locating gunshot residue particles is done by the amount of backscatter electrons found on samples as opposed to the initial search for proper morphology (round particles) as was the procedure in the early stages of searching for gunshot residue on samples. The testing samples from one of the victims discussed above is now tested on a modern state of the art Scanning Electron Microscope/ Energy Dispersive X-Ray analysis as opposed to that available and used in this case almost two decades ago. The SEM used is a Tescan Vega 3 with Oxford gunshot residue software and hardware. The search allows for quicker search, smaller particles detected and more acccurate analysis by the Energy Dispersive X-Ray detector.

8036-05, Session 2

Scientific working group on gunshot residue (SWGGSR): progress report

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This presentation will report on the progress of the Scientific Working Group on Gunshot Residue (SWGGSR). This international working group updated the ASTM guide E-1588 in 2010 and is now close to publishing an extensive 100 page guideline on gunshot residue analysis by scanning electron microscopy energy dispersive x-ray spectrometry. The guide will include direction in topics such as instrumental requirements, calibration and quality assurance, procedure, interpretation, documentation and report writing, contamination issues, ammunition, testimony preparation, training, as well as a glossary of terms and references. The presentation will enhance the viewers knowledge of the workings of SWGGSR and its future planning.

8036-06, Session 2

Characterization and source identification of fugitive dusts by light and electron microscopy

R. S. Brown, MVA Scientific Consultants (United States)

Industrial emissions are characteristic of the manufacturing process that produced them. The storage, production and transportation of raw materials, finished product and byproducts create particles that can be characterized using a combination of polarized light microscopy (PLM), scanning electron microscopy-energy dispersive x-ray spectrometry (SEM-EDS), Fourier transform infrared microspectroscopy (FTIR), confocal Raman microspectroscopy (CRM) and analytical transmission electron microscopy-energy dispersive x-ray spectrometry with selected area diffraction (AEM). Complex mixtures of dust that settle on surfaces and individuals inside and outside of a manufacturing facility provide particles that can be compared directly to reference materials from suspected sources. The analysis procedure involves characterization of the optical properties of the particulate comprising the sample by PLM. Further characterization of the particulate is accomplished by preparing sub-samples for SEM-EDS of water soluble and water insoluble phases. Polymeric materials can be characterized by FTIR and/or CRM using direct microanalysis or micro-extraction using organic solvents. The fine particle fraction is prepared by following ASTM D6602-03b - Standard Practice for Sampling and Testing of Possible Carbon Black Fugitive Emissions or Other Environmental Particulate, or Both (American Society for Testing and Materials) using AEM for particle characterization. By applying these microscopical techniques to fugitive dusts, a direct comparison to suspect sources can be performed to include or eliminate them as a possible source of the dust. Even when reference samples are unavailable, possible industrial processes can be suggested to facilitate further investigation by using a database of particle analysis results compiled over many years.

8036-07, Session 2

Application possibilities of several modern methods of microscopy and microanalysis in forensic science field

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Microscopy and microanalysis methods have a strong position in forensic field but recent technical innovations have been bringing new possibilities of their application.

One of the interesting applications is X-ray Powder Microdiffraction (micro-XRPD) - an analytical method that allows complex phase analysis on the area of a comparable order to the area under study by the rest of standard methods used at forensic workplaces (namely optical microscopy and SEM/EDS). It is a complementary process to these methods, enabling exact forensic-technical expert analytical operations to be performed without sample disturbance and so that it fully preserves its probative value.

Microscopy and microanalysis are very useful in forensic gemology. With high-tech today a whole series of phases get to the market that were not primarily meant for gemology use but are interesting also for use in jewellery. Specialized analytical techniques are needed for their accurate determination.

Combined systems SEM/FIB in forensic science allow study of inner structure of gunshot residues and post-blast residues, nanocomposites, give unambiguous conclusion for cuts of crossing strokes (which is impossible to identify using other methods, including autoemission), etc. Last but not the least there is also a wide range of possibilities embracing separate imaging of ions, which are in many cases crucial for material fields.

Of course, not even one method are a panacea, they are commonly used in combination with other methods (in microanalytical area mainly SEM-EDS/WDS, Raman microspectrometry, optical microscopy, XRF, FTIR, X-ray methods - XRD, imaging, etc.)

8036-18, Session 2

Analysis of particles produced during airbag deployment by SEM/EDS and their deposition on surrounding surfaces

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Airbags can be encountered in forensic work when investigating a car crash and typically are constructed with primer-like material to begin the deployment apparatus. This mechanism can produce particles ideal for SEM-EDS analysis. A recent study published by Berk studied airbags with vents and showed that it is possible for particles generated from the deployment of these airbags to deposit on surfaces in the vehicle as the airbags deflate. This presentation will show mid-point results of a study still in progress in which non-vented airbags were analyzed to determine if they exhibit the same particle depositing features as their vented airbag counterparts. Further investigation in this study was performed to find more airbags which produce gunshot-residue-like particles containing lead, barium, and antimony from airbag deployment. To date, the study has resulted in (1) some non-vented airbags producing particles suitable for SEM/EDS analysis that exit the particular airbag and deposit on the surrounding surfaces and (2) no gunshot-reside-like particles detected from airbag residue.

8036-08, Session 3

Quantitative scanning electron microscopy

A. E. Vladár, P. Cizmar, B. Damazo, P. P. Kavuri, M. T. Postek, National Institute of Standards and Technology (United States)

Scanning electron microscopes (SEMs) are incredibly versatile instruments for millimeter to nanometer scale imaging and measurements of size and shape. Unfortunately, there are shortcomings of the SEMs today that make it impossible to achieve excellent accuracy and repeatability, especially at high magnifications. With an ideal SEM it would be possible to collect two images of the same sample and after subtraction get only random noise as the result. Current SEMs fail this test, because the collected images always contain various amounts of distortion due to a number of problems ranging from sample drift to charging. There are problems in the acquisition of the raw images, in their processing and the evaluation algorithms generally used to arrive at the results disregard the governing physics of the signal generation, and report inaccurate values that are plagued with unpredictable biases.

Fortunately there are new, better methods that were implemented and the NIST so-called Reference SEMs that now have excellent repeatability and accuracy. These are used for the certification of scale calibration and other standards used in integrated circuit and nanotechnology development and production. Very fast digital imaging and real-time corrective composition of SEM images developed for the Reference SEM have shown superiority over both traditional fast or slow image collection methods. A high-precision sample stage with laser interferometry provides traceability and compensation for stage drift and vibration with sub-nanometer performance.

Most of the new methods can be used in other SEMs as well to realize quantitative scanning electron microscopy.

8036-09, Session 3

Comparison of channeling contrast from ion and electron images

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Dual platform instruments having a focused ion beam (FIB) column and a scanning electron microscope (SEM) have been used extensively for the characterization of crystalline materials. Ion channeling contrast (ICC) and electron channeling contrast (ECC) are caused by variation in the signal resulting from changes in the angle of the incident beam and the crystal lattice of the target. ICC is directly influenced by the incident ion range in crystalline materials. The ion range is larger for on-axis and low-index crystal orientated grains, resulting in the emission of fewer secondary electrons at the surface yielding dark contrast. Ions are stopped closer to the surface for off-axis crystal orientated grains, resulting in the emission of many secondary electrons yielding bright contrast. Conversely, backscattered electrons (BSEs) are the primary contribution to electron induced channeling contrast. BSEs are diffracted according to the well known Bloch wave electron diffraction phenomenon to form an electron channeling pattern (ECP). When either the imaging magnification of a single grain is large enough or the grain size is small enough such that the ECP is not visible, the contrast level observed will be that contrast value from the center of the original ECP. The BSE emission of the ECP peaks when the electron beam is normal to the surface of an on-axis grain, and therefore, bright contrast is observed. Thus, ICC and ECC images yield inverse contrast behavior for on-axis oriented grains. That is, on-axis grains will appear dark in ICC images but bright in ECC images.

8036-10, Session 3

FIB/SEM-EDX operations for intracellular granules characterization

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FIB provides a cross sectioning tool for submicron dissection of organs, tissues, and cells; with SEM, it makes complementary morphological information available at the same time, that can be completed by EDX. This study gives insight into the microstructure of biological samples, with particular interest in the detection and characterization of granules in the digestive gland cells of P. scaber. A qualitative metal analysis and quantitative details about grain amount and distribution are possible, implementing the interest for the role of isopod in toxicology. Such analysis provides information of the cellular storing pattern, and the metal metabolism whose tight regulation is needed. The developed techniques provide a well structured approach to the investigation of unicellular organisms like Bacillus thuringensis and Bacillus laterosporus with attention to the presence of organic crystals. Finally in the same way, the presence can be investigated of metals granules in nematodes.

8036-11, Session 3

Pursuit of clean SEM and HIM

P. P. Kavuri, A. E. Vladár, M. T. Postek, National Institute of Standards and Technology (United States)

Contamination is a nuisance to microscopist and microanalyst. Contaminants such as hydrocarbons are polymerized by their interaction with the beam and are deposited as a dark layer on the sample. This layer not only disfigures the image but also alters the dimensions of the features on the sample, especially in the nanometer scale and decreases the secondary electron emission. It is not be possible to eliminate contamination completely. Hence it is imperative to minimize contamination.

In order to mitigate contamination we used the following techniques: a low vacuum automatic plasma cleaning method for cleaning the sample chamber (Evactron), cleaning the sample in potent chemical solution (piranha solution), an aggressive plasma cleaning method to clean the sample (Fischione), plasma cleaning samples in the SEM chamber, and sample cleaning in the ESEM.

These techniques were very effective in mitigating contamination. The low vacuum automatic plasma cleaning method was useful for cleaning the sample chamber of SEMs and HIM and samples that can not with stand aggressive plasma cleaning (Fischione) and samples whose size limits their entry into fischione. Samples such as silicon wafers with micro-fabricated feature which will get damaged in plasma could be cleaned in chemical solution. And samples that can not withstand cleaning action of piranha solution or any of the plasma cleaning processes could be cleaned by exposure to the electron beam in the ESEM mode.

8036-12, Session 4

Advanced SCPM image composition with intra-frame drift correction

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Nanometrology with application of scanning charged-particle microscopes (SCPMs) is one of the most important fields inevitable for future advances in many industries. Drift in SCPMs is one of the most important factors hindering metrology at nanometer scale. At NIST, drift-corrected image acquisition (DCIC) technique has been developed. This technique enables real-time composition of super-fast and extensively noisy frames, which provides undistorted images with a desired signal to noise ratio (SNR). Frames are acquired very quickly, which significantly reduces drift-related distortion within frames. However, if the frequencies of the drift are high, individual frames may still slightly suffer from the drift-related distortions.

A technique enabling correction of drift-related corruptions in super-fast frames has been developed. Drift (and vibrations) may be caused by mechanical motions of the sample, sample stage, and column, temperature expansion, or atmospheric pressure. All these are continuous physical processes. When the SCPM frames are taken very quickly and also frequently, it is possible to accurately find the drift function. This function can then be used to compensate for the drift-related displacements of the frame pixels. However, in order to be able to use this technique, it is necessary to find exact times, when each pixel is acquired. This is possible, if all dead times are known. Dead times, e.a. times between acquisitions of two neighboring pixels, lines and frames, when no signal is measured, can be discovered using variable-frequency modulated light source. Light is applied into the chamber, where it affects the signal in the photo-multiplier. Analysis of frames altered by the modulated light of multiple frequencies provides all information needed for calculation of all dead times.

8036-13, Session 4

The characterization of nanoparticles using analytical electron microscopy

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The production and application of nanoparticles continues to increase, consequently increasing the presence of nanoparticles in the environment. For this reason, the ability to accurately characterize and identify nanoparticles becomes very important. Nanoparticles can be very difficult to characterize because of their extremely small size, therefore a combination of microscopical techniques may be needed to conclusively identify them. Analytical electron microscopy (AEM) involves the use of a transmission electron microscope (TEM) in conjunction with energy dispersive x-ray spectroscopy (EDS) and selected area electron diffraction (SAED). AEM presents another option in the characterization of nanoparticles, because of its high magnification capability, the ability to gather elemental data and also the ability to determine the internal structure of a single nanoparticle. The combustion of materials produces aggregates of nano-sized by-products such as, carbon soots, fumes, and fly ash. Using AEM, these combustion nanoparticles can not only be differentiated from other nanoparticles within the environment but can also be distinguished from each other because of the differences in morphology, elemental composition and particle size distribution. The elemental information gathered from carbon soots during AEM analysis can also give an indication of the original source of the combustion by-product. Manufactured nanoparticles such as carbon nanotubes appear very similar to carbon soot using some microscopical techniques, but their distinctive morphology can be easily differentiated using AEM. Paints contain nano-sized pigments that may be unique to that particular paint. AEM can assist in providing a more definitive classification of these nano-sized pigments that cannot be accurately identified by other microscopical techniques alone, because of their extremely small size or opacity.

8036-14, Session 4

Transmission electron microscopy of electrospun GaN nanofibers

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Electrospinning of technology-relevant compounds could offer a simple bottom-up solution to integrate one-dimensional nanostructures in practical devices [1]. Indeed, the reported ease of use in electrospinning, combined with the spatially controlled deposition of fibers in adequately patterned substrates could open unexplored avenues in micro and nano-systems technology manufacturing.

GaN one-dimensional structures find their way amongst this selection of technology-relevant systems operating as both active and passive components, such as light emitters for in-chip communications or reversed-bias diodes in UV detectors [2]. Compared to their thin-film counterparts, GaN one-dimensional structures hold the expectancy of decreased defect densities largely originated by lattice and thermal mismatch with the seed substrate [3]. The seed substrate is usually sapphire or silicon as extremely high temperatures and pressures are needed to grow large native GaN crystals.

We have reported earlier progress in producing polycrystalline wurtzite-polymorph and photo-conductive GaN nanofibers by electrospinning [4]. This paper describes the current efforts to understand nucleation and grain growth during the thermal treatment following electrospinning. Transmission Electron Microscopy (TEM) analysis of GaN shows high orientational competition amongst grains, as seen in Figure 1.

X-Ray Diffraction analysis confirmed dominant hexagonal 101 wurtzite preferential overall orientation. These are the first TEM viewgraphs confirming the high crystallinity of the electrospun fibers.

8036-15, Session 4

Study of LCE nanocomposites through electron microscopy

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Nano-optical mechanical actuation based on nanotube-enriched polymeric materials is a much sought-after technology. In this scheme, light sources promote mechanical actuation of polymeric materials producing a variety of nano-optical mechanical systems such as tactile displays, artificial muscles, and nano-grippers among others.

Photo-mechanical actuation is preferred to electromechanical transduction in multiple environments because it is wireless, provides low noise, and allows for electro-mechanical decoupling. It also has the potential for much higher spatial resolution. However, few materials exhibit this property. Zhangi& Ijima [1] reported one of the earliest papers on single-wall carbon nanotube (SWCNT) actuation to visible light where bundles of SWCNTs are stretched, bent, or repelled reversibly by hundreds of microns when exposed to light. Despite large actuation effects, little interest was stirred into this subject.

More recently, Polymer Carbon Nanotube Composites (PCNCs) and Liquid Crystal Elastomers (LCEs) reportedly changed their shape upon irradiation in a reversible fashion [2]. Indeed, Ahir and Terentjev[3] engineered PCNCs that could either compress or expand upon infrared irradiation and attributed actuation to nanotube alignment. The mechanism involved in photoactuation was tentatively modelled as rigid nanotubes suffering orientational order imposed by uniaxially applied strain. In the proposed model photon absorption forms kinks, reversibly decreasing nanotube length. However, fundamental understanding of opto-actuation down to the atomic level is still missing and the suggested model is yet to be verified through direct experimental data.

To offer direct insight into photoactuation, we propose to examine photoactuation of carbon nanotubes (CNTs) composites by in situ Scanning and Transmission Electron Microscopy (SEM and TEM). In preparation for these tasks, specific aspects of scanning electron microscopy of polymer nanocomposites as well as the suitability of different thinning techniques have been discussed recently [4]. We present preliminary results from TEM sample preparation by Focus Ion Beam (FIB) thinning (shown in Figure 1) and the observed actuation by in situ SEM and TEM.

8036-16, Session 4

Morphological classification and microanalysis of fractured and degraded tire rubber

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The characterization of rubber particles undergoing environmental degradation plays a role in assessing the life cycle of a tire.

Tread particles were obtained from laboratory abrasion tests of a passenger car tire and submitted to leaching in an aqueous solution.

The material, before and after leaching, was imaged by scanning electron microscopy; elemental micro analysis was also carried out by an EDX probe.

The surface morphology of the particles was quantitatively described by means of an image analysis algorithm known as “spectrum enhancement”. A surface “roughness” indicator was introduced. The latter was compared to the relative concentrations of sulfur, silicon (from silica) and zinc in each sample.

The dependence of surface roughness and element concentrations on the duration of leaching are easily explained in terms of bond dissociation enthalpies.

Morphological and microanalytical data of abrasion particles (before leaching) are compared to the data of particles from a wear test carried out on car tires of the same compound on a steering pad.

8036-17, Session 4

Morphological analysis and classification of dispersion in a polymer nano-composite

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The images to be analyzed and classified were obtained by transmission electron microscopy and represented nano-composites made of alumina nano-particles dispersed in polyethylene terephthalate by two methods: Haake batch mixing (HBM) and twin screw extrusion (TSE) continuous mixing. The classification algorithm implements a train-validate scheme based on principal components analysis. Supervised training maximizes a figure of merit with respect to a parameter n-tuple, ψ, which in turn controls the calculation of morphological indicators of each image. The latter are vectors w [ψ] yielded by the “spectrum enhancement” algorithm. Image training sets are automatically formed. The HBM and

TSE images are treated separately. Classification results are interpreted in statistical terms. Their relation to filler dispersion and, to some extent, filler distribution is also presented. The most remarkable result is the correspondence between the 1st principal component, z1 and a statistical topography index determined in the past from the same images by visually scoring filler particles. The whole procedure is statistically reliable and exportable to image sets of other nano-dispersions.

8036-19, Session 5

Nanometer-scale imaging and metrology, nano-fabrication with the Orion helium ion microscope

B. Ming, A. E. Vladár, M. T. Postek, National Institute of Standards and Technology (United States)

The helium ion microscope (HeIM) is a new, powerful instrument for nano-metrology and nanotechnology. As an emerging imaging and measurement tool it offers several advantages over the traditional scanning electron microscope (SEM) currently in use in research and manufacturing facilities across the world. Resolution 2 to 4 times better than that from comparable SEMs is theoretically possible, due to the very high source brightness and the short wavelength of the helium ions. Ion images with unprecedented resolution have been routinely collected on a wide range of samples with sub-nanometer features. Due to the substantially smaller interaction volume of the helium ion beam in the sample, the signals generated, especially secondary electrons, reveal more surface details, as compared with an electron beam in a SEM. Imaging by the HeIM can further benefit from the superb depth of field and the fact that He ion imaging is less susceptible to sample charging.

The HeIM is a potent tool for milling and modifying surface structures at the nanometer scale, due to the relatively low mass of the helium ion, the narrow ion beam, and especially the low beam currents. It is possible to mill close to 10 nm diameter holes and create other nanoscale structures that cannot be fabricated with any other method. It is expected that, as with the electron beam, it is feasible to expose resist and deposit various materials with He ion beam irradiation. The work is at its exploratory stage, and likely soon will yield more exciting results.

8036-20, Session 5

Investigation of cellular interactions of nanoparticles by helium ion microscopy

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The helium ion mircroscope (HIM) probes light elements (e.g. C, N, O, P) with high contrast due to the large variation in secondary electron yield, which minimizes the necessity of specimen staining. A defining characteristic of HIM is its remarkable capability to neutralize charge by the implementation of an electron flood gun, which eliminates the need for coating non-conductive specimens for imaging at high resolution. In addition, the small convergence angle in HIM offers a large depth of field (~5x FE-SEM), enabling tall structures to be viewed in focus within a single image. Taking advantage of these capabilities, we investigate the interactions of engineered nanoparticles (NPs) at the surface of alveolar type II epithelial cells grown in culture. The increasing use of nanomaterials in a wide range of commercial applications has the potential to increase human exposure to these materials, but the impact of such exposure on human health is still unclear. One of the main routs of exposure is the respiratory tract, where alveolar epithelial cells present a vulnerable target. Since the cellular interactions of NPs govern the cellular response and ultimately determine the impact on human health, our studies will help delineating relationships between particle properties and cellular interactions and response to better evaluate NP toxicity or biocompatibility.

The Rutherford backscattered ion (RBI) is a helium ions imaging mode, which backscatters helium ions from every element except hydrogen, with a backscatter yield that depends on the atomic number of the target. Energy-sensitive backscatter analysis is being developed, which when combined with RBI image information, support elemental identification at helium ion submicron resolution. This capability will enable distinguishing NPs from cell surface structures with nanometer resolution.

8036-21, Session 5

Formation of embedded gold nanoclusters and nanocluster-cavity pairs in $SrTiO_3$ single crystals

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Metal nanoclusters on dielectric surfaces sometimes lead to unique physical and chemical properties. In most cases, an atomic scale understanding of the interactions between metal clusters and oxide surfaces has not been established. In addition, at high temperatures these clusters agglomerate and thus reduced the nano effect. Hence, embedded nanoclusters (at the surface region) to reduce these agglomerations attracts lots of attentions in recent years. In this work, we successfully show that using MeV ion implantation at moderate temperatures, embedded gold nanoclusters can be formed at the SrTiO3 (100) surfaces. We have used a suite of imaging capabilities including newly developed Helium ion microscopy (HIM) and scanning transmission electron microscopy (STEM) with high-angle-annular-dark-field (HAADF) imaging to understand the structural properties and spatial distribution of the Au clusters. The results indicate that gold nanoclusters were formed uniformly throughout the implanted region. Small nanoclusters within larger clusters were formed at 200°C and 300°C implantations. Size of the nanoclusters ranges from 5 to 30 nanometers. On the other hand, when the gold ions were implanted at high temperatures (700°C), nanocluster-vacancy pairs were formed uniformly throughout the implanted region. In cluster free regions where the Au concentration is low, the HADDF results clearly indicate the substitution of Au for cations. The Au clusters and the cavity show spatial association, indicating a strong interaction during their respective clustering process.

8036-22, Session 5

Creating nanohole arrays with the helium ion microscope

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A number of articles have been written on the use of nanohole arrays for various chemical and biological sensors [1]. The performance and sensitivity of these sensors depend strongly on the size, shape, and aspect ratio of the nanoholes. Commonly used techniques for creating nanohole arrays include electron beam lithography, direct milling using a gallium FIB, and nanoimprint lithography [2]. None of these techniques however offer the possibility of easily creating extremely small (sub-10nm), high aspect ratio (20:1 or greater) holes.

The helium ion beam has been used to create 5nm, 20:1 aspect ratio holes in different material like gold and silicon nitride. The combination of a sub-nm probe (<0.35nm) and small beam tails creates a highly localized interaction between the beam and sample, which results in the formation of sub-10nm holes. The comparatively low sputter rates of the helium ion beam offers greater precision and control in drilling the nanoholes. We will discuss the use of the helium ion microscope for the creation of nanohole arrays and the applications this could enable in chemical and biological sensing.

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8036-23, Session 5

Plasma FIB system for large volume cross-sectional metrology and analysis

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A new plasma ion source has been developed that can produce high current density probes for cross-sectioning and analyzing structures at the microscale and nanoscale.

This source extracts ions from a high density plasma. This dense plasma is produced by inductively coupling RF electromagnetic waves into a low pressure gas. The high brightness and low energy spread of this ion source make it ideal for producing nanoscale and microscale ion probes with an electrostatic lens system. A high current focused ion beam column has been developed that can produce microscale crosssections nearly a hundred times faster than conventional FIB technology. This rapid cross-sectioning rate enables metrology of structures across the microscale from 1 micron to 1 millimeter. A dual focused ion beam system has been developed that combines a high current Xenon plasma FIB column with a conventional Gallium LMIS column on a single system that is ideal for performing cross-sectional metrology on large structures such as MEMS devices, 3D-ICs, through Silicon vias (TSVs), and metallurgical samples. The Xenon plasma FIB can remove large volumes of material to expose embedded structures but can also remove thin slices to precisely locate the cross-section face. The Ga FIB is used to image the large areas exposed by the plasma FIB and provides good grain and material contrast. This dual FIB system has been utilized to perform unique cross-section metrology that can not be done with conventional methods cross-section such as Ga FIB, broadbeam cross-sectioning tools, or mechanical polishing.

8036-24, Session 5

Secondary electrons energy distribution and energy selective imaging in helium ion microscope

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Helium ion microscope (HeIM) is a novel and rapid developing imaging and lithography technique [1]. The most of imaging characteristics are determined by SE excitation parameters, such as secondary electrons (SE) yield and SE energy distribution (SEED) of every particular target material.

In this work, SEED in HeIM was investigated experimentally for three metals of (Mo, Ni, Pt) by means of retarding potential technique with hemispherical geometry. It was found that the width of ion beam excited SEED for all investigated materials in HeIM was significantly narrower than that of SEED excited by electron beam in scanning electron microscope (SEM) and even more narrow than predicted by previous numerical simulations [2]. The energy of the SEED maximum increased with the increase of the material work function value.

SEED shape was analyzed using modified Chung-Everhart model [3] when the SEED inside the solid, S(E), was approximated by the power dependence:

where a=2 for SEM. The fitting of SEED obtained in HeIM using this model gave a significantly larger a=3.3 for all investigated materials.

The reasons of the lower energy transfer efficiency in ion-electron interaction are discussed. It is concluded that the discrepancy between measured results and simulation data [2] might be explained taking into consideration two additional mechanisms of ion-induced SE: Auger neutralization of He ions and kinetic excitation by fast neutrals.

Impact of thin foreign surface layer on SEED was investigated as well and it was shown how the energy selective imaging in HeIM might be used in applications.

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8036-25, Session 6

Progress on a metrological scanning probe microscope for traceable dimensional metrology at the nanoscale

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We report on progress of the design, construction and preliminary evaluation of a metrological Scanning Probe Microscope (mSPM) currently under development at the National Measurement Institute Australia (NMIA). Metrological principles guiding the design and construction of the instrument are highlighted. The mSPM facility is being established as part of the NMIA nanometrology program and will provide the link in the traceability chain between dimensional measurements made at the nanometer scale and the realization of the SI meter at NMIA.

The mSPM will provide a measurement volume of 100 µm × 100 µm × 25 µm with a target uncertainty of 1 nm for the position measurement. Its main components are a metrological frame that defines the reference coordinate system; a translation stage to implement the displacement between the probe and the sample; sensors to measure the displacement; a probe head and a sensor to quantify the interaction between probe and sample; and a feedback system to control the relative position between probe and sample, i.e., the scanning motion.

Laser interferometry, employing a high performance all-digital phase meter, is used for traceable measurement of the displacement between the sample stage and the metrological frame along the three perpendicular axes of motion. We describe the design principles that are aimed at minimizing the magnitude of the potential contributions to the uncertainty of the displacement measurements. These include alignment (particularly Abbé) errors, deformation of the mechanical structures, e.g. due to thermal expansion; motion errors of the translation stage; form errors of the interferometer mirrors; non-linearities of the interferometers; and fluctuations in the refractive index of air.

8036-26, Session 6

Measurement strategies and uncertainty estimations for pitch and step height calibrations by metrological AFM

V. Korpelainen, J. Seppä, A. Lassila, MIKES Mittatekniikan keskus (Finland)

Gratings and step height standards are generally used in calibration of AFMs. To achieve traceability in the calibration, the standards must have been calibrated prior to use. Metrological AFMs with online laser interferometric position measurement can be used in the calibration of the standards. MIKES has developed and characterized an interferometrically traceable metrological AFM (IT-MAFM) [1]. Measurement times with the IT-MAFM are relatively long. Therefore we have developed measurement strategies for step height and pitch calibrations to reduce the measurement time and, thus, effects of drifts. In pitch calibration, data is collected only from both sides of the measurement area and area in the middle is skipped. Correlation algorithm and estimated pitch value (from previous or less accurate measurements) is used to define the accurate pitch value. During the step height calibration flat areas are scanned with higher speed and the edges with lower speed. The positions of the edges are approximated from previous scan line and the scan speed slows down just before the edge. Detailed uncertainty estimations for step height and pitch calibrations based on characterization and uncertainty estimations of the IT-MAFM will be given. The main uncertainty components in step height calibration are out-of-plane error caused by flatness error in the measurement mirror in Z direction and repeatability of the measurement. In pitch calibration the main error sources are Abbe error and cosine errors caused by sample alignment.

[1] V. Korpelainen. J. Seppä and A Lassila,. Precision Engineering 34 2, p. 735-744, 2010

8036-27, Session 6

Study of a large range metrological atomic force microscope applied for calibration of a vertical PZT stage

S. Wang, S. Tan, G. Xu, A*STAR National Metrology Ctr. (Singapore)

In this paper, a method using a large range metrological atomic force microscope (LRM-AFM) is described to calibrate a vertical PZT stage. The LRM-AFM consists of an AFM probe and a nano-measuring machine with built-in He-Ne laser interferometers. Unlike normal AFMs with limited horizontal scanning ranges less than 100 μm and even a shorter vertical range of 10 μm, LRM-AFM is featured with a large horizontal scanning range up to 25 mm and a vertical scanning up to 5 mm while still keeping a high resolution of 0.1 nm. In the experiment, a vertical PZT stage is mounted onto the system and an optical-flat is attached on the top of the PZT stage as the sample. The AFM probe working in the tapping mode is used as a null indicator which is sensitive to the movement of the optical-flat directly driven by the vertical PZT stage. At each state of the PZT stage with different applied voltages, the AFM probe can approach the surface of the optical flat while keeping no horizontal scanning in the system. The displacement of the vertical stage is measured by the laser interferometer and the corresponding applied voltage on the PZT stage is also recorded. All collected data are retrieved to establish a relationship of the stage displacement versus the applied voltage on the PZT. The results show that the system is capable of doing calibration on the PZT stage in the range of up to 250 μm with an expanded uncertainty of less than 5 nm.

8036-28, Session 6

Traceable calibration of a critical dimension atomic force microscope (CD-AFM)

R. G. Dixson, N. Orji, National Institute of Standards and Technology (United States)

The National Institute of Standards and Technology (NIST) has a multifaceted program in atomic force microscope (AFM) dimensional metrology. One component of this effort is a custom in-house metrology AFM, called the calibrated AFM (C-AFM) [1,2]. The NIST C-AFM has displacement metrology for all three axes traceable to the 633 nm wavelength of the iodine-stabilized He-Ne laser.

A second major component of this program is the use of critical dimension atomic force microscopy (CD-AFM). CD-AFM is a commercially available AFM technology that uses flared tips and two-dimensional surface sensing to scan the sidewalls of near-vertical features [3]. Features of this sort that are commonly encountered in semiconductor manufacturing and other nanotechnology industries.

NIST has experience in the calibration and characterization of CD-AFM instruments and in the development of uncertainty budgets for typical measurands in semiconductor manufacturing metrology [4]. A third generation CD-AFM was recently installed at NIST. We will describe the performance of this instrument and describe the development of our methods over three generations of CD-AFM.

1. J. A. Kramar, R. Dixson, N. G. Orji, “Scanning Probe Microscope Dimensional Metrology at NIST,” to be published in Meas. Sci. Technol. (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).

3. Y. Martin and H. K. Wickramasinghe, “Method for imaging sidewalls by atomic force microscopy,” Applied Physics Letters Vol. 64, 2498-500 (1994).

4. N. G. Orji, R. G. Dixson, A. Martinez, B. D. Bunday, J. A. Allgair, and T. V. Vorburger, “Progress on implementation of a reference measurement system based on a critical-dimension atomic force microscope,” J. Micro/Nanolith. MEMS MOEMS Vol. 6, 023002-1-10 (2007).

8036-29, Session 7

Effects of tip characteristics on nanoparticle metrology with atomic force microscopy

M. A. Lawn, A. K. Jämting, J. Herrmann, National Measurement Institute of Australia (Australia)

Accurate dimensional metrology of nanoparticles using atomic force microscopy (AFM) has the advantage of being capable of imaging non-conductive surfaces in both air and liquid media, and requiring less invasive sample preparation than electron microscopy. Nevertheless, accurate nanoparticle metrology with AFM is not entirely straightforward. In AFM images, in-plane dimensions are distorted by the convolution of the AFM tip shape and the nanoparticle, while out-of-plane dimensions can be distorted by the force of the tip deforming the particle, and also by the interaction force between the tip and the nanoparticle differing from the interaction force between the tip and the substrate.

A wide range of AFM tips are commercially available, varying in sharpness, hardness and aspect ratio amongst other parameters. We present the comparative results of an investigation into the performance of a selection of AFM tips in nanoparticle metrology. Monodisperse reference material nanoparticles were deposited on atomically flat substrates to produce samples with individual particles, or monolayer island arrays of particles, attached on the substrate. The nanoparticle samples were imaged with a commercially available AFM with flexure-hinged translation stages in X, Y and Z directions. Closed-loop displacement control is provided, in each of the three directions of motion, by linear variable differential transformers incorporated into the translation stages.

Nanoparticle dimensions, and uncertainties, derived from analysis of images acquired with the different AFM tips were compared to determine optimal tip characteristics for nanoparticle metrology. This is of particular interest since AFM measurements of nanoparticle reference materials provide a link in the traceability chain between ensemble measurement techniques, such as dynamic light scattering and centrifugal liquid sedimentation, with realizations of the SI meter.

8036-30, Session 7

Development of photomask linewidth measurement and calibration using AFM and SEM in NMIJ

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In semiconductor industries, a photomask is widely used for an original plate to print an image of a circuit pattern on a silicon wafer. For a quality control of semiconductor devices fabricated through a transfer etching processes, inspection equipments to measure the pattern size of photomasks are needed to be precisely calibrated, and to be traceable to length standards. Therefore the linewidth standards are important to certificate the inspection systems.

Return to Contents

We developed a method for measuring linewidth patterns of photomasks, and started a calibration service of the photomask linewidth measurement. For the photomask standards, high-quality of chromium film patterns, typical thickness of about 80 nm, having sharp edges (edge angles more than 85 degree) and smooth side walls on a quart glass substrate were used. Two kinds of microscopes, an atomic force microscope (AFM) and a scanning electron microscope (SEM), were employed to calibrate the linewidth.

At the first, the surface profile of line structures were inspected using the AFM, so that the distance between the left and the right side walls at the edge positions were geometrically-determined. A tip shape of the AFM probes was measured using a needle sample. The definition of the edge positions is a 10 % level from the top film surface. Then, linewidth values measured by the calibrated SEM were corrected by the AFM data. Using this method, an uncertainty of the linewidth measurement was evaluated at 60 nm for a linewidth range of 0.5 um - 10 um.

8036-31, Session 7

New developments at PTB in 3D-AFM with tapping and torsion AFM mode and vector approach probing strategy

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The development of advanced lithography requires metrology methods for 3D structures with a desired uncertainty of about a nm or even below. True 3D metrology of these structures including form (width, height, edge slope, corner rounding and footing) and line edge/width roughness is one of the most challenging metrology tasks today. Among other potential critical dimension (CD) metrology techniques such as scatterometry, optical microscopy and CD-SEM, 3D-AFM is a unique technique for direct, accurate, and non-destructive measurements. However, a number of challenges exist in 3D-AFMs concerning several aspects, such as special 3D AFM probing tips, highly sensitive 3D probing technique, suitable measurement strategies for minimizing tip wear, and the (effective) tip geometry characterization.

In this paper, we introduce new developments at PTB in 3D-AFM with tapping and torsional oscillation mode (TT-AFM). In its configuration, the AFM tip oscillates simultaneously in both vertical and lateral directions. As the benefit, the tip can probe 3D surfaces with its oscillation direction nearly perpendicular to the surface, offering high 3D probing sensitivity. In contrast, the conventional AFM oscillates its tip in vertical direction only; its probing sensitivity is weak in measuring vertical sidewall structures since the tip-sample interaction force changes little during the tip oscillation. In its design, the vertical and torsional oscillations of the AFM probe are generated by two piezo stacks driven by signals (Sv + St) and (Sv - St), where Sv and St are the sinusoidal signal at the vertical and torsional resonance frequencies of the cantilever, respectively. The cantilever oscillation is determined by conventional light deflection by means of a quadrant photo detector whose signals are processed using two lock-in-amplifiers to obtain the information about both oscillation modes simultaneously.

Due to the tip dilation effect, the measured CD values show an offset of the (effective) tip width from the true CD value of the structure. For obtaining highly accurate CD measurements, the tip width should not only be calibrated accurately prior to measurements, but also be kept constant during measurements. In order to minimize tip wear, we have implemented a so called “vector approach probing” (VAP) measurement strategy where the surface is measured point by point. At each measurement point, the tip is moved towards the surface in its perpendicular direction until the desired tip-sample interaction is detected and then immediately withdrawn from the surface. Compared to conventional AFMs where the tip is kept continuously in interaction with the surface, the tip sample interaction time using the VAP method is greatly reduced and consequently tip wear is reduced. The VAP method has firstly been developed for a commercial AFM “Nanostation 300”. In the TT-AFM, a high-end DSP system is applied where the tip-sample interaction was recorded and processed in real time, leading to a measurement speed of approx. 20 points/sec.

A sophisticated 3D-AFM measurement software has been developed. With the software, an unknown structure can firstly be measured from top by the VT-AFM functioning as a conventional AFM. The obtained result is then applied as a template, and a task for true 3D measurements will be automatically generated. The instrument could be operated conveniently both with a graphic user interface or script commands. In addition, an automatic drift compensation algorithm was realized to account for the drift influence on the measurement stability.

Preliminary experimental results show promising performance of the developed system. For instance, the probing repeatability on a surface at the same point reaches 0.12 nm (1σ), and the repeatability of the real true 3D profiles is better than 1 nm (p-v). Using a flared AFM probe, the repeatability of the middle CD value measured on a 300 nm line structure of a PTB photo mask reaches 0.28 nm (1σ), and the change of the measured middle CD values is less than 1 nm within 197 images which were taken over 30 hours.

8036-32, Session 7

Pitch metrology for data storage: a plan for useful pitch standards down to 5 nm

D. A. Chernoff, D. L. Burkhead, Advanced Surface Microscopy, Inc. (United States)

No abstract available

8036-33, Session 7

Meniscus effects: a new model for ink transport in dip-pen nanolithography

B. L. Weeks, M. W. Vaughn, Texas Tech Univ. (United States); O. A. Nafday, NanoInk, Inc. (United States)

No abstract available

8036-34, Session 7

Development of the interference microscope for traceable step height standard measurements and AFM calibration

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We report in progress development of the primary nanometrology capacity at National Metrology Institute of Brazil. The primary interference microscope (IM) of Linnik type has been constructed and being under detailed characterization. The instrument is traceable to the meter SI unit via stabilized He-Ne laser as a reference wave-length standard. The registration of the fringes is done by automated CCD system with 2 possible processing approaches: interferometric pattern processing and the phase stepping technique. We report some progress in development of the hardware and software adequate for sub-nanometer resolution of the instrument. The instrument permits both point ant topography kind of measurements. Thus, comparison of advantages and disadvantages of the both techniques can be performed. Detailed 3D topography comparator software developed for this specific task is found to be quite useful for this study. Results of optical measurements are compared with those obtained with AFM metrology class AFM. The detailed study of systematical errors of IM is being performed and will be reported. The instrument is aimed for international key comparisons of the step height standards.

8036-35, Session 8

Compressive decoding enabled lensless fluorescent imaging on a chip

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Lensless imaging is emerging as a powerful alternative to conventional microscopes for monitoring biological samples on a chip. Lensless technologies eliminate the need for complex and bulky optical components, with the assistance of novel theories and numerical algorithms. Along the same lines, here we introduce a wide-field lensless fluorescent imaging modality that can achieve ~10μm resolution over >8cm2 imaging field-of-view without the use of any lenses, thin-film interference filters or mechanical scanners. In this on-chip fluorescent imaging platform, excitation of cells or particles (e.g., located within a micro-chip) is achieved through the side-facet of a rhomboid prism. After interacting with the three-dimensional sample volume, the pump is rejected through total internal reflection occurring at the bottom interface of the micro-chip. With the removal of the weakly scattered excitation light (through the use of an additional absorption filter), only the fluorescent emission from the specimen is collected by a fiber-optic faceplate and is delivered to an opto-electronic sensor array (e.g., a CCD chip) for digital image capture. These recorded lensfree fluorescent images are then rapidly decoded using a compressive sampling algorithm to achieve ~10μm resolution over entire chip area (e.g., >8cm2). We evaluated the performance of this high-throughput platform by imaging various fluorescent particles as well as labeled cancer cells. In addition, we simultaneously monitored vertically stacked micro-channels (separated by 50-100μm axially) using the same lensfree on-chip platform. Such a wide-field on-chip lensless imaging modality might be quite useful for high-throughput screening applications, rare-cell analysis, as well as for microarray research.

8036-36, Session 8

Through-focus scanning optical microscopy

R. Attota, National Institute of Standards and Technology (United States)

A relatively new “through-focus scanning optical microscopy” (TSOM-pronounced as “tee-som”) method transforms conventional optical microscopes to truly 3D metrology tools for nanoscale to microscale dimensional analysis with potentially sub-nanometer scale sensitivity comparable to typical scanning electron microscopy (SEM) and atomic force microscopy (AFM). The method can be used in both reflection and transmission modes of microscopes. It is applicable to a wide variety of target materials ranging from transparent to opaque, and shapes ranging from simple nanoparticles to complex semiconductor memory structures, including buried structures under transparent films. Potential applications of TSOM include defect analysis, inspection and process control, critical dimension (CD) metrology, photomask metrology, overlay registration metrology, nanoparticle metrology, film thickness metrology, quantum dots, 3D interconnect metrology (large range depth analysis such as TSVs), line-edge roughness measurement, and nanoscale movement of parts, e.g., in MEMS/NEMS. Numerous industries could benefit from the TSOM method -such as the semiconductor industry, MEMS, NEMS, biotechnology, nanomanufacturing, nanometrology, data storage, and photonics. The method is relatively simple and inexpensive, has a high throughput, provides nanoscale sensitivity for 3D measurements and could enable significant savings and yield improvements in nano/microscale metrology and manufacturing. Potential applications are demonstrated using experiments and simulations.

8036-37, Session 8

High-speed 3D nonlinear optical imaging using FPGA, deformable and scanning mirrors

M. Samim, Univ. of Toronto (Canada); V. Barzda, Univ. of Toronto Mississauga (Canada)

Recent developments towards high-speed imaging capabilities have gained significant notice in the field of microscopy. The advances in microscopy are stretched to imaging of rapid dynamics of important biological processes. Hardware and software used for diverse detection schemes are rearranged to perform video-rate imaging more optimally and in the cost-effective manners. Multi-contrast, multi-foci nonlinear optical microscopes are the most recent examples in this field. These microscopes are, for example, capable of capturing simultaneous images of orthogonal polarization from two distinct optical sections, in both forward and backward directions. The converging, diverging and/or reference beams, that are reflected off of the surface of the deformable mirrors, and are conjugated with the back-aperture of a microscope objective, can be focused at different axial depth. One such microscope is currently being developed in our lab, using also a Xilinx Vertix-5 FPGA board and high-speed galvanometer/scanning mirrors. The optical wavefronts of a novel Yb:KGW femto-second (1028 nm) laser-beams are monitored by the microlens-array Shack-Hartmann wavefront sensor. We demonstrated the ability of the 39-actuator deformable mirrors in reshaping the phasefront and correcting for the optical aberrations to achieve the diffraction limited focal volume for deep excitations. Here, we present the schematics and the design of this novel microscope and the data illustrating the ability to focus at distinct axial depths. The three-dimensional video rate scanning capability will be used to study the rapid dynamics of organisms, such as their blood flow, cardiac activities, and muscle contractility.

8036-38, Session 8

Dispersion free all reflective confocal microscope objective

W. J. Walecki, Sunrise Optical LLC (United States); M. Scaggs, Neoteric Concepts, LLC (United States); F. Szondy, Sunrise Optical LLC (United States)

We describe results of simulation of a novel all reflective ultra-high bandwidth confocal objective design. The design is an improved David Schafer objective [1]. While Shafer demonstrated that his objectives reaches NA = 0.7 while preserving good imaging quality of the system [1], our objective offers excellent performance even for NA = 0.8 and possibly beyond. .

In our approach we propose following improvements:

1.The “dual reflection” optical path [1] will be replaced by “three and higher reflection path” where each primary and secondary reflector is impinged three or more times enabling NA = 0.8 and beyond.

2.Application of the excitation with radially polarized excitation beam [2] further tightening excitation spot.

We also disclose a new configuration of the confocal microscope system employing our objective and eliminating entirely temporal broadening of the collected radiation from sample. The emission from the sample is collected by the same all reflective objective, is reflected by the front surface of the beam splitter without suffering any temporal broadening, while the constant temporal broadening of the excitation radiation in the beam splitter is compensated by use of pulse compressor integrated with the light source.

The potential applications in novel 3D optical microscopic techniques, and laser machining are also discussed.

[1] David R. Shafer, et al. US Patent 4,863,253 Issue date: Sep 5, 1989

[2] Stadler, J., et al. , Opt. Lett., Vol. 33, No. 7, 681-683, 2008.

8036-39, Session 8

A λ/50 near-field scanning microscope resolution using a nano-antenna enhanced C-shaped ridge nano-aperture

Y. Cheng, Y. Takashima, Y. Yuen, P. C. Hansen, L. Hesselink, Stanford Univ. (United States)

Due to insufficient amount of light available of a round nano-aperture, conventional near-field optical microscope suffers from very slow scanning speed in order to get sufficient signal-to-noise ratio, which is not practical for a wafer-scale scan. Metallic nanostructures have been studied for more than a decade as means to concentrate optical power to a subwavelength scale. A C-shaped nano-aperture, previously designed in our group, has been theoretically and experimentally proved to efficiently concentrate optical power to a sub-100 nm scale. However, due to current nanofabrication limit, the optical resolution of the C-aperture is limited to 50-70 nm under near-IR illumination. We recently reported a C-aperture nano-tip (CAN-tip) by attaching a nano-antenna to the ridge of a C-aperture at the exit surface. With efficient concentration of on-resonance Plasmon waves to the ridge, a C-aperture is able to generate a near-field spot of two to three orders higher intensity than a round nano-aperture with similar near-field spot size. By tuning the antenna length of a CAN-tip to make the antenna con-resonant as the C-aperture, the near-field intensity can be one order even higher than a planar C-aperture according to FDTD calculations. The optical spot size at the near-field is proportional to the tip size and can be smaller than 15 nm according to current technology. We fabricated this CAN-tip using focused ion beam milling and tested it in an NSOM configuration. Results from scanning the CAN-tip over e-beam lithography fabricated nano-structures match the simulations and a sub-20 nm optical resolution was demonstrated. This design opens a new path for further improving the optical energy concentration with metallic nanostructures and can be applied in optical near-field recording, heat-assisted magnetic recording, and single molecule detection.

8036-40, Session 8

Use of fluorescence and scanning electron microscopy as tools in teaching biology

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Recent nationwide surveys reveals significant decline in students' interest in Math and Sciences. The objective of this project was to inspire the young minds in using various techniques involved in Biological Sciences including Scanning Electron Microscopy. We used Scanning Electron Microscope in demonstrating various types of Biological samples. SEM Top Models in recent decade has revolutionized the use of Scanning Electron Microscope. Using SEM Top model TM 1000 we studied some biological specimens like fungal spores, pollen grains, diatoms, plant fibers, dust mites, insect parts and leaf surfaces. We also used fluorescence microscopy to view, to record and analyze various specimens with an Olympus BX40 microscope equipped with FITC and TRITC fluorescent filters, a mercury lamp source, DP-70 digital camera with Image Pro 6.0 software. Photographs were taken at bright field, the fluorescein-isothiocyanate (FITC) filter, and the tetramethylrhodamine (TRITC) filter settings at 40X. A high pressure mercury lamp or UV source was used to excite the storage molecules or proteins which exhibited autofluorescence. We worked with the REU summer students on sample preparation and observing various samples to observe with SEM. Critical Point Drying (CPD) and metal coating with the sputter coater were followed before observing some cultured specimen and the samples that were soft in textures with high water content. SEM Top allowed investigating the detailed morphological features that can be used for classroom teaching. This project inspired the research students to pursue their career in higher studies in science and 45% of them entered into the Graduate school.

8036-41, Session 9

Universal yield curves: understanding electron and ion interactions

D. C. Joy, The Univ. of Tennessee (United States); B. J. Griffin, The Univ. of Western Australia (Australia)

Universal curves are functions which attempt to fit a related range of experimental data, such as measurements of electron induced secondary electron (eSE) yields , by a single equation. Typically this employs normalized variables, for example the SE yield would be expressed as a fraction of the maximum yield SEmax for that material and the energy E is given as a multiple of the energy Emax at which the SE yield achieves it maximum value. The observation that e-beam induced SE yield profiles when plotted in this fashion all have closely the same form has been known for sixty years or more and the validity of this result is somewhat supported by the fact that a simplified model of SE emission, based on the Bethe stopping power and the Salow concept of SE diffusion, leads to an equation identical in form to the experimental version. Even if the derivation of the result is questionable the universal curve is valuable because it provides a rapid and reliable way of testing experimental yield data.

Recent studies of ion induced SE (iSE) yields have shown that, for several different ion beams and for a wide range of elemental targets and energies, a universal yield curve also exists. While its form is generically similar to the electron case it differs in detail even though the underlying model for the generation of the iSE is identical to that for eSE production. More puzzling is the fact that this iSE curve only seems to apply to pure elements because the curve for even simple binary materials (AB) differs significantly in form from the iSE curves for pure elements.

This presentation will consider the questions- (1) are universal curves meaningful or just a forced fit?; (2) would electron and ion beams be expected to produce the same parametric behavior?; and (3) what is the relationship between these universal curves and that suggested for ions by Dietz and Sheffield (1975) which is able to accommodate both elements and compounds?

L A Dietz and J C Sheffield, (1975), J.App.Phys., 46, 4361

8036-42, Session 9

3D-measurement using a scanning electron microscope with 4 Everhart-Thornley detectors

T. Vynnyk, R. Scheuer, E. Reithmeier, Leibniz Univ. Hannover (Germany)

In this paper, a new revision of the photometric or the so-called "Shape from Shading" method is presented. In comparison to established approaches, the efficiency of the detector system was taken into account. For this purpose the CAD-3D-Modell of the scanning electron microscope (SEM) chamber was imported into the FEM simulation software Comsol Multiphysics, which was used to solve the electrical field distribution. Based on this distribution, the electron trajectories in the modelled SEM with Everhart-Thornley (ET) detectors were investigated. The tests were held for systems with one, two and four Everhart-Thornley detectors. Besides varying the number of detectors, the working distances, collector grid voltages and the form of the collector grid were modified while their influence on the collection efficiency of each detector was determined. Using the gathered information a new collection grid, which provides a homogenous emission signal for each detector of a multiple detector system is developed. Finally, the results of the preceding tests are utilized for a reconstruction of a three dimensional surface, using the photometric method, where the common requirements of the cosine Lambert's law for the angle distribution of the emitted electrons are suppressed. The developed algorithm was experimentally tested on different measurement objects and analysed with regard to its accuracy and resolution limits.

8036-43, Session 9

Simulation of SEM images of core-shell nanospheres using CHARIOT Monte Carlo software

S. K. Wei, A*STAR Institute of Materials Research and Engineering (Singapore); S. Babin, S. S. Borisov, Abeam Technologies (United States); M. Y. Han, A*STAR Institute of Materials Research and Engineering (Singapore)

Synthesized nanoparticles with specific controlled properties are of special interest in medicine, biology, physics, and material science. Nanoparticles are characterized by size-dependent properties. By controlling the size, it is possible to design materials with required optical, magnetic, elastic, chemical etc. properties.

Predicting and understanding image formation in SEM will enable dimensional metrology of nanoparticles. The commercially available CHARIOT Monte Carlo simulation tool was used to simulate electron scattering and images of core-shell object. The simulation involves advanced physics of electron scattering, especially at low electron voltages below 50 eV. The CHARIOT platform can specify complex 3D geometries, including core-shell objects.

Core-shell objects with 50 nm and 100 nm diameters of inner sphere were considered. At a 5 kV beam, the signal from the edges of the outer shell turned out to be brighter than the signal from the top; the inner shell is not visible. At 20 kV, the inner shell became clearly visible. The edges of the inner shell are not as well defined though; this presents a challenge for accurate metrology of their dimensions, though the signal is sufficient for an estimation of the sizes. The details of the contrast at variable voltages and core sizes are discussed.

SEM signals across the shell as well as simulated 2D SEM images are presented. Experimental images of core-shall objects taken at these two voltages are also presented. The correspondence of the simulation and experiment is discussed; a good agreement was found.

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8037-01, Session 1

Long-range target discrimination using UV fluorescence

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This paper describes the work conducted within a project funded by the Materials and Components for Missiles Innovation and Technology Partnership. An active imaging system using UV fluorescence for target discrimination is proposed.

Measurements show the fluorescent return wavelength is characteristic of the fluorophore material. Targets are discriminated from clutter spectrally.

The burst-illumination-lidar-like system transmits a laser pulse and the fluorescent return is detected with a synchronised gated imaging receiver. A short gate length is required to reduce solar clutter; the proposed detection uses a microchannel plate CCD detector with a gate length which can be reduced to less than 1ns. The MCP-CCD has a high detectivity which limits detector noise, so this noise source is not the limiting factor.

The required laser pulse energy, laser size and robustness limit the choice of pulsed sources. The COTS solution identified is a diode pumped 1064nm laser with a 4th harmonic converter. Diode pumped Nd:YAG, Nd:YLF and Nd:Alexandrite lasers have superior performance but require development for this application.

A pessimistic range model evaluates the optical powers for the whole optical system. The results compare the received fluorescent power to the noise equivalent power of the detector and the CW solar power received to evaluate the detection range. Use of the MCP-CCD with each laser provides detection ranges in excess of the requirement for all the samples measured. The lowest range is for black paint with the COTS laser system and is 2860m; the best ranges exceed 5km.

8037-02, Session 1

Slant path 1.5 μm range gated imaging close to ground

O. Steinvall, M. Elmqvist, K. Karlsson, O. K. Gustafsson, T. R. Chevalier, Swedish Defence Research Agency (Sweden)

This paper will report experiments and analysis and simulations of slant path imaging using 1.5 μm gated imaging. The measurements were taking place at a former airfield along a 2 km path. The sensor was elevated by a lift in steps from 2-12.5 meters. Targets were resolution charts. The turbulence was measured along the path with a scintillometer. Turbulence information was also obtained at various path positions including the elevated cage using anemometers. The camera was collecting both passive and active images in the SWIR region. In the passive mode (using solar illumination) the noise due to speckles are eliminated and the influence by scintillation limited. In the active mode on the other hand these noise sources are present to a varying degree depending on stabilized frame averaging and on the sensor elevation. A trend is that the image quality is much improved for elevated sensor positions. Two light sources in the camera FOV (head lights from a car) will allow for independent turbulence level estimates.

The paper will present evaluated images for both passive and active modes obtained at different elevations and the result compared with theory including image simulation.

8037-03, Session 1

Near infared lidar system for perimeter security and surveillance in low-visibility weather conditions

R. I. Billmers, RL Associates Inc. (United States)

RL Associates, Inc. is currently developing a near-infrared (NIR) range-gated light detection and ranging (Lidar) system for identification of hazards and security threats on the ground at airports and military installations. The system is capable of interrogation the region immediately surrounding unoccupied runways, compounds, etc. and can provide a clear image under many visually obscured weather conditions, such as rain or fog. The system will further be able to detect and identify objects or security threats and transmit all of the available information to external security stations or remote air traffic control stations as well as directly to the pilots of the approaching aircraft. RL Associates, Inc. is currently leading the industry in NIR (1.5um) active imaging systems and is drawing on their intimate knowledge of the technology in developing the NIR Lidar System. The system is compact, lightweight, and operates around 1.5 um, which is safe to the human eye. Major components of the Lidar unit include a laser transmitter, a fast gated detector, and narrowband optical filter. Backscattered noise from obscurants is greatly reduced by the range-gated camera system, and the narrowband optical filter provides additional noise rejection. Range to the target or hazard can be determined by the time-of-flight of the return signal. The gate delay of the camera can then be changed appropriately to image at various ranges through or beyond any obscurants.

8037-04, Session 1

Characterisation of small targets in a maritime environment by means of laser range profiling

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A shortened characterisation process of small sea-surface targets in complex environ-ments is required. Laser range profiling is a technology that can provide in a fast recognition and/or identification of (potential) threats at relatively large distance. Laser range profiling analysis can be performed by comparing measured profiles with a database of range profiles obtained from 3D models of possible targets, or from measurement campaigns if plenty measured profiles are on hand. Comparing measured profiles with a reference database is then performed using, e.g., formal statistical correlation techniques or histogram dissimilarity techniques. Characterisation methods of measured range profiles from field trial data were investigated. We focused on the use of a reference database generated via 3D target models. Several histogram dissimilarity measures were examined in order to enable fast and reliable characterisation algorithms.

8037-05, Session 1

High-resolution hydrographic airborne laser scanner for surveying inland waters and shallow coastal zones

M. Pfennigbauer, A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria); F. Steinbacher, M. Aufleger, Leopold-Franzens-Univ. Innsbruck (Austria)

Repetitive surveying of inshore waters is becoming more and more essential to evaluate reservoir sedimentation, river degradation, water flow and water level dynamics, structure and zone variations of rivers and riparian areas. This can only be achieved in an effective way by employing hydrographic airborne laser scanning. A new laser scanner for acquisition of high-resolution hydrographic data dedicated for surveying inland waters and shallow coastal zones is introduced. Measurement results obtained with the compact airborne laser scanning system employing a narrow laser beam at 532 nm, operating at a net measurement rate of 110 kHz are presented. Advantages and limitations of this new approach are discussed and potential fields of applications are assessed.

8037-06, Session 1

Underwater laser serial imaging using compressive sensing and digital mirror device

B. Ouyang, F. R. Dalgleish, W. Britton, B. Ramos, Florida Atlantic Univ. (United States)

In this paper, the application of Compressive Sensing (CS) in an underwater laser serial imager is explored. CS theory states that a sparse signal can be acquired using a small set (less than Nyquist sampling rate) of random linear measurements. In a CS based imager, the target is modulated either at the illuminator or at the receiver with a set of binary random measurement matrices in serial mode using a spatial light modulator such as Digital Mirror Device (DMD). A single element detector such as photomultiplier tube (PMT) is used to obtain the corresponding set of measurements. A nonlinear optimization algorithm uses these measurements and the corresponding set of measurement matrices to reconstruct the image.

In underwater laser serial imaging applications, CS can provide some distinct advantages: it simplifies the optical design and sampling electronics and offers high photon efficiency. In addition, the illuminator-based design is especially suitable for bi-static laser imaging configuration. However, in turbid coastal water, dispersive scattering renders existing CS measurement matrices ineffective. To overcome such obstacle, a new multi-resolution measurement matrix design and the “Model assisted image processing” concept, where a radiative transfer model is incorporated into an operational system to predict the modulation pattern at the target are proposed. Simulations were conducted to verify the effectiveness of this technique. Performances at a range of imager depths and attenuation coefficients were analyzed. The simulation has shown some very promising results, with reconstructed images exhibiting good contrast and resolution at multiple attenuation lengths. The proposed technique is also compared with traditional laser line scan (LLS) design and other structured illumination based imager.

8037-07, Session 1

High-precision, accuracy, and resolution 3D laser scanner employing pulsed-time-of-flight measurement

M. Pfennigbauer, A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria); J. Pereira do Carmo, European Space Research and Technology Ctr. (Netherlands)

We present experimental results of a high-speed 3-D laser scanner developed for the European Space Agency within an activity dealing with a high precision relative attitude control sensor for formation flying. By employing pulsed-time-of-flight measurement, we demonstrated sub-mm accuracy and precision as well as unprecedented resolution of single-shot measurements to natural targets at distances up to 150 m. The instrument is based of RIEGL’s commercial terrestrial laser scanners with a scan range of 100° x 360° and a net measurement rate of 125 kHz. The system’s performance is demonstrated with different test setups and potential field of application are assessed.

8037-08, Session 1

In cooperation with laser radar

V. V. Molebny, National Taras Shevchenko Univ. of Kyiv (Ukraine); G. W. Kamerman, FastMetrix, Inc. (United States); O. Steinvall, Swedish Defence Research Agency (Sweden)

Laser radar operates in cooperation with other constituents of a system providing the information for final customer. Main types of information needed by the customers are analyzed: from surveillance to multi-dimensional data including range and velocity. In a simplest case of a portable rangefinder, information is provided to an operator directly. In fire-control systems, the information is processed in more complicated manner to control the guns. For aiming high-energy lasers, several closed-loops can be used. Limitations, trade-offs and reserves of laser radars are compared for different techniques. The problems of information processing, exchange and fusion are brought to light in multi-spectral, multi-channel and multi-technique systems. Special attention is paid to systems combining different principles to achieve synergetic effects (e.g., combinations with passive infrared, microwave and terahertz techniques, etc.). Operation of laser radar in counter-measure environment is discussed.

8037-09, Session 1

Highly sensitive lidar with sensor-head of thumb size by using optical fiber preamplifier

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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.

We optimized the gain of optical fiber amplifier and TIA, so that LIDAR can detect single photon. As a result, the detection limit of our LIDAR system is determined by shot noise.

This small and highly sensitive measurement technology shows great potential as LIDAR with optical preamplifier.

8037-10, Session 2

Line of sight analysis using voxelized discrete lidar

S. Hagstrom, D. W. Messinger, Rochester Institute of Technology (United States)

Modern small-footprint LIDAR systems have the ability to resolve structural details at sub-meter sizes, which make them ideal for collecting information to use in line of sight analysis. Many existing techniques used to map line of sight apply simple surface triangulation to the LIDAR point cloud, but are not well suited to scenes with significant 3D structure and

overlapping objects. Newer voxel-based techniques have the ability to describe scene structure accurately, but typically suffer from a lack of information if all scene surfaces are not exhaustively sampled by the LIDAR. LIDAR instrument position is typically discarded after producing the point cloud, but we show how it can be used to identify areas in voxel maps where insufficient data are available. Using this knowledge of under-sampled areas we demonstrate construction of an improved line of sight map with metrics that indicate where and why errors in the line of sight are likely to occur. During the summer of 2010 an airborne experiment over the RIT campus collected both LIDAR and high resolution visible imagery. The LIDAR point cloud was sampled at several returns per square meter, and the accompanying visible imagery is used to provide context and truth information for LIDAR derived products. A real-world voxel line of sight map created from this LIDAR collection is presented along with an analysis of the associated derived errors.

8037-11, Session 2

Extracting intelligence from ladar sensing modalities

A. M. Burwinkel, S. J. Shelley, Etegent Technologies, Ltd. (United States)

Modern LADAR sensors have the potential to utilize a number of sensing modalities that provide a rich array of information in addition to traditional 3D geometry. Imaging polarization, multi-spectral reflectance/absorption and vibration spectral signature characteristics can all be sensed, potentially in a single LADAR sensor. This paper will examine how these rich sensing capabilities enhance the utility of LADAR sensing for Intelligence, Surveillance and Reconnaissance (ISR), Automatic Target Recognition (ATR) and assisted target recognition applications. The research utilizes a strong understanding of underlying physical phenomena, enabling the development of data exploitation capabilities that are not brittle to small variations from assumed targets and environmental conditions, and minimizing the need for experimentally obtained training data. Physics-based signal processing research has demonstrated promising ability to extract useful and actionable intelligence from the various sensing modalities of modern LADAR systems. A summary of the intelligence provided by the LADAR sensing modalities is presented as well as a demonstration of how the individual modes or combinations of LADAR sensing modes can be leveraged to add unique and valuable information to intelligence gathering missions. Particular utility is demonstrated for detection of adversary presence in cluttered, obstructed, hidden or underground environments. Furthermore, research has shown 3D geometry, polarization, multi-spectral and vibrometry LADAR sensing modalities can provide valuable intelligence for identifying and/or classifying the adversary and analyzing threat.

8037-12, Session 2

Automatic merging of lidar point-clouds using data from low-cost GPS/IMU systems

S. E. Budge, Utah State Univ. (United States); K. von Niederhausern, Ball Aerospace & Technologies Corp. (United States)

Stationary lidar (Light Detection and Ranging) systems are often used to collect 3-D data (point clouds) that can be used for terrain modeling. The lidar gathers scans and these scans are then merged together to map a terrain. Typically this is done using a variant of the well-known Iterated Closest Point (ICP) algorithm when position and pose of the lidar scanner is not accurately known. One difficulty with the ICP algorithms is that they can give poor results when points that are not common to both scans (outliers) are matched together.

With the advent of MEMS (microelectromechanical systems) -based GPS/IMU systems, it is possible to gather coarse position and pose information at a low cost. This information is not accurate enough to merge point clouds directly, but can be used to assist the ICP algorithm during the merging process.

This paper presents a method called Sphere Outlier Removal (SOR), which accurately identifies outliers and inliers, a necessary prerequisite to using the ICP algorithm. SOR incorporates the information from a low cost GPS/IMU to perform this identification. Examples are presented which illustrate the improvement in the accuracy of merged point clouds over traditional ICP when the SOR algorithm is used.

8037-13, Session 2

Terrain classification of ladar data point clouds

A. L. Neuenschwander, L. A. Magruder, M. Tyler, The Univ. of Texas at Austin (United States); M. M. Crawford, Purdue Univ. (United States)

Terrain classification, or bare earth extraction, is an important component to ladar data analysis or exploitation. A successful approach provides a flexible methodology (adaptable for topography and/or environment) that is capable of integrating multiple ladar point cloud data attributes. Specific attributes include elevations derived from the first and last returns as well as peak amplitude. Several approaches based on utilizing multiple attributes have been investigated for a variety of ladar systems and surveys. These methodologies have been evaluated for coastal, high-relief, and urban areas to determine performance criteria necessary for successful terrain discrimination. This paper will discuss which attributes and are most valuable for various environments.

8037-14, Session 2

Automated method for detection and quantification of building damage and debris using light detection and ranging (lidar) data

R. Labiak, Rochester Institute of Technology (United States) and Air Force Institute of Technology Civilian Institution Program (United States); J. W. van Aardt, D. Eychner, E. Wirch, H. Bischof, Rochester Institute of Technology (United States)

Disaster management has become increasingly important worldwide in recent years, given the prevalence of natural and man-made disasters. There is a growing need for rapid and accurate damage and debris assessment following natural disasters, terrorist attacks, and other crisis situations. Research is ongoing at the Rochester Institute of Technology (RIT) to develop an end-to-end operational tool that will ingest a light detection and ranging (LIDAR) point cloud of a post-disaster scene, and autonomously output a building damage map showing both heavily damaged and collapsed buildings. The tool is being built and tested using LIDAR data of Port-au-Prince, Haiti, collected by RIT just days after the January 2010 earthquake. This research enhances existing algorithms for LIDAR point classification (ground/non-ground), feature classification (buildings, vegetations, roads, etc.), and seeks to develop new algorithms for building damage and debris detection and quantification. Normalized height, height variation, intensity, and multiple return information are among the parameters being used to develop rules for building extraction and vegetation removal. Various approaches are being explored to perform damage assessment, with a focus on the automatic detection of roof planes. The algorithms will be implemented in a common programming language where the processing will be optimized for large data sets. The goal is for the operational tool to be implemented in the field, using available equipment in a close to real-time or post-processing environment. Results will be presented at the conference.

8037-15, Session 2

Lidar depth image compression using clustering, re-indexing, and JPEG2000

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Large LiDAR (Light Detection And Ranging) data sets are used to create depth mapping of objects and geographic areas. The suitability of image compression methods for these large LiDAR data sets was explored, analyzed and optimized. Our research interprets LiDAR data as intensity based "depth images", and uses k-means clustering, re-indexing and JPEG2000 to compress the data. The rst step in our method applies the k-means clustering algorithm to an intensity image creating a small index table, an index map and residual image. Next we use methods from previous research to re-index the index map to optimize compression when using JPEG2000. And lastly we compress both the re-indexed map and residual image using JPEG2000, exploring the use of both lossless and lossy compression. Experimental results show that in general we can compress data to 23% of the original size losslessly and even further allowing for small amounts of loss.

8037-16, Session 2

Rapid high-fidelity visualisation of multispectral 3D mapping

P. M. Tudor, M. A. Christy, General Dynamics UK Ltd. (United Kingdom)

A number of vehicle carried mobile LIDAR scanning solutions now exist for the rapid creation of 3D maps of urban areas and other complex terrain. These solutions typically provide captured 3D data in the form of 3D 'Point Clouds' which can be combined with additional 2D colour imagery to produce coloured point cloud data or further processed to form polygon-based 3D models.. The use of point clouds to visualise captured data has the benefit of being simple and rapid, but the comparatively sparse 3D data can appear ghostly and diffuse especially when viewed 'up close'. Using the captured data to create textured polygonal 3D models has the benefit of producing a high fidelity visualisation that approaches the sensation of being present at the original location. However, the creation of these models is time consuming, difficult to fully automate and the results can lose key terrain details or create scene artefacts. This paper describes techniques researched and developed by General Dynamics UK Limited in order to produce rapid visualisation of fused multi-spectral 3D data that approaches the visual fidelity of polygon-based models whilst retaining the rapid turnaround and key structural detail of 3D point cloud data. The general approaches to data capture and data fusion are identified as well as the central underlying mathematical transforms, data management and graphics processing techniques used to support rapid visualisation of very large multi-spectral 3D datasets. Performance data with respect to real-world 3D mapping as well as illustrations of visualisation outputs are included.

8037-17, Session 2

A calibration and error correction method for improved texel (fused lidar/digital camera) images

S. E. Budge, Z. Wang, 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.

8037-18, Session 2

Quality metrics for 3D laser radar systems

N. A. Lopez, J. R. Stevens, R. R. Burton, FastMetrix, Inc. (United States)

In this paper we discuss several metrics for 3D laser radar systems, including: contrast transfer functions, edge & line spread functions, Z noise, Z resolution, 3D point spread functions and data voids. These metrics describe perceptual quality attributes such as contrast, resolution and noise. We discuss how these metrics could be used for system performance evaluations and comparisons of noise removal algorithms.

8037-19, Session 3

Sensitivity of the polarization ratio method to aerosol concentration

M. G. Snyder, North Carolina State Univ. (United States); A. M. Brown, The Johns Hopkins Univ. (United States); C. R. Philbrick, North Carolina State Univ. (United States)

A multiwavelength multistatic optical scattering instrument is being developed to characterize spherical aerosols. This instrument uses 405 nm (blue), 532 nm (green) and 655 nm (red) diode lasers and two CCD imagers to measure the angular distribution of light scattered from aerosols. The incident light is polarized parallel or perpendicular to the scattering plane, the scattered intensity is measured at backscattering angles of 120° to 170° by CCD imagers. The phase function for each polarization is used to form the polarization ratio, which is used to characterize the scattering aerosols. This method has proven to be a reliable way to characterize spherical aerosols by matching the measured polarization ratio with the ratio calculated by the Mie scattering equations. This method has been used to determine the number density, size distribution and index of refraction of the aerosols. The sensitivity of the polarization ratio to the particle concentration is explored using a narrow distribution of one micron polystyrene beads in a chamber. The aerosol concentration found by a Mie based inversion technique is compared with the predicted settling rate, and the concentration measured by an Aerodynamic Particle Sizer (APS). This study provides the basis for transitioning this instrument to measuring multiple particle size ranges and concentrations for common aerosols in an outside environment.

8037-20, Session 3

Pseudorandom noise code-based technique for cloud and aerosol discrimination applications

J. Campbell, N. S. Prasad, M. Flood, W. Harrison, NASA Langley Research Ctr. (United States)

NASA Langley Research Center is working on a continuous wave (CW) laser based remote sensing scheme for the detection of CO2 and O2 from space based platforms suitable for ACTIVE SENSING OF CO2 EMISSIONS OVER NIGHTS, DAYS, AND SEASONS (ASCENDS)

mission. ASCENDS is a future space-based mission to determine the global distribution of sources and sinks of atmospheric carbon dioxide (CO_2). A unique, multi-frequency CW laser absorption spectrometer (LAS) operating at 1.57 micron for CO_2 sensing has been developed. Error reduction techniques are needed to eliminate or quantify the impact of clouds and aerosol layers on the signal to noise ratio (SNR) of retrieved signals. Accordingly, effective aerosol and cloud discrimination techniques are being investigated in order to determine concentration values with accuracies less than 0.3%.

Pseudo-random noise (PN) codes are well known in the communications applications for their use in encoding communication channels such as in spread spectrum communications. They are also used in RADAR, SONAR, and LIDAR applications. In communications, maximum length (ML) sequences are commonly used. For instance a simple method to measure range with CW LIDAR would be to transmit a signal that is amplitude modulated with the PN code. The cross correlation between the reflected signal and the reference transmitted code provides range profile. The peaks of this profile indicate where the scattering centers are, such as clouds, ground, etc.

One may use modified versions of these ML sequences that take advantage of the unique autocorrelation properties to generate new codes that are perfectly orthogonal to each other over a limited range. This gives us the ability to design a multichannel differential absorption lidar (DIAL) system to measure the relative absorption of different laser wavelengths at a particular range. As such, this technique gives us the ability to detect specific atmospheric species using CW laser based LAS and/or lidars.

In this paper, we discuss the demonstration of a PN code based technique for cloud and aerosol discrimination applications. Proof-of-concept experiments carried out using SONAR based LIDAR simulator that was built using simple audio hardware and LabVIEW software interface will be presented. This system uses high frequency audio carriers modulated by modified ML sequences to simulate specific laser wavelength modulated ML sequences. We have been able to demonstrate the concept of using these modified ML sequences to build a dual channel DIAL system.

8037-21, Session 3

Laser remote sensing of atmospheric properties

C. R. Philbrick, T. P. Wright, H. D. Hallen, North Carolina State Univ. (United States)

Laser remote sensing using Raman Lidar, Differential Absorption Lidar (DIAL), and Differential Absorption Spectroscopy (DAS) techniques provide capabilities for measuring most of the major physical and chemical properties of the atmosphere. Lidar techniques have been demonstrated which can: (1) measure the primary atmospheric species (N_2, O_2, H_2O, CO_2), (2) detect several chemical species that exist in the background atmosphere in low concentrations (O_3, CH_4, ...), or may be released in plumes, (3) determine the aerosol optical properties, (4) study the growth and dissipation of aerosol layers, (5) investigate dynamical properties, such as atmospheric stability, boundary layer thickness, gravity waves, turbulence structures, planetary wave driven stratospheric warming events, convective entrainment of moisture, micro-physical growth of cloud particles, (6) measure atmospheric temperature profiles, (7) use resonance processes to detect the presence of trace chemicals, and (8) apply resonant scattering processes to describe several upper atmosphere properties in the 80-100 km range. Even, with all of the capabilities demonstrated by these techniques, little progress has been made in providing routine data products using such instruments. Whereas, only a few laboratories had developed the several areas of expertise needed to carry out measurements with lidar instruments in the past, these capabilities are rapidly becoming wide spread now. Advances in rugged and stable laser sources make it feasible to consider even wider applications of laser remote sensing techniques in the future. The present capabilities of lidar techniques are examined and several opportunities for future measurements are described in the context of robust data for providing routine data products.

8037-22, Session 3

Detection of microwave emission from solid targets ablated with an ultra-short pulsed laser

J. A. Miragliotta, B. Brawley, C. Sailor, J. B. Spicer, J. W. Spicer, The Johns Hopkins Univ. (United States)

In addition to visible and near-IR emission, recent investigations have shown that electromagnetic (EM) pulses in the microwave and RF regions of the spectrum are generated during femtosecond laser-matter interactions if the laser source is sufficiently intense to ablate and ionize an illuminated solid target material. Although the mechanisms for the EM pulse are not fully characterized, it is reported that this phenomena arise from two mechanisms associated with terawatt to petawatt level laser interactions with matter: (1) ionization via propagation in air, and (2) plasma generation associated with the laser-excited solid material.

Over the past year, our group has examined the microwave emission profiles from a variety of femtosecond laser ablated materials, including metals, semiconductors, and dielectrics. We have directed our measurements towards the characterization of microwave emission from ablated surfaces in air using laser peak powers in excess of 1012 Watts (energy/pulse ~ 50 mJ, pulse width ~ 30 fsec, laser diameter at target ~200 microns). We have characterized the temporal profile of the microwave emission at 10 GHz, which began ~1 nanosecond after sample illumination (resolution limit of our measurement system) and radiated for ~25 nanoseconds. The emission from all samples was determined to be omni-directional. We observed a difference in the minimum fluence required to generate emission from conductive and insulative materials; however, the peak amplitude from these respective materials were quite similar at the upper laser energy levels of our system (~ 50 mJ).

8037-23, Session 4

All-fiber coherent doppler lidar for wind sensing

S. Abdelazim, The City College of New York (United States)

Coherent Doppler LIDAR is being utilized to develop a mobile wind speed measuring station. We at CCNY are building an all fiber based eye safe laser system to measure wind speed in urban areas. A 1.5µ.m polarization maintained fiber optics master oscillator power amplifier system is used, which utilizes components from the telecommunication industry. We have calculated the optimum local oscillator power for maximum optical detector's efficiency. A/D conversion is performed at 400 MHZ by using a data acquisition card with FPGA on board, which can be programmed to perform autocorrelation and/or FFT onboard for faster performance.

The system consists of the following components: 1) Laser source 2) Modulator 3) Fiber Amplifier 4) Optical Antenna 5) Detector 6) Signal Processor. In our system, a fiber coupled 1545.2 nm laser is used for the master oscillator. This source is split using a fiber coupler. One signal is used as a local oscillator (LO), while the other signal is modulated and frequency shifted using an AOM (acousto-optic modulator). The modulated signal is then amplified and transmitted through an optical antenna. The scattered signal will be received by the optical antenna and mixed with the LO signal through a 50/50 coupler. The mixed signal will be detected by a balanced detector, which generates a RF electrical signal. The RF signal is then processed using a signal processor to extract information about frequency shift and signal strength as a function of time delay.

8037-24, Session 4

Minimization of differential Doppler induced fringe averaging in holographic aperture ladar

R. L. Bobb, B. D. Duncan, Univ. of Dayton (United States); M. P. Dierking, Air Force Research Lab. (United States)

In this paper we discuss the simulation and experimental mitigation of the Differential Doppler induced fringe averaging phenomenon experienced in holographic aperture ladar (HAL). HAL, as compared to traditional SAL (synthetic aperture ladar), uses a 2D planar imaging detector instead of single point detection. The differential Doppler effect in HAL arises from the difference in line-of-sight speeds experienced across an extended target as the transmitter/receiver platform moves along a specified velocity vector. Simulations were performed to quantify the effects of differential Doppler on a pupil plane receiver array flying past a stationary target on the ground. In our simulation, a broadside point transmitter was used to flood illuminate a target, as we have demonstrated that the differential Doppler effect is greatest in the broadside illumination case. After mixing the return beam with an extended master oscillator, interferogram fringes arise due to: 1) the deterministic structure of the target; and, 2) the differentially Doppler shifted signal field beating with a fixed frequency master oscillator. These fringes are in turn corrupted by speckle if the target is diffusely scattering. The main goal of our work to date has been to find a maximum integration time, based upon the geometry of the problem, and therefore the expected bandwidth of the differential Doppler shift, that allows minimal temporal averaging (i.e., degradation) of desired interference fringe structures. A table top experiment was designed and used to confirm the results of our simulation.

8037-25, Session 4

Pulsed coherent fiber lidar transceiver for aircraft in-flight turbulence and wake-vortex hazard detection

S. Gupta, M. Akbulut, Y. Chen, J. Hwang, H. Verdun, F. Kimpel, Fibertek, Inc. (United States)

We report on the development of a fiber-optic pulsed coherent lidar transceiver for use as an in-flight sensor. The eye-safe (1.5um) pulsed coherent lidar transmitter is based on an all-fiber, ultra low-noise, polarization-maintaining, multi-stage master-oscillator power-amplifier configuration, providing up to ~200uJ/pulse at high (25kHz) repetition rates. The transmitter is controlled by a high-speed FPGA (field-programmable-gate-array), and can operate over a range of pulse formats, with pulsewidths adjustable from microseconds (for coherent lidar) down to ~320psec (for direct-detection lidar). With its robust and compact design, this enables use as a multi-function in-flight aircraft sensor for forward looking turbulence detection, wake-vortex hazard detection during landing, as well as for slam-range detection.

The coherent receiver consists of balanced photodetectors and an ultra low-noise analog front-end coupled to a high-speed digitizer and an FPGA based real-time signal processor. A back-to-back optical detection sensitivity <0.2pW is measured. In a typical mode for pulsed coherent lidar operation with ~800nsec pulsewidth, the simulated detection range is greater than ~2.5km (with 100 m range resolution bins) using multi-pulse averaging. Axial doppler velocity measurement over ±26m/sec with resolution of ~0.1m/sec is estimated, that is sufficient for recognizing wake-vortex hazard signatures using a compatible scan pattern. Real-time digital signal processing leads to the required sensitivity at 12 updates per second, with 60 range bins each. In earlier testing, wind currents of few meter/sec up to 1km away were observed in clear air conditions. We present detailed performance simulation of this coherent lidar sensor using wake-vortex eddy models, and also report on the latest laboratory results and preliminary field-testing of this pulsed coherent fiber-optic lidar transceiver.

8037-26, Session 4

Vertical and horizontal wind profiling from a high-energy, pulsed, 2-micron, coherent-detection doppler lidar and intercomparison with other sensors

U. N. Singh, NASA Langley Research Ctr. (United States)

This paper presents an overview of 2-micron laser transmitter development at NASA Langley Research Center (LaRC) for coherent-detection lidar profiling of winds. The novel high-energy, 2-micron, Ho:Tm:LuLiF laser technology developed at NASA Langley was employed to study laser technology currently envisioned by NASA for future global coherent Doppler lidar winds measurement. The 250 mJ, 10 Hz laser was designed as an integral part of a compact lidar transceiver developed for future aircraft flight. Ground-based wind profiles made with this transceiver will be presented. NASA Langley is currently funded to build a complete Doppler lidar system using this transceiver for the DC-8. The DC-8 lidar system is a likely component of future NASA hurricane research. It will include real-time data processing and display, as well as full data archiving.

The LaRC mobile lidar was deployed at Howard University facility in Beltsville, Maryland as part of NASA HQ funded (ROSES-2007, Wind Lidar Science Proposal entitled “Intercomparison of Multiple Lidars for Wind Measurements”. During the campaign the 2-micron coherent lidar was operated alongside a 355-nm direct detection lidar to demonstrate the combined hybrid wind lidar concept. In addition to the lidars, several other meteorological sensors were located at the campaign site, including wind measuring balloon sondes, sonic and propeller anemometers mounted on a tower, and a 915-MHz radio acoustic sounding system. Comparisons among these wind measurement sensors will be presented.

8037-28, Session 5

Piston phase determination and its effect on multi-aperture image resolution recovery

J. R. Kraczek, P. McManamon, J. W. Haus, Univ. of Dayton (United States); J. C. Marron, Lockheed Martin Coherent Technologies (United States)

Multi-aperture coherent LADAR techniques can be applied to generate high resolution images. When setting up a system with multiple apertures, misalignment of the apertures that cause the beams entering the apertures to have mismatched optical path lengths will degrade the image resolution. Post-processing image sharpening techniques to correct for piston phase, as well as other aberration corrections, require computing power and time. We study whether or not by directly determining the piston phase the processing time can be shortened by providing measured piston phase information to the image sharpening algorithms. We perform a phase measurement using a high speed detector in each aperture, performing a temporal heterodyne measurement. By using a frequency offset local oscillator in a temporal heterodyne setup, the piston phase of each aperture can be inferred. This is then added to the post-processing codes to speed up the time to achieve a single high resolution image. A two sub-aperture experimental design has been devised, each with a temporal heterodyne added to extract phase information. Experiments have been completed that demonstrate the phase measurements. Simulations of the benefits for two or more apertures have been conducted. Speed of sharpening algorithm convergence will be compared for spatial heterodyne multiple sub-aperture imaging, and for spatial heterodyne multiple sub-aperture imaging assisted by piston phase measurements as described above.

Return to Contents

8037-29, Session 5

Short pulse synthetic aperture ladar

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Synthetic Aperture Ladar (SAL) can obtain cross-range resolutions beyond the diffraction limit by exploiting the motion of the ladar platform. Range resolution is obtained through the transmission of high bandwidth pulses. SAL systems can be designed to transmit pulses on the order of a microsecond in duration, utilizing techniques such as Linear Frequency Modulation (LFM) to increase the bandwidth of the pulse. However, the longer the pulse duration, the more sensitive the system is to object motion within the field of view. Conversely, the transmission of short pulses (on the order of a nanosecond in duration) will reduce the sensitivity of the system to target motion. Furthermore, since an acceptable range resolution can be achieved from the inherent bandwidth of a transform-limited one nanosecond pulse, it is unnecessary to further broaden the spectrum via LFM. This can reduce system complexity substantially. The application of this concept to long range remote sensing will require amplification of the transmitted pulse. This will most likely result in a saturated optical amplifier. The carrier depletion that occurs when an amplifier is saturated has been shown to induce a frequency chirp on the amplified pulse1. This research will explore the system requirements resulting from the long range application of the short-pulse SAL concept, and the possibility of exploiting the amplifier-induced frequency chirp to increase the bandwidth of the transmitted pulse.

1. Agrawal, G. P. and Olsson, N. A., “Self-Phase Modulation and Spectral Broadening of Optical Pulses in Semiconductor Optical Amplifiers”, IEEE J. Quant. Elec., 25(11), 2297-2306 (1989).

8037-30, Session 5

Impact of Gaussian beam jitter on Gaussian beam coherent laser radar performance

P. Gatt, S. M. Shald, Lockheed Martin Coherent Technologies (United States)

In this paper we present analytic models of the CNR loss or efficiency due to Gaussian line-of-sight jitter and pointing bias, as a function of the correlation coefficient between the transmit and back-propagated local oscillator beams of a coherent laser radar. We also present theoretical expressions for the signal power variance including speckle noise. This theory is developed for point, extended and Gaussian targets. It is shown that the Gaussian target solution converges to the point and extended target solutions under the appropriate small and large diameter target limits. Including correlation between the transmit and BPLO beams allows one to predict performance as a function of target range, since at zero range the two beam positions are fully correlated, whereas at infinite range they are fully uncorrelated.

Numerical experiments were developed and the resulting measurements are shown to agree with the analytic theory. The validated simulation tool is then exercised against other targets (e.g., a disk), for which closed form solutions are elusive. Analysis of the best-fit Gaussian target to arbitrary target shapes is also explored.

8037-31, Session 6

Green laser vibrometry based on single frequency monolithic microchip laser

A. J. Antonczak, P. Koziol, J. Z. Sotor, K. M. Abramski, Wroclaw Univ. of Technology (Poland)

The main coherent sources for laser Doppler vibrometry are He-Ne lasers which have many advantages like stabile single frequency operation and very good beam quality. However they have a few serious disadvantages - large dimensions, low efficiency and relatively high power consumption. To avoid above disadvantages He-Ne laser can be replaced by much smaller compact microchip laser operating in the visible region. The main candidate is a neodymium doped single frequency microchip laser with intracavity second harmonic generation. We developed such a Nd:YVO4/YVO4/KTP monolithic single frequency green laser operating at 532nm with narrow linewidth of radiation - 85kHz, good beam quality - M2 = 1.1, the output power up to 50mW and power stability better than 1%. Total power consumption for typical operating conditions (Pout = 10mW) is around 3W. Using this laser two configurations of laser Doppler vibrometer were investigated - with single and double frequency Bragg shifts. As a reference surface of vibrating object we used a piece of white sheet of paper placed on the loudspeaker. We measured heterodyne signals as a mixing result of scattered and reference beams. In both configuration we obtained signals with high S/N ratio above 30dB @ RBW = 510kHz for the vibrometer output power 2.4mW and distance to the moving object 0.3m. Study was carried out as a function of laser power, the distance to the moving object and the resolution bandwidth filter RBW. In our opinion single frequency stable, solid state green lasers gives new possibilities in development of miniature laser vibrometry.

8037-32, Session 6

Multichannel flexible fiber vibrometer

A. Waz, P. R. Kaczmarek, A. J. Antonczak, G. Dudzik, J. Z. Sotor, G. Sobon, K. Krzempek, K. M. Abramski, Wroclaw Univ. of Technology (Poland)

We develop flexible fiber system for vibrometry applications. For many applications it is important to have possibility to measure simultaneously many points of vibrating object in order to compare their amplitude and phase relations. We build such a system based on fiber telecommunication WDM (Wavelength Division Multiplexing) technique. Its idea deals with four channel WDM technique, where four independent fiber pigtailed DFB diode lasers operating at different wavelengths (from ITU grid), are the sources of coherent lights. Each diode laser is responsible for analysis of separate point of vibrating object. First the beams from the lasers are split into two sets: transmitting and reference. Four transmitting channels are combined into the common fiber WDM multiplexer and they are shifted 40 MHz in frequency by acousto-optic Bragg modulator. After that they are amplified by the common buster amplifier and they are split into four sensing fiber terminated with the fiber collimators. The transmitted laser beams are focused on the vibrating object and the weak, Doppler shifted, scattered beams are collected into the receiving fiber collimators. All four receiving signals are combined together with the appropriate reference signals in the 50/50 fiber couplers and the signals are mixed at the balanced photodetectors (fiber coupled p-i-n diodes). The heterodyne signals obtained at the 40 MHz carrier are FM modulated. To find the vibration signals the signal processing based on analog and digital demodulation was applied. There will be presented optical configuration, some signal processing solutions, results and parameters of the device.

8037-33, Session 6

Airborne laser vibrometer for seismic subsurface inspection

A. D. McAulay, Lehigh Univ. (United States)

We consider a laser-seismic system for detecting and identifying buried objects from airborne platforms. For acoustic waves, the frequency (or bandwidth) must be high enough to provide adequate resolution in the ground for finding buried objects of the desired size and range of depths and low enough to couple efficiently into the ground and propagate as a seismic wave in the earth. For finding small buried objects at shallow depths, self-aligning noise makers may have to be dropped. An alternative is to use high power microwave pulse sources such as a Vircator [1] to arc across an air gap, as in lightning, to produce a loud

acoustic pulse. Yet another possibility is to focus two powerful free-electron laser beams to meet close to the ground to produce an arcing plasma sound source at the ground. A laser from the aircraft now scans the region in a vibrometer interferometer [1] configuration to measure the amplitude of the oscillations in the seismic wave at spots along the surface of the ground. The oscillating earth's surface frequency modulates the laser beam and amplitude is obtained from the power in the sidelobes. For this application a free-electron laser [1] can be designed for any desired frequency and has a good range of tunablility to adapt to different circumstances [1]. From knowledge of the oscillation amplitudes along the surface, after the sound source has activated, we can determine reflectors and scatterers in the ground using methods of geophysics [2], [3].

8037-34, Session 7

Flash ladar waveform measurements using an intensified photodiode focal plane array

C. Bracikowski, C. M. Wong, T. Uchima, B. K. Baldauf, Northrop Grumman Aerospace Systems (United States)

Vegetation characterization, forest biomass and canopy structure measurements, and foliage penetration (FOPEN) missions are best conducted using a digitizing ladar system to obtain an entire ladar intensity waveform from the canopy top, through multiple tree layers and down to the ground in just one laser pulse. In the past, these missions have often been conducted using a single pixel scanning ladar such as the commercially available ladar from Riegl, the NASA Laser Vegetation Imaging Sensor (LVIS) system or the Carnegie Airborne Observatory (CAO). A linear-mode detector array with single photon sensitivity and ability to retrieve multiple pulse returns per pixel per laser flash will greatly enhance mission performance and provide higher value data for these scientific missions. In this paper, we describe our recent ladar waveform measurements recorded with a single photon sensitive, linear mode, 4x4 pixel Intensified Photodiode (IPD) flash ladar focal plane array.

8037-35, Session 7

Topographic mapping flash lidar for multiple scattering, terrain, and forest mapping

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The Topographic Mapping Flash Lidar (TMFL) developed at Ball Aerospace combines a pushbroom format transmitter at 1064 nm with a flash focal plane receiver. The wide 20 degree field of view of the instrument enables broad swath coverage from a single laser pulse without the need for a scanning mechanism. These features make the TMFL design particularly suited for space flight. TMFL has been demonstrated during an airborne flight where data were gathered over a forest plot to measure tree waveforms. Topographic maps were assembled of river beds and geologic areas of high relief. The TMFL has also been used to observe multiple-scattering phenomena in clouds by illuminating a steam plume from the aircraft above. Signal was recorded off-axis from the illuminated laser line by as much as 1 degree. The TMFL study of multiple-scattering is valuable as it provides a unique way to significantly improve the calibration of measured backscatter for space lidars. Lidar backscatter was also measured from water surface and was shown to correlate with models of water surface roughness.

8037-36, Session 7

Drogue tracking using 3D flash lidar for autonomous aerial refueling

C. Chen, R. Stettner, Advanced Scientific Concepts, Inc. (United States)

Autonomous aerial refueling (AAR) is an important capability for an unmanned aerial vehicle (UAV) to increase its flying range and endurance without enlarging its size. This paper presents a novel tracking method that utilizes both 2D intensity and 3D point-cloud data acquired with a 3D Flash LIDAR sensor to establish relative position and orientation between the receiver vehicle and the drogue during an aerial refueling process. Unlike classic vision-based sensors, a 3D Flash LIDAR sensor is capable of imaging through fog and clouds in the dark and can provide 3D point-cloud data in real time without motion blur. The proposed method segments out the drogue through 2D analysis and estimates the center of the drogue from 3D point-cloud data for flight trajectory determination. A level-set front propagation routine is first employed to identify the target of interest and establish its silhouette information. Sufficient domain knowledge, such as the size of the drogue and the expected operable distance, is integrated into our approach to quickly eliminate unlikely target candidates. A statistical analysis along with a random sample consensus (RANSAC) is performed on the target to reduce noise and estimate the center of the drogue after all 3D points on the drogue are identified. Challenging cases where the drogue is partially occluded due to a bounded field of view (FOV) are also investigated. The estimated center and the silhouette of the drogue will serve as the seed points to efficiently locate the target in the next frame.

8037-49, Poster Session

Simulated lidar waveforms for understanding factors affecting waveform shape

A. M. Kim, R. C. Olsen, Naval Postgraduate School (United States)

Full-waveform LIDAR is a technology which enables the analysis of the 3-D structure and arrangement of objects. An in-depth understanding of the factors that affect the shape of the full-waveform signal is required in order to extract as much information as possible from the signal. A simple model of LIDAR propagation has been created which simulates the interaction of LIDAR energy with objects in a scene. A 2-dimensional model tree allows controlled manipulation of the geometric arrangement of branches and leaves with varying spectral properties. Results suggest complex interactions of the LIDAR energy with the tree canopy, including the occurrence of multiple bounces for energy reaching the ground under the canopy. Idealized sensor instrument response functions incorporated in the simulation illustrate a large impact on waveform shape.

8037-55, Poster Session

Simulation results on false-alarm reduction method by intensity dividing in three-dimensional imaging direct-detection laser radar using Geiger-mode avalanche photodiodes

T. H. Kim, H. J. Kong, M. S. Oh, S. E. Jo, KAIST (Korea, Republic of)

In this paper, a new method to reduce the false-alarm probability in three-dimensional (3D) imaging direct-detection laser radar system using Geiger-mode avalanche photodiodes (GmAPD) is proposed. A GmAPD or a GmAPD focal plane array is used as a detector in long-range 3D imaging direct-detection laser radar system due to its high sensitivity. In general, a number of time-of-flight (TOF) data is needed to distinguish

signals and noise because a GmAPD generates identical electric signals corresponding to laser-return pulse and noise.

The method proposed in this paper is implemented by using two GmAPDs with intensity dividing optics and employing an AND gate logic 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.

With the theoretical model which is based on the Poisson statistics, the detection and false-alarm probabilities in both cases of a GmAPD and two GmAPDs with intensity dividing are calculated and compared. In addition, experiments are performed to prove the advantage of the new method proposed and the results are shown. The experimental results represent that the false-alarm probabilities are considerably decreased.

8037-56, Poster Session

Fluorescence/depolarization lidar for mid-range stand-off detection of biological agents

J. Wojtanowski, Z. Mierczyk, K. Kopczyński, M. Zygmunt, W. Piotrowski, A. Gietka, P. Knysak, T. Drozd, M. Muzal, A. Mlodzianko, A. Gawlikowski, M. H. Kaszczuk, R. Ostrowski, M. Jakubaszek, J. Mlynczak, Military Univ. of Technology (Poland)

LIDAR system for real-time standoff detection of bio-agents is presented and preliminary experimental results are discussed. The detection approach is based on two independent physical phenomena:

- laser induced fluorescence (LIF),

- depolarization resulting from elastic scattering on non-spherical particles.

The device includes three laser sources, two receiving telescopes, depolarization component and spectral signature analyzing spectrograph. It was designed to provide the stand-off detection capability at ranges from 200 m up to several kilometers. The system as a whole forms a mobile platform for vehicle or building installation. Additionally, it's combined with a scanning mechanics and advanced software, which enable to conduct the semi-automatic monitoring of a specified space sector.

For fluorescence excitation, 3-rd (355 nm) and 4-th (266 nm) harmonics of Nd:YAG pulsed lasers are used. They emit short (~6 ns) pulses with the repetition rate of 20 Hz. Collecting optics for fluorescence echo detection and spectral content analysis includes 25 mm diameter f/4 Newton telescope, Czerny Turner spectrograph and 32-channel PMT. Depending on the grating applied, the spectral resolution from 20 nm up to 3 nm per channel can be achieved.

The system is also equipped with an eye-safe (1.5 µm) Nd:YAG OPO laser for elastic backscattering/depolarization detection. The optical echo signal is collected by Cassegrain telescope with aperture diameter of 12.5 mm. Depolarization detection component based on polarizing beam-splitter serves as the particle-shape analyzer, which is very valuable in case of non-spherical bio-aerosols sensing.

8037-37, Session 8

Flash ladar focal plane array technologies

G. M. Williams, Jr., Voxtel, Inc. (United States)

The design and performance of several new flash ladar and wavefront sampling avalanche photodiode (APD) focal plane arrays (FPAs) is discussed. Several high-gain, low-excess-noise InGaAs APD array and readout integrated circuit technologies will be overviewed. The abilities of these focal plane arrays to perform flash ladar pulse time-of-arrival sampling and high-speed pulse waveform sampling are assessed, and the issues in scaling the designs to large formats are detailed.

8037-38, Session 8

Geiger-mode ladar cameras

P. Yuan, R. Sudharsanan, X. Bai, J. C. Boisvert, P. A. McDonald, E. L. Labios, Spectrolab, Inc. (United States); B. A. Morris, J. P. Nicholson, G. M. Stuart, H. Danny, Boeing-SVS, Inc. (United States); S. T. Van Duyne, G. Pauls, S. D. Gaalema, Black Forest Engineering (United States)

The performance of Geiger-mode LAser Detection and Ranging (LADAR) cameras is primarily defined by individual camera attributes, such as dark count rate (DCR), photon detection efficiency (PDE), jitter, and crosstalk. However, for the expanding LADAR imaging applications, other factors, such as image uniformity, component tolerance, manufacturability, reliability, and operational features, have to be considered. Recently we have developed new 32x32 and 32x128 Read-Out Integrated Circuits (ROIC) for LADAR applications. With multiple filter and absorber structures, the 50-um-pitch arrays demonstrate pixel crosstalk at the 0.01% level, while maintaining a PDE greater than 40% at 4 V overbias. Besides the improved epitaxial and process uniformity of the APD arrays, the new ROICs implement a Non-uniform Bias (NUB) circuit providing 4-bit bias voltage tunability over a 2.5 V range to individually bias each pixel. All these features greatly increase the performance uniformity of the LADAR camera. Cameras based on these ROICs were integrated with a data acquisition system developed by Boeing SVS. The 32x32 version has a range gate of up to 7 us and can cover a range window of about 1 km with 14-bit and 0.5 ns timing resolution. The 32x128 camera can be operated at a frame rate of up to 20 kHz with 0.3 ns and 14 bit time resolution through a full CameraLink connection. We will discuss additional performance metrics of these newly developed Geiger-mode LADAR cameras at the meeting.

8037-39, Session 8

Coincidence processing algorithms for GmAPD laser radar systems

N. A. Lopez, FastMetrix, Inc. (United States)

Coincidence processing (CP) algorithms rely on statistical densities and global thresholding to remove X-Y-Z point caused by noise that are present in raw point clouds produced from data collected with laser radar systems employing arrays of Geiger-mode Avalanche Photodiode (GmAPD) detectors. While CP is the tool of choice for filtering GmAPD raw point cloud data, very little technical documentation describing the different algorithms is available today in the literature. In this paper we provide an overview of four CP techniques which have been developed by MIT Lincoln Laboratory and The Johns Hopkins Laboratory Applied Physics Laboratory, namely: Density CP, Z CP, Neighborhood CP and Maximum A Posteriori CP. We describe the advantages and shortfalls of these CP techniques along with common artifacts that are present in the resulting filtered point clouds.

8037-40, Session 8

Advanced coincidence processing of 3D laser radar data

A. N. Vasile, R. M. Marino, L. Skelly, M. O'Brien, MIT Lincoln Lab. (United States)

Data collected by 3D laser radar systems, which utilize arrays of avalanche photodiode (APD) detectors operating in Geiger-mode, contain a large amount of noise. We implemented an improved algorithm for noise removal and signal detection called Multiple-Peak Spatial Coincidence Processing (MPSCP). Field data, collected using an MIT-LL 3D Ladar sensor, were used to test the MPSCP algorithm against a baseline algorithm, called Multi-Peak Range Coincidence Processing (MPRCP). Two image quality metrics were developed to quantitatively

determine how well each algorithm removes image noise, while reconstructing the best estimate of the underlying 3D scene geometry. The new algorithm has an order of magnitude improvement in SNR and 2-3x improvement in range estimation and angular resolution compared to the baseline algorithm.

8037-41, Session 8

Target detection capabilities of flash ladar detectors

G. M. Williams, Jr., Voxtel, Inc. (United States)

Much research has been done to develop single-pulse “flash LADAR” systems. A physics-based Monte Carlo model (RIT DIRSIG) is used to analyze various flash LADAR focal plane technologies, including Geiger-mode (Gm) and linear-mode (lm) avalanche photodiode (APD) arrays. The efficiency with which each detector technology detects target-returned photons is analyzed, and used to generate receiver operating characteristic (ROC) curves showing expected performance as a function of scene clutter, target range, laser pulse width and amplitude, as well as the detector’s detection efficiency, dark count rate, and dead time.

8037-42, Session 8

Linear-mode avalanche photo-diode detectors with a quasi-deterministic gain component: statistical model studies

D. G. Youmans, Cobham Analytic Solutions (United States)

Recent advances in InAlGaAs linear-mode avalanche photo-diode detectors by Voxtel, Inc. and others have demonstrated a nearly constant (“quasi-deterministic”) gain leading electron pulse which is then followed by a McIntyre gain distribution “tail” of electrons. At low incident photon / photo-electron levels, this quasi-deterministic gain electron pulse increases the probability that the deterministic-plus-McIntyre gain output electrons exceed a threshold, resulting in a “detection,” hence a better receiver-operating-characteristic (ROC). The McIntyre electron-gain alone fluctuates greatly, resulting in a poor ROC at low PE levels. Since these detectors can cover the 400 to 1600nm wavelength regions, they are useful for many ladar and lidar systems.

In this paper we examine the ROC (Pdetection vs PFalseAlarm) statistics of these new detectors as a function of the quasi-deterministic gain mean and standard deviation for various rms ROIC (readout integrated circuit) noise levels. Single photo-electron and multiple photo-electron detection statistics will be examined for predicting an ROC. Measured APD data will be presented as available.

8037-43, Session 8

GHz low-noise SWIR photo receivers

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

Next generation LIDAR mapping systems require multiple channels of sensitive photoreceivers that operate in the wavelength region of 1.06 to 1.55 micron, with GHz bandwidth and sensitivity less than 300 fW/√Hz. Spectrolab has been developing a high sensitivity receiver using InAlAs/InGaAs impact ionization engineering (I2E) avalanche photodiode (APD) structures for this application. APD structures were grown using a metal organic vapor epitaxy (MOVPE) method and mesa devices were fabricated using these structures. We have achieved low excess noise at high gain in APD devices by optimizing avalanche threshold energies by varying the thickness and the bandgaps of I2E layers. An impact ionization parameter, k, of about 0.15 has been achieved using InAlAs/InGaAlAs as a multiplier layer. I-V data of these devices showed dark current less than 2nA at a gain of 20 at room temperature and a capacitance of 0.4pF for a typical 75 micron diameter APD. The quantum efficiency is about 70% at 1.06 micron. A photoreceiver has been built by integrating I2E APD devices with a low noise GHz transimpedance amplifier (TIA). Initial test board data of the photoreceiver showed a bandwidth of 1GHz at room temperature. The final photoreceivers are packaged in TO-can packages with TE cooler integrated. We will present characterization data of these GHz low noise photoreceivers at the meeting.

8037-44, Session 9

Lidar characteristics for detecting and tracking high-speed bullets

J. S. J. Peri, The Johns Hopkins Univ. (United States)

A physics-based analysis has been carried out to determine the lidar characteristics for detecting and tracking a high-speed bullet. The results cover detection range as a function of energy per pulse, beam diameter and M^2. The discussion includes irradiance per pulse, beamwaist, time between pulses, pulse repetition frequency and average irradiance, all as functions of range. The experimentally measured BRDF of a bullet was used in the calculations.

8037-45, Session 9

Small UAV surveillance and detection system

R. Franz, B. S. Goldberg, Adsys Controls, Inc. (United States)

In recent conflicts, Unmanned Aerial Vehicles (UAVs) have become instrumental for reconnaissance as well as weapon delivery. Remotely operated, UAVs perform key missions while keeping soldiers out of dangerous environments. Small UAVs with wingspans < 1 meter have become especially important and widely proliferated. They are inexpensive, difficult to detect, and provide quick reaction intelligence data. Their small size limits the payload weight, but they are performing increasing roles as the technology advances. Unfortunately, as US and Allied forces benefit from widespread use of small UAVs, enemy forces are also employing this technology in ever-increasing numbers to gather intelligence and carry out attacks against our forces. A system to detect and negate enemy UAVs is needed to address this growing concern. A laser weapon system is a promising platform to negate and disable small UAVs, however, such a system must also perform surveillance to detect and track these small, low-signature threats. We present a novel system using both optical and acoustic sensors to detect these low-signature threats with sufficient accuracy for directed energy engagement. Several innovative features allow fast hemispherical coverage with ranges extending to 10km. A high fidelity system simulation provides performance predictions for different scenarios.

8037-46, Session 10

High output power, injection-seeded KTA ring-cavity optical parametric oscillator

R. Foltynowicz, M. D. Wojcik, Utah State Univ. (United States); A. V. Smith, AS-Photonics, LLC (United States)

We have demonstrated the seeding of a high-power, folding prism, NCPM-KTA, ring-cavity optical parametric oscillator (OPO). The OPO was pumped with an injection seeded 7ns, 30Hz, flash-pumped, Q-switched, Nd:YAG at a wavelength of 1064.162nm. The injection-seeding of the OPO was done using a SLM DFB diode laser which produced a signal and idler of 1535.2nm and 3468.3nm, respectively. The OPO achieved a conversion efficiency of 27%, maximum signal power of 243mJ, and a FWHM linewidth of 853MHz. Given the high power output, narrow linewidth, and seed laser tunability of this OPO, this source has the potential use for remote chemical detection via differential absorption LIDAR.

8037-47, Session 10

High-power diode-pumped Q-switched Er3+:YAG single-crystal fiber laser for active imaging system

I. Martial, Lab. Charles Fabry (France); J. Didierjean, N. Aubry, Fibercryst SAS (France); F. Balembois, P. Georges, Lab. Charles Fabry (France)

Active imaging systems are becoming increasingly important on the operation field. To answer to this need, new laser sources must be developed in the eye-safe range. The Er3+:YAG crystal is one of the most attractive materials for the development of multi-watt compact laser in this range. In this work, several technological features were combined to achieve a high performance laser source. A laser diode at 1532 nm was used instead of usual EDFA pumping. This enables cost and size reduction for the laser, as well as lower heat generation. Single-crystal fibers were used as gain medium. This innovative laser medium combines the good thermal management and the pump guiding ability of glass fibers with the emission cross sections and structural qualities of single-crystals. The high numerical aperture of single-crystal fibers allows off-axis pumping scheme, leading to a simpler and cheaper system.

The experimental setup consists of an actively cooled 0.5% Er3+:YAG single-crystal fiber which has a diameter of 800 µm and a length of 60 mm put in a bi-concave cavity with a length of less than 200 mm. It is pumped in off-axis configuration by a high power fiber-coupled laser diode at 1532 nm. In Q-switched operation 2 mJ pulses at 1 kHz with a duration lower than 38 ns were obtained under 58 W of absorbed pump power. The beam presented an M^2 factor lower than 1.8 in both directions. This work was supported by the French ministry of defense under contract n°0834019.

8037-48, Session 10

Field tests of optical ranging using PRBS modulation techniques

J. M. Kovalik, K. E. Wilson, M. W. Wright, W. Williamson, Jet Propulsion Lab. (United States)

JPL has developed and tested an optical ranging system using a Pseudo-Random Bit Stream (PRBS) modulation technique. The optical transceiver consisted of an infrared laser transmitter co-located with a receiver telescope. The infrared laser beam was propagated to a retro reflector and then received by a detector coupled to the telescope. The transceiver itself was mounted on a gimbal that could actively track moving targets through a camera that was bore sighted with the optical detector. The detected optical signal was processed in real time to produce a range measurement with sub mm accuracy. This system was tested in the field using both stationary and moving targets up to 5 km away. Ranging measurements to an aircraft were compared with results obtained by differential GPS techniques.

8037-50, Session 10

System gain optimization in direction detection ladar system

L. Wu, Y. Zhao, Y. Zhang, Y. Zhang, J. Wu, Harbin Institute of Technology (China)

In this paper, the research on the direct detection process is made by statistical method. An equivalent direct detection receiver model is presented for the random process of detection. The model simplifies the random impulse responses of the electrons counting of returned signal, background radiation and dark current as a Gaussian random process with high enough gain. An investigation based on Gaussian distribution of system output in ICCD scannerless range-gated Ladar system is conducted with the calculations of error probability, absolute error and relative error. The study on multiple optimized variables, including system gain, threshold and pulse width, to meet different request is necessary to be conducted. In this paper only optimized system gain are considered to be the unique manipulated variable. The research shows that optimized gains of the system are required for different requests during the detection process. The optimized gains are calculated separately based on the Gaussian model of the random process to achieve the lowest error probability, the lowest absolute error and relative error, and requested detection range. The simulations show that the values of optimized gains tend to increase along with the target distance, although the increasing speeds are different. To meet multiple requests, an evaluation model based on cost function is constructed with 3 kinds of weights representing varied importance of requests: vital request, normal constraint and minor importance. The simulation shows that the evaluation model is capable of setting optimized gains for different circumstances and the settings of the weights are vital to the performance of Ladar system.

8037-51, Session 11

Virtual navigation of interior structures by lidar

Y. Xi, X. Li, Y. Duan, Univ. of Missouri-Columbia (United States); N. H. Maerz, Missouri Univ. of Science and Technology (United States)

We developed and integrated the technology needed for generating a geometric model of the interior of a building, cave or other structure using ground-based Light Detection And Ranging (LIDAR) scanning technology through glass or open windows or doorways, in darkness or bright sun, as well as scanned from inside the structure accessed by a remotely driven LIDAR scanner.

We procured a state of the Art Leica HDS6000 LIDAR scanner, and a robotic crawler. We modified the crawler to add lift capabilities and automatic leveling capabilities. All functions of both the crawler and the LIDAR scanner are remotely (wirelessly) controlled by a single laptop computer. We developed and documented a protocol for the LIDAR scanning, and scanned multiple different targets.

We developed a prototype software system based on OpenGL® and Visual C++® that can automatically reconstruct the 3D scene of the interior of a building or other structure from point clouds acquired by the ground-based LIDAR scanner. We developed a user-friendly Graphical User Interface (GUI) that allows the users to interactively visualize, navigate and walk through the room from different view angles, zoom in and out, etc. The reconstructed 3D scene can be exported in the “OBJ” data format that is fully compatible and exportable to other commercial visualization software.

In addition, the system can automatically generating the floor plan of the interior structures which can be very useful for the user to have a high level understanding of the interior of the building and is complementary to the interactive 3D visualization provided by our software system.

8037-52, Session 11

Spectral ladar as a UGV navigation sensor

M. A. Powers, General Dynamics Robotic Systems (United States); C. C. Davis, Univ. of Maryland, College Park (United States)

We demonstrate new results using our Spectral LADAR prototype, which highlight the benefits of this sensor for Unmanned Ground Vehicle (UGV) navigation applications.

This sensor is an augmentation of conventional LADAR and uses a polychromatic source to obtain range-resolved 3D spectral point clouds. These point cloud images can be used to identify objects based on combined spatial and spectral features in three dimensions and at ranges up to 100 meters. The Spectral LADAR transmits nanosecond supercontinuum pulses generated in a photonic crystal fiber. Backscatter from distant targets is dispersed into 25 spectral bands, where each spectral band is independently range resolved with multiple return pulse recognition.

Our new results show that Spectral LADAR can spectrally differentiate terrain types, such as mud and sand, from favorable driving surfaces (e.g. dry ground, roadway). This is a critical capability, since mud and sand are potentially hazardous, require modified vehicle dynamics, and are difficult to identify based on 3D spatial signatures. Additionally, we demonstrate the benefits of range resolved spectral imaging, where highly cluttered 3D images of scenes (e.g. containing camouflage, foliage) are spectrally unmixed by range separation and segmented accordingly. Spectral LADAR can achieve this unambiguously and without the need for stereo correspondence, sub-pixel detection algorithms, or multi-sensor registration and data fusion.

8037-53, Session 11

Brassboard development of a MEMS-scanned ladar sensor for small ground robots

B. L. Stann, J. F. Dammann, U.S. Army Research Lab. (United States); P. Jian, Aerotek, Inc. (United States); M. M. Giza, W. B. Lawler, U.S. Army Research Lab. (United States)

The Army Research Laboratory (ARL) is researching a short-range ladar imager for navigation, obstacle/collision avoidance, and target detection/identification on small unmanned ground vehicles (UGV). To date, commercial UGV ladars have been flawed by one or more factors including low pixelization, insufficient range or range resolution, image artifacts, no daylight operation, large size, high power consumption, and high cost. ARL built a breadboard ladar based on a newly developed but commercially available micro-electro-mechanical system (MEMS) mirror coupled to a low-cost pulsed Erbium fiber laser transmitter that largely addresses these problems. Last year we integrated the ladar and associated control software on an iRobot PackBot and distributed the ladar imagery data via the PackBot's computer network. The un-tethered PackBot was driven through an indoor obstacle course while displaying the ladar data on a remote laptop computer real-time over a wireless link. We later conducted additional driving experiments in cluttered outdoor environments. This year ARL partnered with General Dynamics Robotics Systems to start construction of a brass board ladar design. This paper will discuss refinements and rebuild of the various subsystems including the transmitter and receiver module, the data acquisition and data processing board, and software that will lead to a more compact, lower cost, and better performing ladar. The current ladar breadboard has a 5-6 Hz frame rate, an image size of 256 (h) x 128 (v) pixels, a 60° x 30° field of regard, 20 m range, eyesafe operation, and 40 cm range resolution (with provisions for super-resolution or accuracy).

8037-54, Session 11

Compact 3D lidar based on optically coupled horizontal and vertical scanning mechanism for the autonomous navigation of robots

M. Lee, S. Baeg, M. Baeg, Korea Institute of Industrial Technology (Korea, Republic of); K. M. Lee, H. S. Lee, LG Innotek (Korea, Republic of); J. O. Park, Hyundai Rotem Co. (Korea, Republic of); H. K. Kim, Samsung Electro-Mechanics (Korea, Republic of)

The purpose of this research is to develop a new 3D LIDAR sensor, named KIDAR-B25, for measuring 3D image information with high range accuracy and high speed. To measure a distance to a target object, we design a range measuring module, which is implemented by the direct time of flight method, a pulsed laser diode module as an illumination source (pulse width: 5 ns, wavelength: 905 nm, repetition rate: 30kHz), and an Si APD photo detector module, which has high sensitivity and wide bandwidth. Also, we design a horizontal and vertical scanning mechanism, which is coupled with optical components as one compact module to reduce its size and weight. This sensor has the optical passes of emitted and receive, which are separated and parallel to each other. The structure of the KIDAR-B25 sensor has proven mechanical stability up to 5Hz (vertical)/20Hz (horizontal). The range of vertical plane can be measured up to ±10 degree with 0.125 angular resolution. The whole horizontal plane (360 degree) can be also measured with 0.0625 degree angular resolution. Since the KIDAR-B25 sensor is planned to be used in a mobile robot for navigation, we conducted an outdoor test for evaluating its performance. The experimental results show that the captured 3D imaging data can be applicable to the navigation information of the robot for detecting and avoiding the moving objects with real time.

Conference 8038: Atmospheric Propagation VIII

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8038-01, Session 1

Monte Carlo-based multiple-scattering channel modeling for non-line-of-sight ultraviolet communications

R. J. Drost, B. M. Sadler, U.S. Army Research Lab. (United States)

Although the concept of non-line-of-sight (NLOS) ultraviolet (UV) communications has been studied for decades, recent advances in the design and manufacturing of light-emitting diodes, filters, and sensors have ignited new interest. In addition to offering communication bandwidth to supplement traditional technologies, the optical channel experienced by light in the deep-UV band (200-300 nm) presents unique opportunities to address particular communication challenges. For example, the absorption by ozone of solar radiation in this band leads to nearly noiseless channels, thus allowing for the use of photon counting receivers, while the scattering of UV light by the atmosphere enables NLOS operation.

In this paper, we discuss a Monte Carlo channel model of a NLOS UV communication system, accounting for the possibility that a transmitted photon experiences multiple scattering events before being received. By simulating the propagation of many photons based on probabilistic rules derived from physics considerations, a computationally efficient algorithm is obtained that allows for the study of the contribution of various orders of scattering to the received signal and to the system impulse response function. We then demonstrate the use of this channel model in the exploration of several system configurations. For example, we examine the effect of system parameters such as transmitter beam width and receiver field-of-view on the faithfulness of a well-known linear model of path loss for short-range NLOS UV systems, and we explore geometry design for interference reduction in a full-duplex link. The use of the model to study such diverse system implementations demonstrates its general applicability.

8038-02, Session 1

Performance modeling of the effects of aperture phase error, turbulence, and thermal blooming on tiled subaperture systems

C. L. Leakeas, R. J. Bartell, S. J. Cusumano, Air Force Institute of Technology (United States); M. Whitely, MZA Associates Corp. (United States)

Laser weapon systems comprised of tiled subapertures are rapidly emerging in importance in the directed energy community. Performance models of these laser weapon systems have been developed from numerical simulations of a high fidelity wave-optics code called WaveTrain which is developed by MZA Associates. System characteristics such as subaperture shape, fill factor, exitance profile, separation distance, mutual coherence, differential jitter, and beam quality rms wave front error are defined for a focused beam on the target. Engagement scenarios are defined for various platform and target altitudes, speeds, headings, and slant ranges along with the natural wind speed and heading. Inputs to the performance model include Fried diameter, turbulence strength, thermal blooming distortion number, Greenwood frequency, atmospheric and molecular absorption and scattering. The performance model fit is based on power-in-the-bucket (PIB) values against the PIB from the simulation results. The goal is to develop robust performance models for aperture phase error, turbulence, and thermal blooming effects in tiled subaperture systems.

8038-03, Session 1

Practical calculation of the beam scintillation index based on the rigorous asymptotic propagation theory

M. I. Charnotskii, Zel Technologies, LLC (United States); G. J. Baker, Lockheed Martin Space Systems Co. (United States)

Asymptotic theory of the finite beam scintillations (Charnotskii, WRM, 1994, JOSA A, 2010) provides an exhaustive description of the dependence of the beam scintillation index on the propagation conditions, beam size and focusing. However the complexity of the asymptotic configuration makes it difficult to apply these results for the practical calculations of the scintillation index. We propose an estimation technique and demonstrate some examples of the calculations of the scintillation index dependence on the propagation path length, initial beam size, wavelength and turbulence strength for the beam geometries and propagation scenarios that are typical for applications. We suggest simple analytic “bridging” approximations that connect the specific asymptotes with the accuracy sufficient for the engineering estimates. Proposed technique covers propagation of the wide, narrow, collimated and focused beams under the weak and strong scintillation conditions.

Direct numeric simulation of the beam waves propagation through turbulence expediently complements the asymptotic theory being most efficient when the governing scales difference is not very large. We performed numerical simulations of the beam wave propagation through turbulence for conditions that partially overlap with the major parameter space domains of the asymptotic theory. The results of the numeric simulation are used to confirm the asymptotic theory and estimate the accuracy of the “bridging” approximations.

8038-04, Session 1

Generation of atmospheric turbulence-induced time-varying optical signals for space-to-ground laser links

M. Toyoshima, T. Sasaki, H. Takenaka, Y. Takayama, National Institute of Information and Communications Technology (Japan)

This paper discusses a simulation model for generating time-varying optical signals based on the atmospheric turbulence spectrum for space-to-ground laser links. The frequency characteristics of the downlink are theoretically derived. The speckle patterns were averaged and the frequency response of the received optical signal was filtered by the telescope aperture. The time-varying optical signal is generated based on the von Karman spectrum. The parameters are compared and fitted to the measured results. The simulated results are presented herein.

8038-05, Session 1

Fading probability density function of free-space optical communication channels with pointing error

Z. Zhao, R. Liao, Michigan Technological Univ. (United States)

The turbulent atmosphere causes wavefront distortion, beam wander, beam broadening of a laser beam. These effects result in average power loss and power fading at the receiver aperture and thus degrade performance of a free-space optical (FSO) communication system. In addition to the atmospheric turbulence, a FSO communication system also suffers from laser beam pointing error which causes excessive power loss and power fading. This paper proposes and studies an

analytical method for calculating the fading probability density function (pdf) induced by both atmospheric turbulence and pointing error based on the fast-tracked laser beam fading profile and the joint effects of beam wander and pointing error. In order to evaluate the proposed analytical method, large-scale numerical wave-optics simulations are conducted. Three mathematical pointing error models are studied, namely, the Gaussian random model, the uniform random model, and the sinusoidal sway model. In the simulations, the FSO system is supposed to use a collimated Gaussian laser beam propagating along a horizontal path. The refractive index structure parameter ranges from 5e-15m^(-2/3) to 5e-13m^(-2/3). The propagation distance ranges from 200m to 3200m. The simulations cover from weak to strong fluctuations. In all the studied cases, the overall fading pdf curves calculated using the analytical method match accurately the corresponding pdf curves obtained directly from large-scale wave-optics simulations, and they also give more accurate bit-error-rate curves and outage probabilities than the gamma-gamma and lognormal pdf models.

8038-06, Session 2

Characterizing aerosol extinction in the UV-NIR spectral range

G. G. Gimmestad, D. W. Roberts, Georgia Tech Research Institute (United States)

The Georgia Tech Research Institute (GTRI) is developing a transportable multi-lidar system known as the Integrated Atmospheric Characterization System (IACS). The system will comprise three lidars: an imaging lidar for profiling refractive turbulence, a Raman lidar for profiling water vapor, and an aerosol lidar operating at 0.355, 1.064, and 1.625 microns for profiling aerosol extinction. All of the lidar transmit/receive optics will be co-aligned on a common mount, pointable at any elevation angle from horizontal to vertical. The entire system will be computer controlled to facilitate pointing and automatic data acquisition.

The purpose of IACS is to characterize optical propagation paths during outdoor tests of electro-optical systems. The tests are anticipated to include ground-to-ground, air-to-ground, and ground-to-air scenarios, so the system must accommodate arbitrary slant paths through the atmosphere with maximum measurement ranges of 5-10 km.

Elevation angle scans will be used to calibrate the atmospheric extinction profiles and data from the three wavelengths will be used to determine the aerosol Angstrom coefficient, enabling interpolation of results to other wavelengths in the 0.355 to 1.6 micron region. The measurement and analysis methodologies are described and simulation results are presented. Some lidar engineering challenges and solutions are also presented.

8038-07, Session 2

Validation of technique to hyperspectrally characterize the lower atmosphere with limited surface observations

R. M. Randall, S. T. Fiorino, M. F. Gerling, A. D. Downs, Air Force Institute of Technology (United States)

This paper demonstrates the capability of AFIT/CDE's Laser Environmental Effects Definition and Reference (LEEDR) model to accurately characterize the meteorological parameters and radiative transfer effects of the atmospheric boundary layer with only surface observations of temperature, pressure, and humidity. The LEEDR model is a fast-calculating, first principles, worldwide surface to 100 km, atmospheric propagation and characterization package. This package enables the creation of profiles of temperature, pressure, water vapor content, optical turbulence, atmospheric particulates and hydrometeors as they relate to line-by-line layer transmission, path and background radiance at wavelengths from the ultraviolet to radio frequencies. Physics-based cloud and precipitation characterizations are coupled with a probability of cloud free line of sight (CFLOS) algorithm for air-to-air, air-to-surface, and surface-to-air (or space) look angles. 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 . However, the LEEDR user can also directly input surface observations. This research compares the LEEDR vertical profiles created from input surface observations to actual observations from balloon launches, aircraft, and satellites. Additional comparisons are made to vertical profiles derived from short range numerical weather forecasts.

8038-08, Session 2

Simulation of plane wave propagation through non-Kolmogorov turbulent atmosphere: a comparison between simulations and theory

V. S. R. Gudimetla, Air Force Research Lab. (United States); R. B. Holmes, Boeing LTS Inc. (United States)

No abstract available

8038-09, Session 2

Measurements of atmospheric parameters using the SOR atmospheric monitor

E. J. Spillar, Air Force Research Lab. (United States)

We discuss the SOR Atmospheric Monitor's (SAM's) algorithms for estimating a number of atmospheric parameters from Shack-Hartmann wave front sensor measurements. In addition to the previously reported Fried parameter work, we report on estimates of Greenwood frequency, scintillation parameters, as well as the strength of individual turbulent layers and their velocities. We report on a few months of statistics of these parameters at Kirtland AFB.

8038-10, Session 3

Analysis of the propagation channel and its impact on the ORCA laser communication system

D. T. Wayne, T. Leclerc, P. Sauer, R. L. Phillips, L. C. Andrews, Florida Space Institute (United States)

The DARPA Optical RF Communications Adjunct (ORCA) program was designed to bring high reliability high data rate communication to the warfighter via optical networking of airborne platforms. Validation testing of ORCA system predictions and modeling took place at two different locations; the Patuxent River Naval Air Station (PAX) and the Nevada Test and Training Range (NTTR). The University of Central Florida (UCF) was contracted by DARPA to measure path-averaged values of the refractive-index structure parameter Cn2, the inner scale of turbulence l0, and the outer scale of turbulence L0 along the propagation path between the aircraft node and the stationary node atop Antelope Peak at NTTR. UCF also analyzed the aero-optic effects from the aircraft boundary layer, adaptive-optics (AO)compensation issues, and fade statistics at both PAX River and NTTR. We report on data analysis and subsequent conclusions relating to the impact of the channel conditions to ORCA system performance.

Return to Contents

8038-11, Session 3

Free-space optical channel propagation tests over a 147 km link

J. C. Juarez, The Johns Hopkins Univ. Applied Physics Lab. (United States)

No abstract available

8038-12, Session 3

Characterization of impact ionization engineered InGaAs avalanche photodiodes for free-space lasercomm applications

H. R. Burris, Jr., M. S. Ferraro, W. S. Rabinovich, L. M. Wasiczko Thomas, C. I. Moore, B. B. Xu, U.S. Naval Research Lab. (United States); W. D. Waters, W. R. Clark, OptoGration Inc. (United States)

The US Naval Research Laboratory (NRL) is characterizing InGaAs avalanche photodiodes (APDs) with internal structures engineered to reduce excess noise and keff in high gain applications. Results of characterization of APDs (both impact ionization engineered and standard) manufactured by Optogration, Inc. will be presented.

8038-13, Session 3

Analysis of fading in the propagation channel for the ORCA laser communication system

P. Sauer, D. T. Wayne, T. Leclerc, R. L. Phillips, L. C. Andrews, Florida Space Institute (United States)

DARPA's ORCA experiments of long range FSO laser communication links were conducted in northern Nevada between an aircraft and a ground node over a distance of 100 to almost 200 km. An analysis was performed on the fading present in the communication channel during these tests. Mathematical models for the fading channel under atmospheric turbulence are examined and possible effects on performance are analyzed.

8038-14, Session 3

Evaluation of a control algorithm for mobile FSO node alignment

D. Zhou, P. G. LoPresti, H. Refai, The Univ. of Oklahoma - Tulsa (United States)

In order to track, acquire and maintain a free-space optical link between mobile platforms experiencing misalignment due to movement and atmospheric turbulence requires an efficient transmitter control system for pointing, acquisition, and tracking. Recently, a control algorithm was proposed that incorporated a fiber-bundle approach for beam steering at the transmitter in addition to GPS data exchange, alignment systems, and unique properties of the receiver. This paper investigates the performance of the proposed algorithm through experimental methods. The performance is evaluated on several key parameters: coverage area at the receiver plane, the link recapturing time, and the connection up-time during tracking. The dependence of the key parameters is evaluated as a function of important transmitter design choices, including transmitted power, switching time between fibers in the bundle and the threshold power for beam steering. Receiver parameters are fixed to focus the study on the transmitter. The laboratory results show that the optical control system successfully recovered and maintained the link while the receiver was in motion and the signal coverage at the target area was enhanced significantly. The link acquisition times achieved were impacted by noise in the sampled power reading at the receiver, which required more time to process these readings accurately. Uncertainties in the motion of the receiver could also affect the efficiency of link recovery.

8038-15, Session 4

Observations of atmospheric effects for FALCON laser communication system flight test

T. M. Fletcher, J. A. Cunningham, D. Baber, T. Goode, B. Gaughan, ITT Advanced Engineering & Sciences (United States)

The terminals are designed to operate from large unmanned airborne vehicles (UAVs) and piloted aircraft. They provide a secure, two-way data link between airborne platforms and between airborne and ground-based platforms. During the flight test, the lasers were operated at half of the available power, yet still established and maintained a data link between two aircraft at 12,000 feet altitude, across 81 miles. The data link remained locked for approximately 30 minutes during which both aircraft turned, banked, and experienced air turbulence.

8038-16, Session 4

PDF computations for power-in-the-bucket measurements of an IR laser beam propagating in the maritime environment

C. Nelson, The Johns Hopkins Univ. (United States); S. Avramov-Zamurovic, R. Malek-Madani, U.S. Naval Academy (United States); O. Korotkova, Univ. of Miami (United States); R. Sova, The Johns Hopkins Univ. Applied Physics Lab. (United States); F. Davidson, The Johns Hopkins Univ. (United States)

Performance of a free-space optical (FSO) communications link in a maritime environment was evaluated during two field trials conducted off the mid-Atlantic coast near Wallops Island, VA, in July and September 2009. Bi-directional, ship-to-shore data links were established utilizing commercial, single-mode adaptive optics terminals set up between a lookout tower on Cedar Island, VA and a Johns Hopkins University Applied Physics Laboratory research vessel over a range of 2-22 km (optical horizon). This paper presents statistical analysis of the power-in-the bucket captured from four detectors placed alongside the adaptive optics terminal during the September 2009 field trial. The detectors ranged in size from 0.25" to 3.0" in diameter. We will present the histogram reconstruction and compare the data with two analytical models based on the Gamma-Laguerre and Gamma-Gamma distributions. Additionally, dependence of the results on propagation distance, detector aperture size, and parameters of the marine atmospheric spectrum are investigated.

8038-17, Session 4

Near-the-ground laser communication system: anisoplantic studies based on the PSF measurements

A. V. Sergeyev, M. C. Roggemann, C. D. Demars, Michigan Technological Univ. (United States)

Near the ground laser communication systems must operate in the presence strong atmospheric turbulence. The effects of the atmospheric turbulence on the laser beam which are relevant to optical communications are a broadening of the laser footprint, random jitter of the laser beam, and high spatial frequency intensity fluctuations referred to as scintillation. The overall goal of our program is to improve

performance and extend the range of optical communications systems by exploring the use of adaptive optics and channel coding. The knowledge of the turbulence conditions and the ability to describe its properties are the key aspects to make these improvements effective. The developed laser communication system is directed to collect significant amount of the experimental data to statistically describe atmospheric turbulence. 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 communication system described in this paper has two transmitters and two receivers. The transmitter side is equipped with the laser and the bank of 14 horizontally, in-line mounted LEDs. The receiver side consists of two channels for WFS and PSF measurements. The effects of anisoplanatism on the optics point spread function and statistics of Freid parameter r_0 are discussed.

8038-18, Session 4

Evaluation of the performance of a fiber-bundle-based optical wireless link

P. G. LoPresti, D. Zhou, H. Refai, The Univ. of Oklahoma - Tulsa (United States)

A novel receiver and transmitter have been 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 receiver uses an array of carefully selected lenses coupled to an array of optical fibers to maximize the range of condition over which optical power can be collected, and the transmitter uses fiber bundles to implement beam steering and utilizes adjustable divergence to improve the coverage at the receiver. This paper reports on a simulation-based investigation of the total system performance to assess the true impact of the design choices on the operating characteristics of the link. The simulation incorporates prior experimental data into the theoretical calculations for optical propagation to better approximate the performance of the physical designs. Key parameters related to link performance, particularly the area over which the receiver can move and collect sufficient power to maintain the link, are investigated as a function of transmitter power, link length, relative misalignment and the emission pattern at the transmitter. The investigation finds that the coverage area of the receiver can be optimized for a given link length by proper choices of the transmitter emission pattern, the beam divergence, and the number of receiving fibers for a given transmitter power. Trade-offs between the emission pattern and the transmitter power are explored. The results provide guidance on the further development of the overall system.

8038-19, Session 5

Turbulence modeling for non-line-of-sight ultraviolet scattering channels

H. Ding, Z. Xu, Univ. of California, Riverside (United States); B. M. Sadler, U.S. Army Research Lab. (United States)

Recently ultraviolet (UV) scattering channels have received renewed interest for non-line-of-sight (NLOS) communication. Existing approaches by Monte Carlo simulations and field experiments have yielded preliminary but valuable results in channel path loss and impulse response, critical for communication link budget. However, when communication range increases, the effect of turbulence becomes pronounced and inevitably induces additional impairments to system performance. This paper suggests a turbulence modeling method for NLOS UV channels incorporating the effects of scattering and absorption. The modeling results can be applied to study communication performance.

8038-20, Session 5

Laser communication of FM audio/video signals using InGaAs modulating retro-reflectors

K. J. Grant, B. A. Clare, W. Martinsen, K. A. Mudge, Defence Science and Technology Organisation (Australia); H. R. Burris, Jr., C. I. Moore, J. Overfield, C. Gilbreath, W. S. Rabinovich, J. A. Duperre III, U.S. Naval Research Lab. (United States)

There is increasing interest in free space optical communications as an alternative to fibre optics and radio frequency communications, particularly for 'last mile' applications and applications with size, weight and power restrictions. The potential advantages of free space optical communications include: high bandwidth; no licensing issues; smaller lighter payloads; low probability of intercept; and immunity from interference / jamming.

There are numerous applications where it would be beneficial to reduce the payload requirements for on-board communications, and the US Naval Research Laboratory (NRL) has developed coupled-well InGaAs modulating retro-reflectors for this purpose. These have been successfully employed to transmit digital video signals in asymmetric links. However, there are situations where it is advantageous to be able to transmit analogue video due to its significantly lower power requirements, since encoding and compression is not required.

We report on the free space optical transmission of FM audio / video signals using a 6.3mm diameter InGaAs modulating retro-reflector. The experiment was performed at the laser range facility at the Defence Science & Technology Organisation (DSTO) in Edinburgh, South Australia, over a slant path (10m to 1.5m) of length 1.5km. The video was free from artefacts due to atmospheric scintillation for Cn2 up to ~2e-14. For higher levels of atmospheric turbulence, noticeable artefacts were introduced in the video, caused by signal drop-outs. The FM MRR video system was usable over a 1.5km range up until atmospheric turbulence levels reached ~2e-13.

In future extensions to this work, we wish to trial the system over longer ranges, and investigate its performance in applications such as ship-to-shore communications.

8038-21, Session 5

Orbital angular momentum receiver bandwidth for laser communications systems operating in atmospheric turbulence

F. S. Vetelino, R. J. Morgan, Aerospace Missions Corp. (United States)

The Orbital Angular Momentum (OAM) states of photons in paraxial beams allow, in theory, an unlimited number of bits per photon to be used for information encoding in lasercom systems. Atmospheric turbulence scatters the transmitted OAM mode to neighboring modes. The probability of receiving the transmitted mode number decreases with increasing turbulence strength. The degradation is more severe for larger transmitted mode numbers due to their bigger spot size, limiting the range of an OAM encoded lasercom system. To compensate for the lower probability of receiving higher order modes, the concept of receiver OAM bandwidth is defined as a range of received neighboring OAM states allocated to the transmitted OAM mode. By increasing the receiver OAM bandwidth for higher order transmitted modes, the probability to determine the transmitted mode number is similar for all transmitted mode numbers. The optimal system design for OAM encoding using higher order Laguerre-Gauss beams, with the suggested transmitted mode numbers and their corresponding receiver OAM bandwidth, is presented. A closed form analytical expression of the probability to determine the transmitted mode number of the system design is developed. It can be used to easily determine the maximum propagation distance for an OAM encoded lasercom system with a probability to determine the transmitted OAM mode number close to unity.

8038-22, Session 5

Buffered block acknowledgement (BuBa) protocol for highly errored data links

C. I. Moore, H. R. Burris, Jr., L. M. Wasiczko Thomas, M. R. Suite, W. R. Smith, Jr., R. Mahon, W. S. Rabinovich, U.S. Naval Research Lab. (United States)

No abstract available

8038-23, Session 5

Blackbody remote optical thermometry through turbulent atmosphere

G. A. Tidhar, N. S. Kopeika, Ben-Gurion Univ. of the Negev (Israel)

Thermal radiometry allows remote measurement of black-body temperature, by fitting irradiance values measured at different spectral bands to a Planckian distribution with temperature as free parameter. Systematic and random errors in this method were analyzed in depth, and consider 3 main sources of variance: (1) Calibration error, (2) Radiometric errors, (3) Electronic noise and errors.

For the first time, according to the authors knowledge, we suggest a comprehensive physical model which provides quantitative analysis, of the effects of atmospheric turbulence on the accuracy of remote multi-band sensing of scene-objects at different atmospheric path turbulence conditions, system parameters (aperture diameter, spectral bandwidth, spectral bands separation and separation of apertures for a multi-apertures radiometer) as well as the measured object diameter. With some typical scenario examples we demonstrate that significant measurement errors of black body temperature are expected, and conclude with some possible means for their mitigation are correction.

8038-24, Session 5

A flexible testbed for adaptive optics in strong turbulence

J. D. Schmidt, M. J. Steinbock, Air Force Institute of Technology (United States)

In recent years, optical wave propagation through strong atmospheric turbulence and adaptive optics compensation thereof has received much attention in literature and technical meetings. To address these issues in part, researchers at the Air Force Institute of Technology have undertaken modeling and simulation efforts involving laser communication and wavefront sensing over long horizontal paths. Now these efforts are expanding into laboratory experiments utilizing a versatile surrogate turbulence simulator and adaptive optics system. The system can switch between using two different wavefront sensors, a Shack-Hartmann and a self-referencing interferometer. Wavefront reconstruction takes place on field programmable gate arrays, operating at kilohertz frame rates. Further, it has the ability to perform reconstruction and control in software for testing of advanced algorithms (at frame rates below 10 Hz). The entire system is compact enough for transportation to other laboratories and live test facilities. This paper describes the optical layout, architecture, and initial results of real-time operation.

8038-25, Session 5

USAF High Energy Laser (HEL) systems: HEL-generated extinction effects and degradation of multibandpass algorithm efficiencies during missile staging (case PRC DF-21; GHADR 110)

C. A. Paiva, BSM Research Associates (United States)

This comprises continued research addressing missile exhaust plume ionization; such ionization as a function of altitude, exhaust plume expansions, reverse exhaust flows and HEL-generated plasma. It is demonstrated that these processes 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 21 and 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 extinction effects. As a result the HEL fluence (energy in the bucket), and is expected to also decrease in intensity. The overall engagement event results in HEL plasma-plume plasma interactions (absorption-scattering) reducing energy on the infrared focal plane. Specifically such exhaust 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 21/31, from which exhaust plume spatial and temporal characteristics were obtained. 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 missiles, and dedicated 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 assymetric, 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, and North Korean TAEPODONG-2/III ICBM missile systems which are in production.

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8039-01, Session 1

Pulsed 2-micron lasers based on Tm3+-doped monoclinic double tungstate crystals

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Solid-state lasers that operate in the 2 µm eye-safe spectral range are of current interest for many applications including: spectroscopy, remote sensing, photo-medicine, optical communications and metrology to name a few.

In the present work, we report on the realization of pulsed laser operation of thulium (Tm) around 2 µm in monoclinic potassium lutetium double tungstate crystals (Tm:KLu(WO4)2)). This includes, passive Q-switching and passive mode-locking of the Tm laser with Cr2+:ZnSe crystal and single-walled carbon nanotubes (SWCNTs-SA) as saturable absorbers, respectively.

In a hemispherical compact 50 mm long resonator, diode-pumped Q-switching of the Tm:KLuW laser was realized using a Cr2+:ZnSe saturable absorber. The maximum average laser output power reached 104 mW at a repetition rate of 6.5 kHz leading to a single pulse energy of 16 µJ. The maximum peak power amounted to 3.4 kW for the pulse duration of 4.7 ns. Simultaneous Raman generation is under investigation around 2.3 µm.

Passively mode-locking of the Tm:KLuW laser under Ti:sapphire laser pumping was realized. The ultrashort pulsed laser was stable and self-starting. We used a saturable absorber based on single-walled carbon nanotubes (SWCNTs-SA) working in transmission that generated ~10-ps bandwidth-limited pulses at 1944 nm with powers up to 240 mW at 126 MHz. The same SWCNTs-SA, depending on the cavity alignment, produced Q-switched operation at ~33 kHz repetition rate and an average output power of 170 mW.

Further work on energy scaling and pulse shortening is in progress.

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8039-02, Session 1

74% laser efficiency using 10% Yb3+ doped Lu2O3 ceramic

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We demonstrate lasing at 1080 nm in 10%Yb3+ doped Lu2O3 transparent ceramics with an output power > 16 Watts and a slope efficiency of 74%. The samples were pumped with a diode laser operating at 969 nm. The transparent ceramic samples were fabricated using hot pressing of ultra-high purity powders synthesized via a co-precipitation process.

These results represent the highest output power and efficiency obtained for a Yb doped Lu2O3 ceramic laser. This is further highlighted by the record high doping concentration.

8039-03, Session 1

Tm-doped disordered molybdate crystals for ultrashort mode-locked solid state lasers

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Tm3+ is well suited for mode-locked solid state lasers because of the large bandwidth of its optical transitions in comparison to most trivalent lanthanides. Moreover, Tm3+ is frequently used as sensitizer of Ho3+. Recently a significant reduction of the pulse duration down to 191 fs has been obtained by using a disordered crystal, Tm:Ho co-doped NaY(WO4)2, in comparison to Tm:Ho co-doped KY(WO4)2 ordered crystal which only produced 570 fs pulses when tested in the same experimental setup. This shows the relevance of lattice disorder for fs mode-locked lasers. In the present work we studied using an hemispherical cavity two disordered molybdates doped with Tm. The crystals were grown by the Top Seeded Solution Growth method using a Na2MoO4/Na2Mo2O7 flux.

The tetragonal Tm-doped NaGd(MoO4)2 crystal has a Na and Gd distribution over the two possible 2d and 2b sites close to 50 % for each ion. The other disordered crystal was monoclinic Li3Lu3-xTmx(MoO4)8, whose disorder arises from the Li and Lu (and Tm) occupancy of a same 8f crystal site with occupancy factors about 0.2 and 0.8, respectively.

A c-cut 5 at% Tm-doped NaGd(MoO4)2 crystal was pumped at 794.5 nm. The laser output power at 1910 nm reached 0.641 W with a slope efficiency (versus absorbed light) of 50.8%. An a-cut Li3Lu2.7Tm0.3(MoO4)8 crystal provided 0.514 W of laser output with slope efficiency of 71.4 %. The FWHM of the multimode envelop was about 22 nm which promise a Fourier limit of sub 200 fs for the pulse duration.

8039-04, Session 1

Resonantly diode pumped Ho3+:YVO4 2.1-micron laser

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We have demonstrated a resonantly diode-pumped Ho3+:YVO4 laser. The laser was pumped at ~1.9 m and emitted at ~2.1 m. To the best of our knowledge this is the first demonstration of the Ho3+-doped laser based on YVO4 host. The absorption and emission cross sections and other spectroscopic features of the 5I7 - 5I8 transition in Ho3+:YVO4 are presented.

8039-05, Session 2

Spectroscopy and laser performance of resonantly pumped Er3+-doped double tungstate single crystals

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Er-doped laser materials are premier choice in designing resonantly-pumped ultra-low quantum defect highly scalable eye-safe lasers. Using the most efficient 15XX-nm laser diode pumps for pumping Er3+ ions requires laser materials capable of accommodating naturally wide-band (10-12 nm FWHM) output spectrum of those pumps. Er3+-doped double tungstate (DW) single crystals can be material of choice in this case - due to spectrally-broadened absorption lines caused by local disorder in this class of crystals, but so far no reported results were found on resonantly-pumped laser operation of Er3+-doped DW. Here we report the result of spectroscopic and laser characterization of Er3+-doped NaY(WO4)2. Polarized spectroscopy and power scaling aspects of this laser material are analyzed and presented, including the aspects of cryo-cooled laser operation.

8039-06, Session 2

Composite Yb:YAG/Yb:GSAG cryogenic amplifier for picosecond pulses

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Cryogenic cooling of Yb-doped laser gain media has proven to be an effective approach to scaling the average power of solid-state lasers while maintaining good beam quality. However, at cryogenic temperatures, the Yb:YAG gain bandwidth is narrower than at room temperature and thus limits the minimum pulsewidth to a few ps. Two approaches to achieving shorter pulses in these cryogenic Yb-doped systems are using gain media with larger gain bandwidth, such as Yb:LiYF4 (YLF) and using Yb:YAG in conjunction with another Yb-doped gain medium to provide a larger composite bandwidth. This latter approach of using multiple gain media is attractive because it more directly leverages existing high-power cryogenic Yb:YAG technology, and we use it here in a high-power pulsed system capable of 1.6-ps pulses at 5-kHz PRF with 70-W average power. In this system, the second gain medium was Yb:Gd3Sc2Al3O12 (GSAG). GSAG was chosen because its properties are similar to YAG, both being oxide garnets, and its gain peak at cryogenic temperature is offset from, but overlaps with, the gain spectrum in YAG.

8039-07, Session 2

Edge-pumped Yb:YAG disk amplifier with multipassed extraction

J. Vetrovec, D. A. Copeland, Aqwest, LLC (United States); D. Du, General Atomics Aeronautical Systems, Inc. (United States)

We report Yb:YAG disk amplifier using edge-pumped architecture and offering excellent scalability to high-average power in the kW-range with diffraction limited output. Edge-pumping [1] allows for reduced doping of crystals with laser ions, which translates to lower lasing threshold in quasi-3 level materials. In addition, edge-pumping uniquely enables tailoring of gain profile by varying the arrangement of pump diodes. The disk has a composite construction with undoped perimetral edge designed to channel pump light while efficiently outcoupling amplified spontaneous emission (ASE). Thermal management of the disk is provided by a microchannel heat sink offering 1) ultra-low thermal resistance, 2) uniform extraction of waste heat, and 3) excellent dimensional stability. The amplifier uses two Yb:YAG disks and relay optics for multiple extraction passes.

This work discusses modeling, design, and initial test data of the Yb:YAG disk amplifier operating in a multi-passed extraction mode. Trades between pump profile, extraction efficiency, and optical path difference are also presented. Discussion of thermal performance of the disk and the heat sink are also included. This work was in part supported by the US Army ARDEC [2].

1. J. Vetrovec et al., “Progress in the development of solid-state disk laser,” SPIE vol. 5332 pp. 235-243 (2004)

2. J. Vetrovec, D.A. Copeland, B. Scmidt, na D. Du, “Ytterbium-Based Disk Amplifier for an Ultra-Short Pulse Laser,” SPIE 7578-11 (2010)

8039-08, Session 2

Coherent combining of high-power Yb fiber amplifiers

C. X. Yu, S. J. Augst, S. Redmond, D. V. Murphy, A. Sanchez-Rubio, T. Y. Fan, MIT Lincoln Lab. (United States)

Fiber lasers are attractive for many applications because of their high electrical efficiency, compact packaging and good beam quality. Currently kW-level fiber lasers are commercially available from multiple vendors. We characterize the performance of a commercial 0.5-kW Yb fiber amplifier and demonstrate phase coherence while using a 10-GHz linewidth seed laser to overcome SBS-induced limitations. We coherently combine eight such commercial fiber amplifiers by using the stochastic parallel gradient descent technique, a variant of the multi-dither method. We also present scalability analysis to large-count fiber laser combining.

8039-48, Session 2

High-efficiency Yb:YAG thin disk laser at room and cryogenic temperatures

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Yb:YAG thin disk laser performance at room and cryogenic (80K) temperatures will be presented. The Yb:YAG gain media, which is Indium soldered to specialized CuW mounting caps, is cooled using either a pressurized R134A refrigerant system or by a two-phase liquid nitrogen spray boiler. At cryogenic temperatures spontaneous emission measurements reveal sharper transition lines and a decrease in the fluorescence lifetime. Lasing reflects that a true four-level laser.

Interchangeable mounting caps allow the same Yb:YAG media to be switched between the two systems. This allows direct comparison of lasing, amplified spontaneous emission, and temperature performance between 20C and -200C.

8039-09, Session 3

Ultra-high-intensity 1550nm single junction pulsed laser diodes

J. Boucher, Laser Components Canada, Inc. (Canada); J. J. Callahan, SemiNex Corp. (United States)

New generation of eye safe military applications such as range finding, short range illumination and friend or foe identification have started to use the 1550nm wavelength region. This was encouraged by the advent of diode lasers efficient enough to approach the output power of shorter wavelength, 850nm and 905nm, ones. This paper will review the actual performances and technologies of various commercially available 1550nm pulsed laser diodes. The performance and reliability of a new high brightness 1550nm semiconductor laser diode are disclosed and compared. Peak power of up to 35 Watts is achieved out of a single junction 350 micron stripe laser. Similarly, peak power in excess of 20W is achieved with a 180 micron stripe laser. This represents an optical power density of 11.1M W/cm2. Other key advantages of this new laser are a fast axis FWHM divergence of 25 degrees and less than a 10mRad divergence after fast axis collimation. The new diode technology will be explained in some detail covering aspects of design, fabrication and adaptation to meet its final target performances. A description of the optimization of chip dimensions and laser packaging is also undertaken. Finally, various ideas are offered to further improve the laser efficiency and power.

8039-10, Session 3

Elevated-temperature operation of lasers and laser diode arrays

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Northrop Grumman Cutting Edge Optronics has developed a new line of laser and laser diode array products that are specifically designed to operate at elevated temperatures (50-140 oC). These products are designed to provide extended lifetimes at operating conditions commonly encountered in military and aerospace applications.

This paper discusses the special requirements placed on laser diode arrays that are designed for use at temperatures up to 140 oC. The heat sink and solder material selection process is discussed, and characterization data is presented for diode arrays operating with base temperatures up to 140 oC. Slope efficiency and threshold current data is presented and compared to industry-standard models. Lifetime data is also presented as a function of temperature and compared to modeled predictions.

The high-temperature laser diode arrays serve as a building block for high-temperature laser systems. These laser systems are cooled via a radiator to the ambient environment, so high-temperature performance is imperative. Data is presented for laser systems operating at temperature ranges from 50 - 80 oC. Performance is analyzed as a function of ambient temperature and laser diode pump wavelength.

8039-11, Session 3

High-performance blue and green laser diodes based on nonpolar/semipolar InGaN

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We present breakthrough performance from green and blue InGaN-based single-mode laser diodes fabricated on nonpolar/semipolar substrates. High-power, high-efficiency, and long-lifetime continuous-wave laser operation is demonstrated using these novel crystal orientations. For green wavelengths in the 520 nm range, we report on continuous wave single-mode lasing with more than 50 mW of output power. We describe single-mode blue lasers operating with over 23% wall-plug-efficiency and with output powers greater than 750 mW. To the best of the authors' knowledge, this efficiency represents the highest reported to date for a single-mode blue laser. These InGaN-based direct-diode lasers offer significant improvement in performance, size, weight, and cost over conventional gas and solid state lasers. Furthermore, these devices exhibit robust operation over a broad temperature range, can be directly modulated and do not contain harmful residual infrared (IR) radiation typical of second harmonic generation (SHG) lasers. These characteristics are salient considerations for such optical devices in battlefield applications.

8039-12, Session 3

High-brightness QCW pump stacks based on 200W laser diode bars and mini bars at 808nm and 940nm

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Advanced solid state laser architectures place increasingly demanding requirements on high-brightness, low-cost QCW laser diode pump sources, with high power concentration desired within a custom aperture both for side and end pumping configurations. To meet this need, we have developed a new series of scaleable pump sources at 808nm and 940nm. The stacks, available in multiple output formats, allow for custom aperture filling by varying both the length and quantity of stacked laser bars. For these products, we developed next-generation laser bars based on improved epitaxial wafer designs delivering >55% efficiency at power densities of 20W/mm of emission aperture. With >200W of peak QCW power available from a full-length 1cm bar, we have demonstrated power scaling to over 1.8 kW in 9-bar stacks with 55% wall plug efficiency. We will also present the design and performance of several stack configurations using full-length and reduced-length (mini) bars that demonstrate the versatility of both the bar and packaging designs. We will illustrate how the RobustHead packaging technology developed at SCD is capable of accommodating variable bar length, pitch and quantity for custom pumping geometries. The excellent all-around performance of the stacks is supported by reliability data in line with the previously reported 20 Gshot space-grade qualification results of SCD's stacks.

8039-13, Session 3

Extending the locking range of VHG-stabilised diode laser bars using wavefront compensator phaseplates

R. McBride, J. J. Wendland, PowerPhotonic, Ltd. (United Kingdom); N. Trela, H. J. Baker, Heriot-Watt Univ. (United Kingdom)

We describe the successful use of wavefront compensator phaseplates to extend the locking range of volume holographic grating (VHG)-stabilised diode lasers. Locking range determines tolerance to variations in diode temperature, drive current and centre wavelength, and hence is a key performance parameter in many defence applications, such as solid-state laser pumping, where power requirements and environmental conditions can make accurate stabilisation of diode temperature impractical.

Imperfect source collimation, caused by diode bar smile, lens defocus and aberrations, limits the efficiency of VHG feedback, resulting in reduced locking range and variable behaviour from emitter to emitter within a bar. These effects can be compensated by increasing grating strength, but at the cost of reduced system efficiency.

We show that this performance loss can be avoided by using a wavefront compensator phaseplate to optimise the match between forward and reverse wavefronts, maximising feedback into the diode active region. We present results demonstrating the use of this technique to increase locking range for both broad-area (multimode) and single transverse-mode diode laser arrays. The use of wavefront compensation improves emitter-emitter power uniformity and allows wavelength lock to be maintained over a greater range of diode temperature and drive current. It also allows operation with increased distance between diode and VHG, providing greater design flexibility.

By additionally integrating slow-axis collimation into the wavefront compensator optic, we achieve a high-brightness VHG-optimised beam using a highly compact optical system. This improved beam quality then provides the opportunity for further brightness enhancements, such as dense wavelength-combining.

8039-14, Session 4

Recent progress in power scaling of resonantly-pumped Yb-free Er-doped fiber lasers

M. Dubinskii, J. Zhang, V. Fromzel, T. Sanamyan, U.S. Army Research Lab. (United States)

Power scaling capability of resonantly-pumped Yb-free Er-doped fiber lasers, which started showing significant progress during last two years, has been carefully scrutinized lately. Nearly 70% optical to optical efficiency has been achieved based on even COTS laser fibers, and the power has been scaled to over 100 W power levels, which indicates this

Return to Contents

approach to eye-safe fiber laser to be even more promising. This paper presents the very latest results in the diode-pumped Yb-free Er-doped fiber laser development.

8039-15, Session 4

Monolithic, narrow linewidth, polarization maintaining, thulium fiber laser using femtosecond laser written fiber Bragg gratings

C. C. C. Willis, J. D. Bradford, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Narrow linewidth, wavelength-stabilized sources operating in the 2-µm wavelength regime are desirable for applications such as LIDAR and spectral beam combination- due largely to the atmospheric transmission windows there. Thulium-doped fiber lasers are ideal for such applications due to their broad spectral tuning range (~1.8 - 2.1 µm), high power capability, and high beam quality. These same applications also demand robust and compact laser systems, for which fiber Bragg gratings (FBGs) are an important enabling technology. To that end we present a monolithic dual-FBG Tm:fiber laser system pumped with 793 nm laser diodes, delivering >5 W CW with an average spectral width of 90 pm at 2054 nm. The pump delivery fibers are directly spliced to the Tm:fiber laser via a 2+1:1 pump combiner. The output of the pump combiner is spliced to a highly reflective (99% reflective) FBG, which is spliced to the active fiber, and the cavity is terminated with a low reflectivity (34% reflectivity) FBG. All fibers in the cavity are polarization maintaining, are single-mode, and have a 10 µm diameter core and 130 µm diameter cladding. The FBGs are written into passive fiber by illuminating a phase mask with a femtosecond laser producing 80 fs pulses at 800 nm. Despite the lack of any intracavity polarization elements, the output power is preferentially polarized along the slow axis of the fiber with an average polarization extinction ratio of 17 dB.

8039-16, Session 4

Co-pumped 130 W monolithic single frequency fiber amplifier with an optically induced thermal gradient

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It is well-known that co-pumped fiber amplifiers have relatively low SBS thresholds due to the slow rise of the signal and the lack of a steep thermal gradient at the output end of the fiber. Consequently, co-pumped single frequency conventional fiber amplifiers operating without the benefit of externally applied SBS mitigating techniques or acoustic tailoring have been generally limited to output powers well below 100 W. We used laser gain competition between two signals in a co-pumped monolithic polarization maintaining Yb-doped fiber amplifier to achieve 130 W of single frequency output with a slope efficiency of 74%. In this two-tone approach, a broadband 1035 nm seed and a single frequency 1065 nm seed were combined using a WDM and sent into a 7 meter long Nufern 25/400 fiber. By using a skewed seed ratio, we were able to exploit the spectroscopic properties of Yb-doped fibers such that a transfer of power between the two signals occurred at the output end of the fiber; leading to a rapid rise of the single frequency signal in conjunction with the formation of a steep optically induced thermal gradient. Without the benefit of this technique, the SBS threshold was measured at approximately 40 W. This demonstrated an overall SBS suppression factor greater than 5 dB. By wrapping the entire fiber around a cold spool for the two tone configuration, we measured the SBS threshold at 90 W which inferred that the thermal gradient was responsible for a further increase in the output power of 40 W.

8039-17, Session 4

Amplification of gain switched thulium doped laser with 1.5ns pulsewidth

B. N. Samson, J. Ding, C. Wang, K. Tankala, A. L. G. Carter, Nufern (United States)

We recently reported a compact monolithic 2000nm pulsed laser based on a optimized gain switched Tm-doped oscillator cavity. The laser operates with a single spatial mode output, ~1.5ns pulsewidth, 8kW peak power and >200mW average power at 20 kHz repetition rate. The gain-switched laser, consisting of a pair of fiber Bragg gratings and 0.5m of Thulium-doped single cladding fiber, and is core pumped by a high peak power pulsed 1550nm fiber laser. Compared with previous gain switched Tm-doped fiber lasers this system operates with pulse durations approaching 1nsec through optimization of the pump laser and the Tm-doped laser cavity. This compact pulsed 2um laser, to the authors' limited knowledge, represents the first Thulium doped fiber laser with 8kW peak power and several ns pulsewidth which is narrower than the previously reported tens of ns pulsewidth from gained switched Thulium fiber lasers. In this latest work we will amplify these ~1.5nsec pulses in a monolithic large mode area Tm-doped fiber amplifier to investigate the peak power scaling limits of such pulses at 2 m. Although work has been carried out on amplification of longer pulses (>10nsec) at in such Tm-doped fiber amplifiers, little has been done with pulses in the 1nsec region.

8039-18, Session 4

Generation and amplification of femtosecond laser pulses in Tm:fiber

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Femtosecond pulses operating near the 2-µm wavelength regime offer great potential for use, particularly in materials processing applications and nonlinear wavelength conversion. The extremely broad laser tuning range (~1.8 - 2.1 micron) and robustness of thulium doped fiber lasers make them extremely attractive sources of femtosecond laser pulses. We will present the results of recent experiments to generate and amplify femtosecond pulses in thulium doped silica fiber. The mode-locked Tm:fiber oscillator is a ring cavity and uses single-walled carbon nanotubes saturable absorbers to initiate mode-locking at 1.97 µm center wavelength. Soliton pulses are generated at 70 MHz repetition rate with pulses energies of ~40 pJ, ~8 nm (FWHM) spectral width, and a pulse duration of ~500 fs. In order to increase the peak power, we utilize a diode-pumped Tm:fiber-based Raman amplifier. The formation of the Raman soliton broadens the spectrum to as much as 40 nm (FWHM) and smoothes the spectrum, providing time-bandwidth limited pulses of <150 fs with pulse energy up to 9 nJ. By changing the pump power in the Raman amplifier the center wavelength can be tuned from ~1.97 - 2.15 micron. This system provides diffraction-limited beam quality with >60 kW peak power, and is an optimal seed source for chirped pulse amplification (CPA). Using the seed source described pulses were stretched in positive group velocity dispersion fiber to computed durations >40 ps. The stretched pulses were amplified in large mode area Tm:fiber to 120 nJ.

8039-19, Session 4

Atmospheric gas detection using broadband mid-IR thulium fiber-based sources

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Emirates); L. Shah, M. C. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The development of broadband, high-power, high-brightness light sources in the mid-IR is of critical need for applications such as trace gas detection. In particular, the "molecular fingerprint region" around 3-5 µm wavelength includes many strong molecular hydrocarbons absorption lines that are important for environmental monitoring. In order to measure a wide variety of gases, light sources must cover a wide range of wavelengths. This wavelength coverage is typically accomplished using many individual quantum cascade lasers (QCLs) or using tunable narrow linewidth mid-IR optical parametric oscillators (OPOs); however multiple absorptions can be characterized simultaneously using a broadband supercontinuum source.

The rapid development of compact, high-power thulium doped fiber lasers promises to provide new mid-IR supercontinuum systems. The extremely broad "eye-safe" tuning range of thulium doped fiber lasers (~1.8 - 2.1 µm) makes them appropriate for detection of atmospheric water vapor and CO2. We will report initial results using an ultrashort pulse laser system producing >500 mW average power with 9 nJ pulse energy and <150 fs pulse duration. The output spectrum is smooth with ~40 nm (FWHM) bandwidth, and the center wavelength can be tuned from ~1.97 - 2.15 µm, making it ideally suited for the detection of atmospheric CO2. We will also report recent experimental results using this laser as a pump source for mid-IR supercontinuum generation approaching the 3 - 5 µm wavelength region.

8039-20, Session 4

Compactly packaged, photonic crystal fiber-based MOPA delivering mJ-energy, MW-peak-power, near diffraction-limited, high spectral brightness ns pulses

F. Di Teodoro, Northrop Grumman Aerospace Systems (United States)

Pulse fiber lasers (PFLs) are desirable transmitters for field deployed sensors owing to favorable size and weight, low power consumption, and simple thermal management. Large-core photonic crystal fibers (PCFs) have also enabled high pulse energy, peak power, beam quality (BQ), and spectral brightness (SB) suitable for air-/space-based nanosecond-pulse ranging and imaging. However, packaged PFLs typically do not match pulse peak power, BQ and/or SB compared to laboratory demonstrations.

Here, we describe a PCF-based, compactly packaged, nanosecond-pulse master-oscillator/power-amplifier (MOPA) architecture achieving high pulse power, SB, and BQ.

The MOPA features a pulse-programmable diode master oscillator (MO), which seeds a multistage Yb-doped fiber amplifier terminated by a 100um-core, rod-type PCF. For compact packaging, the PCF is divided into four ~36cm-long segments laid out to ensure only minor efficiency penalty compared to a whole PCF of equal overall length. The MOPA can output a wide variety of actively triggered pulse formats since the MO pulse repetition frequency (PRF), pulse width, and pulse shape can be independently and continuously set via its control electronics. Moreover, the very large core rod-type PCF supports high peak power with minimal nonlinear parasitic.

As an example of performance, we generated ~1064nm-wavelength, linearly polarized, ~1.5ns pulses of energy/peak power > 2mJ/1.5MW at 10kHz pulse repetition frequency (PRF), with excellent BQ (M2 = 1.2), high SB (>85% pulse energy into a 0.06nm window) and electro-optic efficiency ~15%.

The laser system is enclosed within a < 15-liter volume package designed to withstand field-level shock, vibration, and thermal excursions.

8039-21, Session 5

Extremely high-brightness, kW-class fiber coupled diode lasers with wavelength stabilization

R. K. Huang, B. Chann, J. D. Glenn, TeraDiode, Inc. (United States)

High-power and high-brightness fiber-coupled direct diode lasers offer superior efficiency, price, reliability, and performance for both military and industrial applications. Defense applications include pumping high performance kW-class fiber and solid state lasers for directed energy. Industrial applications include materials processing, including keyhole welding and laser cutting. TeraDiode, Inc. has developed extremely high brightness fiber-coupled diode lasers using a novel beam combining and shaping technology pioneered at MIT Lincoln Laboratory. TeraDiode's ALPHA-19 laser is a fiber-coupled direct diode laser with a power level of 1,040 W from a 200 µm core diameter, 0.18 numerical aperture (NA) output fiber (90% power content). The kW-class ALPHA-19 laser, with a Beam Parameter Product (BPP) of 18 mm-mrad, has demonstrated substantially higher brightness than other previously demonstrated fiber coupled, direct diode lasers. Furthermore, the center wavelength of this laser is wavelength stabilized. ALPHA-19's center wavelength is 966 nm, and this wavelength remains approximately 966 nm over the entire power range of the laser up to full power. This wavelength stabilized property is essential for fiber and solid state laser pumping applications. We used the ALPHA-19 laser in demonstrations of keyhole welding of stainless steel sheet metal and sheet metal cutting of mild and stainless steel, with sheet thicknesses up to 4.7 mm. Extension of this direct-diode laser technology to higher performance will also be discussed. In addition, the direct diode technology is inherently wavelength selectable and can be applied to brightness scaling of diode lasers of any wavelength of interest for defense applications.

8039-22, Session 5

Progress in commercial wavelength-stabilized high-brightness diode sources suitable for pumping Yb-doped fiber lasers

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High power fiber lasers continue to place ever-increasing demands on the brightness of fiber-coupled diode laser pumps. For example, higher brightness pumps enable increased modal overlap with the gain media, allowing the use of shorter fiber lengths to suppress nonlinearities. High brightness diode laser modules based on arrays of single emitters offer better brightness, improved reliability, and lower cost over equivalent bar-based solutions. To achieve low quantum defect, pumping of Yb-doped fiber gain media at 976 nm is desirable. However, this absorption feature is relatively narrow, resulting in a requirement for strict temperature control of the diode pump module to achieve optimal absorption. We report on the performance of a 100 W, 105µm, 0.17 NA (filled) fiber-coupled module operating at 976 nm. Volume holographic (Bragg) gratings are used to stabilize the emission spectrum to a 0.2 nm linewidth and wavelength-temperature coefficient below 0.01nm/°C with virtually no penalty to the operating power or efficiency of the device. The typical fiber coupling efficiency for this design is >90%, enabling a rated operating efficiency of ~50%, the highest reported for a 100W/100µm-class diode pump module (wavelength stabilized or otherwise). An ongoing lifetest of five modules has passed 2,500 hours with no failures observed to date; results from environmental testing will also be presented.

Return to Contents

8039-23, Session 5

Diode laser beam combining for directed energy applications

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High power diode lasers (HPDLs) have emerged as highly reliable and powerful sources of optical radiation with the highest electrical-to-optical conversion efficiencies, as compared to the alternative laser types. Incoherent beam combining of several HPDL emitters using micro-optics components has been demonstrated as a cost-effective approach for producing high power output beams from small-sized laser packages.

In spite of lower cost, smaller size, and higher output power and reliability, the relatively poor output beam spatial characteristics of HPDL are the limiting factors in a broader adoption of HPDL technology in several directed energy applications.

In this paper, we discuss recent developments in HPDL spectral and spatial beam combining that result in the output beam characteristics suitable for directed energy application. The beam combining is often associated with the additional shaping of the output beam that is tailored to a specific directed energy application which the laser is intended for, including IRCM techniques or remote spectroscopy. We provide some beam combining and shaping results that, in spite of low beam quality of the individual HPDL emitters, produce highly directional beams with low far field divergences.

Some of the beam combining and shaping approaches employ a combination of free-space optics, micro-optics lenses, and lens arrays that are matched to lithographically fabricated diode laser waveguides. Optical design optimization for packaging and integration reduces the output beam distortions caused by the packaging imperfections, such as post-bonding shifts and lens-induced aberrations, as well as environmental conditions.

We show that both spectral and spatial beam combining techniques may complement each other to produce high power low divergence HPDL output beams with increased far field power density required in directed energy applications.

8039-24, Session 5

Passive coherent beam combining of fiber lasers using volume Bragg gratings

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Compact narrow-linewidth high-power lasers with good beam quality are desired for a great number of applications. Even kW level output powers achievable from single large mode area (LMA) fiber lasers are not sufficient for many applications, making beam combining techniques a promising tool. Passive coherent beam combining (CBC) using volume Bragg gratings (VBGs) in photo-thermo-refractive (PTR) glass is presented.

Two identical volume Bragg gratings are symmetrically recorded in the same PTR glass. Using this multiplexed VBG (MVBG), highly efficient combining of two mutually coherent beams is experimentally demonstrated.. A two-channel coherently-locked Yb-doped fiber laser system at tens of watt power levels with narrow linewidth and near diffraction-limited beam quality is demonstrated using this approach. In the presented experiment, the two MVBGs have a FWHM of 120 pm and are symmetrically recorded at an angle of 3.3o in the PTR glass. The output from the two fiber lasers is incident at the degenerate Bragg angles for the two gratings, and overlap along its common bisector upon diffraction. Interference at the grating and common feedback from the bisector arm locks the fiber lasers to common modes and ensures mutually coherent operation. Methods for scaling this technique to multi-kW output power will be discussed.

8039-25, Session 6

Oxide glasses for mid-infrared lasers

B. D. Richards, A. Jha, G. Jose, Univ. of Leeds (United Kingdom); X. Jiang, Max-Planck-Institut für die Physik des Lichts (Germany); M. Dubinskii, U.S. Army Research Lab. (United States)

We present an overview of rare-earth doped heavy metal oxide and oxy-fluoride glasses which show promise as host materials for lasers operating in the 2.5-4.5 µm spectral region for medical, military and sensing applications. By engineering glass composition and purity, tellurite and germanate glasses can support transmission up to around 5 µm and can have favourable thermal, mechanical and environmental stability compared to fluoride glasses. We discuss techniques for glass purification and water removal, and techniques for modifying the phonon structure of the glass for enhanced infrared transmission. By comparing the material properties of the glass, and spectroscopic performance of selected rare-earth dopant ions we can identify promising compositions for fibre and bulk lasers in the mid-infrared. To the authors' knowledge, fluorescence has never been reported in an oxide glass beyond ~2.2 µm and we report initial fluorescence measurements from rare-earth doped heavy metal oxide glasses at wavelengths greater than 2.5 µm. Tellurite glass has recently been demonstrated to be a suitable host material for efficient and compact lasers in the ~2 µm spectral region in fibre and bulk form and the next challenge is to extend the operating range further into the infrared red where silica fibre is not sufficiently transparent and provide an alternative to fluoride glass and fibre.

8039-26, Session 6

Integrated multispectral high-power laser platform for defense and security applications

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Quantum cascade lasers, an emerging electrically pumped semiconductor laser technology, are rapidly becoming the preferred MWIR laser source for many defense and homeland security applications due to their small size, high output power and wallplug efficiency, and high reliability. In the spectral region of prime importance for high power applications, namely between roughly 3.8 µm and 5 µm, QCLs with room temperature continuous wave (CW/RT) output power exceeding 2W are now commercially available.

However, for many applications, necessary spectral coverage exceeds the capabilities of any single laser device. Therefore, there exists a significant need for multispectral laser sources. In this presentation, we describe our new multispectral laser platform incorporating QCLs and other lasers. The present platform provides watt-level outputs near 2.0 µm, 4.0 µm, and 4.6 µm in CW/RT mode. Light from all three lasers is spectrally combined into a single output beam with excellent beam quality - a task made notably easier by employing only one high performance single spatial mode laser device per spectral band. The laser head is compact (11 by 10 by 8 inches), and air-cooled. Air-cooling is a significant benefit for the majority of fieldable applications that cannot tolerate water-cooling, or much less cryogenic cooling. Our rugged and reliable, multispectral laser platform is already finding acceptance at system level.

8039-27, Session 6

Recent advances in high-power quantum cascade laser systems

E. B. Takeuchi, T. Day, B. Chapman, M. B. Pushkarsky, Daylight Solutions Inc. (United States)

Multi-Watt, multi-wavelength quantum cascade laser (QCL) systems have been manufactured and tested against harsh military environmental requirements for aerospace 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. At the same time, portable, battery operated Thermal Laser Pointers have been rapidly advanced and field tested with multi-Watt output. Daylight will review the state-of-the-art in high power QCL-based laser systems, and their performance across several Defense and Homeland Security applications.

8039-28, Session 6

Power scaling of diode-pumped 2.7-μm Er3+-doped Y2O3 ceramic laser

T. Sanamyan, M. Dubinskii, U.S. Army Research Lab. (United States)

Recently we demonstrated a quantum defect limited ~2.7-um 4I11/2 -> 4I13/2 laser operation of an Er3+:Y2O3 ceramic resonantly diode-pumped at 974 nm, which corresponds to a 4I15/2 -> 4I11/2 absorption. The Er3+:Y2O3 material has been identified as the most suitable for 4I11/2 -> 4I13/2 laser operation because it has one of the lowest maximum phonon energies among the oxide laser hosts, 591 cm-1 (6 phonons per energy gap DE = 3500 cm-1). Here we report the latest results of power scaling, to power levels over 10 W CW, of the Er3+:Y2O3 ceramic laser with resonant diode pumping into upper laser manifold 4I11/2. This is, to the best of our knowledge, the highest CW power ever reported for diode pumped lasers emitting in the ~3-um spectral domain.

8039-29, Session 6

Development of tellurite fibers for multiband mid-IR (2-5um) fiber laser source

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Mid-IR lasers based on frequency-conversion in nonlinear crystals have significant limitations in efficiency, power, simultaneous multi-band output, and reliability. Mid-IR super-continuum fiber-based broad spectral sources achieve limited spectral power density (<10mW/nm), and waste large fraction of their power due to atmospheric attenuation. Quantum-cascade semiconductor lasers, although promising, have limited power per laser, and several need to be combined for each band, and then for multi-band operation. Tellurite (TeO2-based) near-single-mode low-loss fibers for mid-IR (2-5um) region, have high Raman gain and large Raman-shifts, thus enabling a cascaded Raman fiber laser source for power-scalable mid-IR multi-band operation.

We report our ongoing work, where highly stable Tellurite glasses with low-loss (<0.24dB/m) in the mid-IR region up to 4.3um, with high Raman gain (~29X silica) and large Raman frequency shift (~1.8X that of silica), have been demonstrated. Multimode and near single-mode core-clad fibers, with low loss (<1.8dB/m) and good optical mode transmission have also been demonstrated. Initial assessment of optical damage susceptibility indicates multi-Watt power handling capability, and pulsed surface damage exceeding 1GW/cm2. Commercially available fiber-optic cleavers/ polisher and fusion-splicer can be used with splice loss <0.25dB, indicating good mechanical robustness. Direct-writing of fiber-Bragg-gratings using femtosecond laser machining is also demonstrated. An all-fiber Raman laser model indicates feasibility of multi-Watt operation per mid-IR band when pumped with commercial 2-um fiber laser source. Ongoing progress on fiber Raman frequency conversion, material issues and further improvement of Tellurite fibers, will also be presented.

8039-30, Session 7

Submicrometer-grained highly transparent sesquioxide ceramics: synthesis, processing, and properties

J. Ballato, Clemson Univ. (United States); K. Serivalsatit, Clemson Univ. (United States) and Chulalongkorn Univ. (Thailand)

Transparent sesquioxide ceramics, i.e. Y2O3, Sc2O3, and Lu2O3, are being developed as alternative to single crystals for high-power solid-state laser systems. In this work, we present the synthesis of these sesquioxide nanopowders by precipitation techniques. The subsequent processing of these nanopowders into submicrometer-grained transparent ceramics was accomplished by modifying the two-step sintering approach. These transparent ceramics exhibited equivalent transparency to that of the single crystal in the near-infrared spectral. The microhardness and fracture toughness of the modified two-step sintered ceramic exceeded those of conventionally sintered ceramic by 25% and 70%, respectively.

8039-31, Session 7

Development of ceramic fibers for high-energy lasers

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Polycrystalline ceramics offer a number of advantages relative to single crystal materials such as lower processing temperatures, improved mechanical properties, and higher doping levels with more uniform distribution of dopants for improved laser performance. Ceramic YAG (Y3Al5O12) and rare earth sesquioxide (RE2O3) fibers promise to enable a number of high power laser devices via high thermal conductivity and higher allowable dopant concentration; however, these materials are not available as fine diameter optical-quality fibers. Powder processing approaches for laser quality polycrystalline ceramic fibers are in development at AFRL. Current processing techniques will be reviewed. The effects of a number of processing variables on the resulting fibers as well as preliminary optical characterization will also be presented.

8039-32, Session 7

Spectroscopy and laser potential of transition metal doped Cd(1-x)MnxTe for MWIR applications

T. Sanamyan, M. Dubinskii, U.S. Army Research Lab. (United States); W. Palosz, J. Kim, S. B. Trivedi, Brimrose Corp. of America (United States)

Tunable lasers in the MWIR are of great utility for IRCM applications. Despite recent successes with OPO-based tunable MWIR sources (frequency converters) there is still a pressing need in efficient laser sources directly tunable in MWIR. Cr2+- and Fe2+-doped low-phonon laser materials are the most promising for this kind of application. We will present the results of our studies on laser spectroscopy of Chromium doped and Chromium-Iron and Cobalt-Iron co-doped single crystals of Cd(1-x)MnxTe. The single crystals of Cd(1-x)MnxTe are grown from melt by Bridgman technique. Fluorescence lifetimes were measured in the temperature range of 10K to 300K. Based on the above studies and our recent success in crystal growth an approach to high power MWIR lasers operating at room temperature is developed and discussed.

8039-33, Session 7

Characterization of dysprosium for visible solid state lasers

S. P. O'Connor, S. R. Bowman, N. J. Condon, U.S. Naval Research Lab. (United States)

Solid-state lasers operating in the visible have always been challenging. The recent advent of deep blue gallium nitride laser diodes open up the possibility of direct visible lasers. Toward this goal, we have investigated the optical properties of trivalent dysprosium. Strong blue and yellow transitions occur from this ion whenever the 4F9/2 state is excited. We have conducted detailed studies of the emission properties of these transitions in both Dy3+ doped YAG and YLF crystals. An array of blue and UV pump source were employed in this study. Cryogenic fluorescent and absorption spectra were analyzed to determine the Dy3+ energy structure. Emission cross sections were computed and compared with theoretical and experimental lifetimes. These experiments reveal evidence of a cross-relaxation process; 4F9/2 + 6H15/2 => 6H5/2 + 6H5/2. This process is significant in YAG for Dy3+ concentrations above 1E20 ions/cc. Since the 6H levels are all silent due to multi-phonon quenching, calorimetry was used to quantify the non-radiative losses and fluorescence efficiency. Evidence of additional cross relaxation processes were observed for UV excitation at 351nm. In this paper we will review our experiments and analysis as well as the implication of these results for a GaN pumped dysprosium laser.

8039-34, Session 7

Performance comparison of SCHOTT laser glasses

M. J. Davis, J. Hayden, SCHOTT North America, Inc. (United States)

Laser glasses have been around for nearly 40 years and remain a commercially viable product. Laser designers have a wide range of glasses to choose from, and include glasses with particularly high emission cross-sections and low non-linear indexes, whereas other glasses have been designed to have superior thermo-mechanical characteristics. As one would expect, laser output under comparable pumping levels also varies among such a wide suite of glasses. However, glass-to-glass performance comparisons are generally lacking. This study will present laser output results for a range of SCHOTT laser glasses using identical laser-diode pumping of small slabs under conditions of relatively low input power and minimal thermal lensing. The cavity consisted of a planar dichroic input mirror (AR at 808 nm; HR at 1054 nm) and a spherical output coupler mirror (ROC = 300 mm; various HR values at 1054 nm). Uncoated samples were placed at Brewster angle in a 60 mm-long laser cavity.

Nd-doped catalog laser glasses were the focus in this particular study, and included SCHOTT LG-680, LG-750, LG-760, LG-770, APG-1, and APG-2; all but the first, a silicate, are phosphate glasses. Nominal Nd3+ doping was approximately 4 x 1020 ions/cm3. Results will be presented that compare the measured values of laser output to estimates based on catalog spectroscopic data (e.g., lifetime, emission cross-section). Future work will focus on various aspects of thermal lensing, a feature common to all laser materials.

8039-35, Session 7

Low-noise single frequency all phosphate fiber laser

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The noise power spectrum of solid-state lasers - including fiber lasers - exhibits a characteristic peak at the relaxation oscillation frequency. The tails associated with this peak extend to neighboring spectral ranges and may increase the noise level above acceptable limits in applications using weak signals. One of the key factors to reduce the relative intensity noise (RIN) amplitude is a low loss laser resonator. We describe a method to ultimately reduce the intensity noise in single frequency phosphate fiber lasers by minimizing intra-cavity losses caused by fusion splices between fibers made of different materials. Conventional fiber Bragg gratings written in silica fibers have been replaced with gratings written in phosphate glass fibers. The quality of the intra-cavity fusion splice has been improved due to material similarity. All-phosphate fiber laser devices have been built and tested utilizing the new gratings. The results show relative intensity noise amplitudes that are very similar to those of conventionally fabricated devices. Challenges in the grating writing process are currently preventing the new devices from surpassing their commercial counterparts in terms of performance. However, this type of all phosphate glass fiber laser may ultimately lead to a new generation of commercial single frequency fiber lasers with improved intensity noise performance.

8039-36, Session 7

Development of Er-doped photonic crystal fiber for high energy laser applications

E. J. Friebele, C. G. Askins, U.S. Naval Research Lab. (United States); C. G. Carlson, U.S. Air Force Academy (United States); M. Dubinskii, J. Zhang, U.S. Army Research Lab. (United States); B. G. Ward, U.S. Air Force Academy (United States)

We report progress in the development an Er-doped PCF for high energy laser applications. The goal of this work is to design and fabricate a LMA 60/400 m air-clad PCF that will be resonantly cladding-pumped for efficiency and will have a high quality output for beam combining. The 12-cell core is triangular to better confine the LP01 mode when the fiber is bent while enabling the LP11 mode to escape the core. PCF design software has been significantly upgraded and now includes SBS modeling and a user-friendly GUI. Preforms for core rods have been made by MCVD and solution doping, and we have obtained Er concentrations >100 dB/m without clustering as evidenced by fluorescent lifetimes of ~10 msec; the background losses of these fibers are ~0.05 dB/m. We will discuss how these results were obtained as well as analysis results such as spatial profiling of Er concentration and lifetime across the core. For the PCF, n of the core must be less than or equal to that of silica; we will report how this was achieved by fluorine doping at several stages of the preform fabrication process. Stacking, bundling and consolidation of the PCF preform is another step that has required significant development, along with obtaining fiber draw parameters to maintain the regularity and geometry of the PCF preform into the fiber. Finally, we report the results of laser characterizations of the fibers.

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8039-41, Poster Session

Ultrafast bandgap photonics applications: IRCM and laser VLO

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Ultra-fast laser is able to change semiconductor optical state: to bleach it and to inflict temporal changes in semiconductor absorptivity, transmittance and polarization characteristics. Such changes in semiconductor optical characteristics depend on the bandgap, therefore its phenomenology is based on Ultrafast Bandgap Photonics. Phenomena of Ultrafast bandgap photonics are time-dependent and the optical effects are reversible with the rate that is from one side defined by recombination rate and from the other side, for a photodetector, is limited by detector rising time. Ultrafast Bandgap Photonics effects may temporally alter photodetector's fundamental characteristics - responsivity and detectivity as well as its response time and spectral bandwidth - all of these may happen without changes in photodetector electrical response. The last effect opens unlimited applications of Ultrafast Bandgap Photonics in Infrared Directional Countermeasures as well as in building up very low observable active applications based on lasers. In this paper we discuss some foundations of ultra-fast bandgap photonics applications in IRCM as well as in laser Low Observables.

8039-42, Poster Session

Spectral beam combining using superimposed reflective volume Bragg grating

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It is an effective approach to get high power laser output by spectral beam combining (SBC) technologies. Reflective volume Bragg grating is a common combining element for high density SBC. The output power of SBC increases with the number of wavelength channels. Increasing the number of wavelength channels is an effective approach to obtain high power SBC laser output. However, increasing the number of wavelength channels makes the total length of the SBC system very long, and there might be not enough number of lasers which emit at different center wavelength for achieving high power SBC output. Moreover, the total bandwidth available for SBC is typically determined by the application requirements. Increasing the number of wavelength channels in a given spectral bandwidth means narrowing the channel spectral separation. For some channel's wavelength, it even can not be emitted by the lasers. In this paper, a simple setup for SBC based on the superimposed reflective volume Bragg grating which containing multiplex phase grating in a single volume holographic element is presented to solve those problems. Two structure models of the superimposed reflective volume Bragg grating - the same grating period but with different slanting angle structure model and the different grating period structure model are analyzed by using the coupled-wave theory, and their applications for SBC system are discussed. The results show that the superimposed reflective volume Bragg grating could combine multiple lasers into a single beam by a single combining element with high combining efficiency, and it has the potential for achieving high power laser output.

8039-43, Poster Session

Generalized active mode locking due to amplitude modulation in a ultra-short pulse laser using maple

D. E. Sierra, Univ. EAFIT (Colombia)

In the last decade the ultra-short pulse lasers are no longer an exclusive element for physics laboratory usage, nowadays many applications require its usage turning into an indispensable need in different disciplines such as: Chemistry, Biology, Engineering, Medicine, ophthalmology, astronomy, among others. Some possible applications as: Ultrafast Excite-Probe for DNA, Ultrafast spectroscopy for control of chemical reactions, two photons microscopy for imaging technologies. To achieve this applications the deep comprehension of the physical phenomena such as mode locking both active and passive is needed. With this aim is necessary the elaboration of mathematical models for its analyses, which could be solved numerically or analytically. In the present work we want to study the generalized active mode locking due to amplitude modulation in ultra-short pulse laser when the laser parameters such as: the net-gain, the modulation strength and the normalized parameter are considered as functions of time. Our models will be solved analytically using computer algebra software (CAS), in specific Maple, in terms of special functions such as: Whittaker, Kummer, Heun, Hermite and Laguerre. In all cases the laser pulse properties will be determined by the properties of the corresponding special functions properties. This proposal implies the determination of an algorithmic method to analyze and design new configurations of ultra-short pulse lasers exploiting the symbolic, numerical, graphic and programming capacities of Maple Software. A possible future trend of research consist in the application of computer algebra software in the study of passive mode-locking via the non linear Schrödinger equation, the non linear Landau-Ginzburg equation and the non linear Klein-Gordon equation. It is expected that these mathematical studies will lead to improved laser technologies for defense and security.

8039-44, Poster Session

Analysis of the performance of VCSELs in WDM

K. Xu, Univ. of California, Irvine (United States)

VCSELs can be modulated at very high speed. VCSELs operating in the visible spectrum are appropriate as source for plastic-fiber systems. VCSELs are often selected as sources in datacom networks operating at 850nm. Applications include the high-speed Gigabit Ethernet. These 850nm VCSELs can be operated up to 10Gb/s. Their low cost and high efficiency make them attractive in applications requiring large numbers of transmitter.

In this paper, we have evaluated the characteristics of a VCSEL emitting at 820nm. For using the bandwidth-length provided by advanced multimode (MM) fiber efficiently, we choose (wavelength division multiplexing) WDM as the multiplexing method, that is 820nm, 840nm, 860nm and 880nm. The spatial spectrum and power distribution at transmitters' output and at fiber's output are measured and discussed. To keep enough power being received by photo-detector, the coupling manner and its efficiency between fiber and receiver are discussed.

8039-46, Poster Session

High-energy microlaser and compact MOPA transmitter

B. K. Brickeen, J. Mosovsky, The Pennsylvania State Univ. Electro-Optics Ctr. (United States)

A compact micro-oscillator incorporating a dual-bounce, grazing incidence gain module with a folded resonator cavity is presented. The gain module, previously developed for Nd:YVO4, is embodied in highly doped ceramic Nd:YAG to generate improved Q-switch performance while maintaining localized pump absorption. The cavity design utilizes dove prism turning optics for increased ruggedness in a doubly folded optics path around the gain crystal. In this manner the intra-cavity mode is increased, for a more optimum overlap with the pump light volume produced by standard lensed laser diode bars, with a minimal increase to the physical dimensions of the oscillator. The overall hermetic package size for the micro-oscillator is 2.3 in3, with conductive cooling through the mounting face of the device. A modified CS-package diode mount is developed to facilitate the reduced size of the oscillator without sacrificing the ability to use a high-energy, side-pumping arrangement.

Output energy from this source is greater than 5 mJ per pulse with nanosecond pulse duration, significantly exceeding the pulse energy available from comparably sized microchip lasers. The oscillator is combined with a high gain, high energy extraction VHGM amplifier to generate a transmitter source on the order of 50 mJ. Cooling for the amplifier module is also a conductive path through the base of the package. Both devices are mounted on opposite sides of a phase-change cooling reservoir to enable self-contained, burst-mode operation. Beam shaping of the oscillator output, in preparation for injection into the amplifier, is contained in a small cut-away path on the reservoir side.

8039-47, Poster Session

Modeling of first-order distributed feedback semiconductor lasers

M. Shih, P. S. Zory, Univ. of Florida (United States)

This work demonstrates the multi-parameter modeling process of calculating coupling coefficients of first order distributed feedback semiconductor lasers, operating on transverse electric modes in the near-infrared and mid-infrared spectrum range. Optical waveguides are common structures in semiconductor lasers. Our waveguide structure has dielectric layers and a metal grating layer. The interface between the metal layer and its neighboring dielectric layer has sinusoidal corrugated geometry. This periodic corrugation provides the propagating waves with the condition of having first- order backward coupling. Coupling coefficients are important parameters about analyzing the performance of lasers. To calculate coupling coefficients of lasers, a mathematical model is constructed by the method of Floquet-Bloch Formalism. Another method of ray optics technique is used to calculate the coupling coefficients, which are compared with the coupling coefficients obtained from the Floquet-Bloch Formalism. This model shows the coupling coefficient will be larger if the corrugation depth at the interface is larger. The coupling coefficient will be larger if the dielectric active thickness and buffer layer thickness is smaller. Besides, this model can consider the optical properties of metals. The metal of gold is considered to be an approximate to a non-lossy or perfect metal. The coupling coefficient of a waveguide with gold gratings is close to that of a waveguide with perfect metal. If the metal grating material is lossier, the coupling coefficient will become smaller. Numerical results show these two methods have good agreements with each other. Physical interpretation and discussion are proposed to support mathematical model results.

8039-37, Session 8

Multifunction laser source for ground and airborne applications

B. Crépy, CILAS (France)

Multiple ground and airborne vehicles could share common and multifunctional laser modules. The host system constraints and requirements have similarities making a laser modular concept interesting. Among the desired functions, the core ones are the designation and the rangefinding capabilities. A diode pumped laser source at 1µm with a switchable OPO stage for wavelength conversion fully satisfies the designation and rangefinding tasks.

Over the last years, CILAS has developed the key technologies for the improvement of the main system parameters with the imperative constraints to be International Traffic in Arm Regulations Free (ITAR Free). Particularly, this novel architecture avoids thermo electric cooler (TEC) generally used to stabilise the wavelength of the laser diode pump source within the entire operational thermal range.

8039-38, Session 8

Laser sources for Raman spectroscopy

J. P. Kilmer, A. Iadevaia, Y. Yin, Photonics Industries International, Inc. (United States)

While regular or conventional Raman spectroscopy can use fixed wavelength cw lasers, advanced Raman spectroscopic techniques such as Stimulated Raman, Surface Enhanced Raman spectroscopy (SERS) and Raman Imaging typically need pulsed lasers. These lasers provide the necessary energy to do these studies. In addition, pulsed lasers are beneficial for the following techniques: Time Resolved Raman (TRR), Resonance Raman, or non linear Raman techniques, such as Coherent anti-Stokes Raman spectroscopy (CARS). Here the naturally narrower linewidth of a ns pulse width laser is advantageous to an ultrafast pulsed laser.

In this paper, we report on the development of a compact, highly efficient, high power all-solid-state Ti:Sapphire laser producing nanosecond pulses at kHz repetition rates with a tunable output wavelength from ~1 microns to ~200 nm and pulse energies up to 1 mJ. The narrow bandwidth of this laser (<0.1cm-1) is ideally suited for applications such as LIF measurement of OH free-radicals concentrations, atmospheric LIDAR and Raman spectroscopy.

New KBBF and RBBF deep ultraviolet (DUV) crystals are now available that enable direct doubling of the SHG output of these tunable Ti:Sa lasers to directly achieve wavelengths as short as 175nm without the need to generate the 3rd and utilizing frequency mixing. This results in a highly efficient output in the DUV, improving the signal to noise ratios in previously difficult wavelength regions. We have recently achieved a few mW of power at 193nm with such direct doubling crystals.

8039-39, Session 8

Liquid metal-cooled heat sink for advanced high-power laser diodes

J. Vetrovec, Aqwest, LLC (United States); J. Junghans, Northrop Grumman Cutting Edge Optronics (United States)

We have previously introduced an innovative active heat sink (AHS) for high-power laser diodes offering unparalleled capacity in high-heat flux handling and temperature control [1]. The AHS employs convective heat transfer by a liquid metal flowing at high speed inside a miniature sealed flow loop. The liquid metal receives waste heat at a high flux, transports it by forced convection, and rejects it at a much lower heat flux. Coolant flow in the loop is maintained electromagnetically without any moving parts. AHS can handle a heat load of several hundred watts at a heat flux over 1,000 W/cm2 with a thermal resistance as low as 0.1 °C/W. AHS thermal conductance can be electronically adjusted, allowing for precise control of diode temperature and the diode light wavelength. In particular, when pumping solid-state or alkaline vapor lasers, diode wavelength can be precisely tuned to the absorption features of the laser gain medium.

This paper presents the active heat sink theory, scaling laws, model predictions, and data from testing at high heat flux and high heat loads.
This work was in-part funded by the National Science Foundation and by the US Air Force.

1. J. Vetrovec and R. Feeler, “Progress in the Development of Active Heat Sink for High-Power Laser Diodes,” SPIE vol. 7583-19 (2010)

8039-40, Session 8

Laser damage testing for ion beam sputtered optical coatings at 2um and 2.94um

C. S. Wood, O. Lyngnes, Precision Photonics Corp. (United States)

High power lasers are moving into the mid-wave infrared for a variety of applications, and robust optical components must keep pace. Ion Beam Sputtering is the preferred deposition method for high laser damage and environmentally robust coatings in the visible and near-infrared spectral regions, and this work demonstrates its extension to longer wavelengths. The 2um and 2.94um regions are receiving a great deal of interest and already produce very high powers/fluences. In this work, PPC will present laser damage testing and absorption measurements for optical coatings in both of these popular wavelength regions. Results will include a variety of substrates, ns-pulsed damage testing, QCW damage testing, absorption, and scatter, and will be compared to other coating deposition methods where available. Results will also include a comparison of the ISO 11254 damage protocol and the 'NIF' damage protocol.

Conference 8040: Active and Passive Signatures II

Wednesday-Thursday 27-28 April 2011

Part of Proceedings of SPIE Vol. 8040 Active and Passive Signatures II

8040-01, Session 1

Status of active and passive signatures for detection and characterization of materials and activities of special interest

C. T. Hawley, National Signature Program (United States)

No abstract available

8040-02, Session 1

Composite signatures from airborne sensors

S. M. Anklam, SpecTIR, LLC (United States)

No abstract available

8040-03, Session 1

Acoustic signature analysis for underground anomalies

L. Solomon, L. Sim, U.S. Army Research Lab. (United States)

Analysis of phenomenology related to culvert inspection is critical when attempting to determine dimensions and type of underground anomaly. Previous research has proven that a single acoustic sensor is capable of detecting natural resonant frequencies of culverts and sewer pipes. These frequencies are directly related to dimensions and complexity of the specific culvert. Persistent monitoring of shifts in resonant frequencies allows one to determine the likelihood that an obstruction is blocking a culvert. Similarly, this research will use various acoustic sensors to exploit events associated with underground anomalies. Special emphasis will be placed on signature analysis as it relates to long-range sound propagation. These signatures can provide added information for geophysical studies and applications related to the discovery of underground anomalies.

8040-04, Session 1

2D signature for detection and identification of drugs

V. A. Trofimov, S. A. Varentsova, Lomonosov Moscow State Univ. (Russian Federation); C. Zhang, J. Shen, Q. Zhou, Y. Shi, Capital Normal Univ. (China)

The method of spectral dynamics analysis (SDA-method) is used for obtaining of 2D signature of drugs. This signature is used for the detection and identification of drugs by transmitted THz signal. We discuss an efficiency of SDA method for identification of pure drugs and of their mixture.

We consider the THz pulses with a few cycles. The pulse transmits as the drugs or their mixture. The question is: can we identify the drug in the mixture of substances with the similar spectra?

8040-05, Session 2

ALADDIN: signatures from uncued video

J. S. Garofolo, National Institute of Standards and Technology (United States)

No abstract available

8040-06, Session 2

Uncertainties of measures in speaker recognition evaluation

J. C. Wu, A. F. Martin, C. S. Greenberg, R. N. Kacker, National Institute of Standards and Technology (United States)

The National Institute of Standards and Technology (NIST) Speaker Recognition Evaluations (SRE) are an ongoing series of projects conducted by NIST. In the NIST SRE, speaker detection performance is measured using a detection cost function, which is defined as a weighted sum of probabilities of type I error and type II error. The sampling variability can result in measurement uncertainties of the detection cost function. Hence, while evaluating and comparing the performances of speaker recognition systems, the measurement uncertainties must be taken into account. In this article, the uncertainties of detection cost functions in terms of standard errors (SE) and confidence intervals are computed using the nonparametric two-sample bootstrap methods based on our extensive bootstrap variability studies on large datasets conducted before. The data independence is assumed because the bootstrap results of SEs matched very well with the analytical results of SEs using the Mann-Whitney statistic for independent and identically distributed samples if the metric of area under a receiver operating characteristic curve is employed. Examples are provided.

8040-07, Session 2

Advances in the design, development, and deployment of the U.S. Army Research Laboratory's Multimodal Signatures Database

K. W. Bennett, U.S. Army Research Lab. (United States); J. Robertson, Clearhaven Technologies LLC (United States)

Recent advances in the design, development, and deployment of U.S. Army Research Laboratory's Multimodal Signature Database creates a state of the art database system with web-based access through a web interface designed specifically for research and development. Tens of thousands of signatures and archived data products are currently available for researchers to support their algorithm development and refinement for sensors and other security systems. Each dataset is stored in HDF5 format for efficient modeling and storing of signatures and archived sensor data, ground truth, calibration information, algorithms, and other documentation. Archived HDF5 formatted data provides the basis for computational interoperability across a variety of computational tools including MATLAB, Octave and Python. The database has a web-based front-end with public and restricted access interfaces along with 24/7 availability and support. This paper describes the overall design of the system and the recent enhancements and future vision including the ability for researchers to share algorithms, data, and documentation in the cloud and providing an ability to run algorithms and software for testing and evaluation purposes remotely across multiple domains and computational tools. The paper will also describe in detail the HDF5 model and format for several multimodal sensor archived data products along with results from researchers who have successfully used the system.

8040-08, Session 2

Understanding and mitigating noise issues in magnetic sensors, resulting in improved signatures

G. Fischer, A. Edelstein, U.S. Army Research Lab. (United States)

The use of small, inexpensive, low-power, low-frequency, ultra-sensitive magnetic sensors to detect field perturbations between 1 nT and 1 pT in real world situations requires one to be aware of limitations imposed by magnetic noise sources. These noise sources can consist of man made signals, geomagnetic noise, and sensor noise. Acquisition and validation of usable magnetic signatures requires one to mitigate these noise sources. In this paper we discuss magnetic noise sources typically encountered as well as methodologies to circumvent or eliminate them. We will specifically focus on: sensor interactions due to differing modalities and proximity effects, the use of gradiometers to reduce geomagnetic noise, issues with rotation for vector magnetometers, thermal drift, and the mitigation of 1/f noise. Specific examples will be given to demonstrate enhancement of detection of magnetic signatures when geomagnetic noise and thermal drift are accounted for. We will also discuss the current state of a magnetic sensor system the MEMS Flux Concentrator, which mitigates 1/f noise.

8040-10, Session 3

Experimental signature studies in random and chaotic distributions in the atmosphere

C. O. Font, J. A. Duperre III, C. Gilbreath, D. Bonanno, E. Tarpara, U.S. Naval Research Lab. (United States)

No abstract available

8040-11, Session 3

Next generation signature-based hyperspectral detection: a challenge to atmospheric modelers

A. P. Schaum, B. J. Daniel, U.S. Naval Research Lab. (United States)

A new class of hyperspectral algorithms has been developed for detection based on a re-flectance signature. These promise performance levels superior to state-of-the-art meth-ods employed in real systems, by creating selective decision surfaces that can be sculpted to mitigate the common plague of ubiquitous outliers. These are commonly caused by sensor artifacts, but they can also be associated with any rare background constituents, especially manmade ones. The new methods therefore offer the best hope for solving the high-clutter urban detection problem, the ultimate test for hyperspectral algorithms. The new class of detectors is based on an affine target subspace model and a continuum fu-sion interpretation of the generalized likelihood ratio test. The latter is modified by mak-ing the log likelihood ratio depend linearly on the unknown target mean in the fusion process. This produces detection algorithms that drape the target subspace and exclude statistical outliers.

The challenge to atmospheric modelers is to create a method for predicting, from a given reflectance spectrum, a low-dimensional radiance subspace lying closer to the sensed tar-get spectrum than the target is to the whitened clutter mean. Three prototype approaches for doing this are discussed: one based on Healey's invariant subspaces, the "universal spectrum" principle employed in Bernstein's QUAC algorithm, and the virtual relative calibration method of Schaum and Priest.

8040-26, Session 3

Coherent uplink arraying techniques for next generation space communications and planetary radar systems

B. Geldzahler, NASA Headquarters (United States)

For several years, NASA has been pursuing demonstrations and development of coherent uplink arraying techniques for the next generation space communications and planetary radar systems. I shall describe the three methods of uplink arraying NASA has pursued all of which have been successful. Emergency spacecraft commanding would benefit from uplink arraying as would radar studies of Near Earth Objects and tracking of orbital debris. In addition radio science experiments would benefit with a 1000 times increase in signal to noise over current systems. I shall share a vision for going forward from laboratory demonstrations to the proposed implementation and deployment of a dedicated multi-purpose facility to infuse an amalgam of these methods into a system that enhances NASA's missions.

8040-12, Session 4

An optical fiber-based intruder detection sensor

X. Yu, Case Western Reserve Univ. (United States)

This paper describes the development of an intruder detection sensor based on a multi-mode optical fiber. The system uses an impulse laser and opto-electrical converter. Experimental observations indicate that the sensing system provides sensitive detection of the change of light transmittal due to the change of curvature of optical fiber. The curvature can be caused by external pressure or disturbance. Therefore, it can be used for high sensitivity, distributed intrusion sensing. The major advantages of the sensing system include: 1) the system is inexpensive by using common type of multi-mode communication cable; 2) the detection is distributive along the fiber.

8040-13, Session 4

The performance of all-optical switching based on fiber Bragg grating

Z. Zang, Kyushu Univ. (Japan); W. Yang, Harbin Institute of Technology (China)

All-optical switching plays an important role in through electronic technology to optical technology, because it is the key component in all-optical communication systems. So it is very useful for designing the high properties and low cost all-optical switches. In this Letter, the nonlinear response of all-optical switching in Yb3+-doped fiber Bragg grating was investigated and a numerical analysis of the switching property based on FBG is presented. The optical performances of the Fiber Bragg Gratings all-optical switches are studied under the case of the cross-phase modulation. The expressions of the threshold switching power under different detuning range are given. Different detuning and couple ratio to the threshold switching power and extinction ratio of devices is also studied. Figure 1 shows the switching characteristics curve of the transmitted and reflected light, for different values of the frequency detuning δ from the Bragg resonance under the condition of L=8. In Figure 1 (a), by increasing the pump power the stop band shifts to higher wavelengths, but only obtains a slow variation transmit ion about 80%~100%, there is no evident switching phenomenon.

In conclusion, the detuning δ and coupling are the important factors which determine the performance of switching. By optimizing the detuning δ and , the optimal switching conditions may be achieved.

8040-14, Session 5

Two-dimensional, active, resonance-Raman signatures of fresh and aged explosives, bacteria, and chemicals

J. Grun, R. Lunsford, U.S. Naval Research Lab. (United States); P. Kunapareddy, S. Nikitin, Research Support Instruments, Inc. (United States); D. B. Gillis, J. H. Bowles, U.S. Naval Research Lab. (United States); J. C. Gump, Naval Surface Warfare Ctr. Indian Head Div. (United States); L. I. Perlovsky, Air Force Research Lab. (United States)

We present two-dimensional, active, resonance-Raman signatures of fresh and aged explosives, bacteria, and a variety of environmental chemicals. We will discuss the distinct features of these signatures and present signatures that would be measured if these substances were measured alone or measured in a complex background that contained a few of these substances mixed together. We will also present results of different codes that attempt to identify the constituents of a complex sample from its two-dimensional resonance-Raman signature.

The two-dimensional signatures were obtained by illuminating the samples with a sequence of laser wavelengths between 210nm and 800 nm; a range which encompasses the resonant frequencies of cells, micro-organisms, cellular metabolites, and many chemicals; and measuring the resonance-Raman spectra of light scattered from the sample at each laser wavelength. The signatures obtained at each illumination wavelengths are then assembled into a single signature, such as the ones shown in Figure 1.

The work is supported by DTRA and ONR.

8040-15, Session 5

Spectral variations in HSI signatures of thin fabrics for detecting and tracking of dismounts

J. Herweg, Rochester Institute of Technology (United States) and Air Force Institute of Technology (United States); J. P. Kerekes, E. Ientilucci, Rochester Institute of Technology (United States); M. T. Eismann, Air Force Research Lab. (United States)

Several hyperspectral imaging (HSI) systems have been developed with the intent of utilizing spectral diversity in a scene to characterize the background and identify targets of interest. With the increased spectral information, targets much smaller than the spatial extent of a pixel, such as pedestrians, can be detected and identified. However, several challenges arise when employing HSI systems for use in the detecting and tracking of pedestrians. Most notably, the signature for the target of interest may or may not be immediately available to the system. The successful identification of sub-pixel targets with any degree of accuracy relies on a priori knowledge of the spectral signature for the targets of interest. Previous work has shown that even if a spectral signature for a pedestrian was acquired at the time of detection, as the pedestrian moved through a cluttered environment its spectral signature changes. This work extends the understanding of the induced spectral variation in human spectral signatures in cluttered environments. The goal of this work was to isolate the spectral reflectivity of highly transmissive targets independent of the background. Using a linear mixing model, the effects of reflective backing materials on the signature of a thin fabric are presented. Also, an issue with tracking a pedestrian from full illumination into the shadow is considered. Reflectance factor signatures were measured using target reflectivity measured both in the lab and in the field to assess spectral variability and detectability.

8040-16, Session 5

Spectral analysis algorithm for material detection from multispectral imagery

J. K. Racine, Defense Intelligence Agency (United States) and Booz Allen Hamilton Inc. (United States)

Material detection from multi-spectral imagery is critical to numerous geospatial applications. However, given the limited number of channels from various air & space-borne imaging sensors, coupled with varying illumination conditions, material-specific detection rules tend to generate large numbers of false positives. This paper will describe a novel approach that uses various band ratios (for example, [Blue + Green]/Red) to identify targets-of-interest, regardless of the illumination conditions and position of the sensor relative to the target. The approach uses a physics-based spectral model to calculate the observed channel-weighted radiance based on solar irradiance, atmospheric transmission, reflectivity of the target-of-interest and the spectral weighting functions of the sensor's channels. The observed channel-weighted radiance is then converted to the expected channel pixel value by the channel-specific conversion factor. With each channel's pixel values estimated, the algorithm goes through a process to find which band ratio values show the least amount of variance, despite varying irradiance spectra and atmospheric absorption. The band ratios with the least amount of variance are then used to identify the target-of-interest in an image file. To determine the expected false alarm rate, the same band ratios are evaluated against a library of background materials using the same calculation method for determining the target-of-interest's channel pixel values.

Testing of this approach against ground-truth imagery, with as few as four channels, has shown a high rate of success in identifying targets of interest, while maintaining low false alarm rates.

8040-17, Session 6

Quantification of constituents in areal and intimate binary mixtures of particulate materials

M. West, K. Manville, R. G. Resmini, MITRE Corp. (United States)

Investigation of accuracy and applicability of linear and non-linear mixture models to analyze the spectra of binary mixtures of particulates.

8040-18, Session 6

Changes in apparent emissivity as a function of viewing geometry

M. West, J. M. Grossmann, C. Deloye, MITRE Corp. (United States)

We observed that the emissivity of the concrete changed dramatically as a function of view angle. The leading hypothesis is that this phenomenon may be due to an effect similar to "shadow-hiding" where the large particles block the more emissive fine particles.

8040-19, Session 6

Complex soil electrical impedivity signatures

S. J. Ghionea, D. M. Hull, U.S. Army Research Lab. (United States)

Electrical resistivity (ER) techniques have been used for many applications in underground anomaly detection, such as archaeological exploration [1] and tunnel detection [2]. Electrical resistivity of both geological and man-made materials may be more generally described as impedivity, which can be complex-valued and can vary with frequency. Impedivity, like resistivity, is an intrinsic material property. The impedivity is related to impedance and is composed of a real part where conduction currents dominate and an imaginary part where displacement currents and dielectric effects dominate. These electrical conduction effects are examined to study their importance to underground detection techniques complementary to ER, such as ground penetrating radar (GPR) and electromagnetic induction (EMI) systems.

Measurements in dry desert soils have shown impedivity variations across the frequency range from 1 kHz to 1 MHz [3]. The complex impedivity of various soils are measured in-situ in field experiments using a custom-built soil measurement apparatus. The measurements are made using galvanic electrodes arranged in a Wenner array. Field measurements made in-situ are important for obtaining accurate results that may change once soil samples are extracted from their natural environment. Soil impedivity signatures on a variety of soils over the frequency band up to 1 MHz will be presented and the results discussed, with some focus on implications for GPR and EMI-based anomaly detection systems.

[1] G. Tsokas, P. Tsourlos, and N. Papadopoulos, “Electrical resistivity tomography: A flexible technique in solving problems of archaeological research,” Seeing the unseen: geophysics and landscape archaeology, CRC Press, 2009, pp. 83-104.

[2] L. Allen et al., Technologies for the Detection and Monitoring of Clandestine Underground Tunnels, Fall 2007 - Project 07-03, Global Innovation and Strategy Center, 2008.

[3] S. Ghionea and D. Hull, “In-situ measurement of soil impedivity,” Proceedings of the MSS BAMS meeting, 2010.

8040-20, Session 6

Crude oil and refined petroleum product detection on terrestrial substrates with airborne imaging spectroscopy

C. S. Allen, George Mason Univ. (United States); M. P. S. Krekeler, Miami Univ. (United States)

The Deepwater Horizon explosion and subsequent sinking produced the largest oil spill in U.S. history. While the incident occurred in the Gulf of Mexico, one of the most prominent portions of the response is mapping the extent to which oil has reached thousands of miles of shoreline. Yet, the most common method of detecting oil remains visual spotting from airframes, supplemented by panchromatic/multispectral aerial photography and satellite imagery. While this imagery provides a synoptic view, it is often unreliable.

Employing spectral libraries for material identification, imaging spectroscopy supplements traditional imaging techniques by providing more accurate petroleum detection and discrimination from water on terrestrial backgrounds. This effort applies a new hydrocarbon-substrate spectral library to airborne imaging spectroscopy data. The library includes four crude oils, five refined petroleum products, and water applied to ten common substrates. Both the crude oils and the refined products represent a wide range of volatilities. The substrates were selected for their ubiquity or the presence of absorption features that overlap hydrocarbon absorptions.

Using common material identification algorithms, the spectra were applied to SpecTIR data from the Hurricane Katrina disaster in 2005 as a proof-of-concept. This effort is the first application of this library to imaging spectroscopy data. Future efforts anticipate applying the same methods to imagery from the Deepwater Horizon incident.

8040-21, Session 6

Analyses of reflectance characteristics of selected plants

M. H. Kaszczuk, Z. Mierczyk, M. Zygmunt, W. Piotrowski, J. Mierczyk, Military Univ. of Technology (Poland)

The paper presents reflectance characteristics of plants. The objects of the research were the selected plants, taking the various levels of organization and structure into consideration, as well as the state of plant health and growth. Considering the various forms of plants construction and structure in the analyzed biological material we included both herbaceous plants, shrubs and trees. The research material was taken at the different stages of plant growth and phases of vegetation.

The values of reflectance were analyzed in the range of wavelengths from 0,2 to 2,5 µm. The values of reflectance for three wavelengths (λ1=850 nm, λ2=905 nm, λ3=1550 nm) were analyzed with particular emphasis. The sample tests were performed immediately after biological material taking and in the several 24-hour time intervals. The time intervals enabled the process of plants wilting and drying. The reflectance measurements were repeated until the moment of plant complete dried out. All measurements were performed with the use of the spectrometer Lambda 900 (Perkin Elmer) equipped with the 150 mm integrating sphere PELA1001 for the measurements of the hemispherical reflectance both of diffuse and specular type.

The obtained reflectance spectra were collected, compared and analyzed in terms of the values of reflectance for each wavelength from the given range. On the basis of the obtained results one calculated the values of signal ratios for the three selected wavelengths: 850/1550nm, 905/1550nm, and 850/905nm. The collected spectra and reflectance characteristics enabled the analyses of both results similarities and differences, which enabled the determination of the reflectance changes tendency associated with the typical processes occurring in plants.

The analyses of plants reflectance characteristics were made for the use of the laser system for identification of terrain elements and their physico-chemical properties.

8040-22, Session 7

Efficient RPG detection in noisy 3D image data

F. Pipitone, U.S. Naval Research Lab. (United States)

No abstract available

8040-23, Session 7

Developing 3D signatures using lidar technology

R. Mitchell, The Aerospace Corp. (United States)

The Signatures Support Program (SSP) leverages the full spectrum of signature-related activities (collections, processing, development, storage, maintenance, and dissemination) within the Department of Defense (DOD), the intelligence community (IC), other Federal agencies, and civil institutions. The purpose of this paper is to use Light Detecting and Ranging (Lidar) technology to generate 3D signatures to add to the signatures pool. Currently, the pool encompasses acoustic, seismic, radio frequency, infrared, radar, nuclear radiation, and electro-optical signatures but not Lidar. Lidar 3D point cloud objects can add to the data content and quality of the signatures database.

Return to Contents

8040-24, Session 7

On the discrimination of solid targets by their depolarization signatures for ladar applications to terrain mapping

X. Cao, Royal Military College of Canada (Canada); G. A. Roy, Defence Research and Development Canada (Canada); R. Bernier, Les Instruments Optiques du St-Laurent Inc. (Canada); G. Tremblay, S. Roy, C. Laflamme, Defence Research and Development Canada (Canada)

Ladar technology has long since established its advantages as a reliable method for automated Terrain Mapping. One still remaining important problem of this methodology though happens at data processing time. Ladars generate huge amounts of data referred to as ‘point clouds’. The very first task in data processing consists of segmenting the terrain image between ground and non ground data points. The standard processing methods all rely on some slope analysis technique. At the present moment, all these techniques still require interactive evaluation and manual editing of the results.

In this work, Ladar polarization is used in order to discrimate between solid targets by their polarization signatures. It is thought that the addition of this feature, over and above just range and intensity, could greatly help in the process wherein ground and non ground points are to be separated. Linear and circular polarizations measurements were performed on 9 different specimen in various conditions and at various wavelengths.

The results presented herein are a first validation of the fact that typical solid targets show a response to the Ladar sensor which conforms to the behavior predicted by the most recent polarimetric BDRF theories. Hence, their polarization signature is expected to be repeatable. The results presented herein also show that, to the extent that more than one wavelength is used, solid targets can be discriminated against each other by the use of their polarization signatures.

8040-25, Session 7

Stereoscopic signatures derived from spectroscopic dielectrometry

C. Gilbreath, U.S. Naval Research Lab. (United States); W. F. Brooks, Northrop Grumman Information Technology-TASC (United States); B. Bajramaj, U.S. Naval Research Lab. (United States); D. Aiken, EMCORE Corp. (United States)

No abstract available

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8041-01, Session 1

Rise of the HMD: the need to review our human factors guidelines

E. E. Geiselman, P. R. Havig, Air Force Research Lab. (United States)

Recent years have brought on a new breed of HMDs. They have high resolution, are daylight readable, and some even have color. While these are all welcomed advances to the field we must remember to review our history. Here we review some the of the research from years past that was done before these advances and discuss them so as to make sure the past is not forgotten and mistakes are not repeated.

8041-02, Session 1

Human-machine interface issues in the use of helmet-mounted displays in short conjugate simulators

J. E. Melzer, Rockwell Collins Optronics (United States)

With the introduction of helmet-mounted displays (HMD) in aviation applications comes the need to train pilots in simulators, preferably those that are low-cost, reconfigurable and transportable. Shorter and shorter distances between the trainee and the projected screen - perhaps as little as 1 or 2 meters - complicate the visual construct. Properly done, this can provide excellent training. Improperly done, this can cause eye strain and possibly negative training. This paper will concentrate on visual issues of vergence, focus and the implications for helmet fitting as they pertain to minimizing adverse physical effects to improve the training scenario.

8041-03, Session 1

How much camera separation should be used for the capture and presentation of 3D stereoscopic imagery on binocular HMDs?

J. P. McIntire, P. R. Havig, E. E. Geiselman, E. L. Heft, Air Force Research Lab. (United States)

Designers, researchers, and users of binocular stereoscopic head or helmet-mounted displays (HMDs) face the tricky issue of what imagery to present in their particular displays, and how to do so effectively. Stereoscopic imagery must often be created in-house with a 3D graphics program or from within a 3D virtual environment, or stereoscopic photos/videos must be carefully captured, perhaps for relaying to an operator in a teleoperative system. In such situations, the question arises as to what camera separation (real or virtual) is appropriate or desirable for end-users and operators. We review some of the relevant literature that has studied the question of stereo pair camera separation using desk-mounted or larger scale stereoscopic displays, and employ our findings to foreseeable HMD applications, including entertainment, teleoperation, information and scientific visualization, and command & control.

8041-04, Session 1

Preliminary experimental results from a dichoptic vision system

M. P. Browne, SA Photonics (United States); K. Moffitt, Human Factors Consultant (United States); D. G. Hopper, B. I. Fath, Air Force Research Lab. (United States)

Our everyday experience is of an expansive yet apparently detailed visual world. This combination supports both the situation awareness (SA) needed for target acquisition and the resolution needed for subsequent identification. Head-mounted displays compromise these factors by either having a large field of view (FOV) with a lower-quality image, or a small field of view with a higher-quality image. A dichoptic HMD vision system has the potential to provide both an expansive and highly detailed visual experience. This HMD configuration presents a large FOV, lower quality image to one eye and a small FOV, higher quality image to the other. The dichoptic approach relies on the observer selecting the high quality image where it is present in the FOV and utilizing the lower quality image and its wide FOV to increase SA. The feasibility of this HMD configuration in terms of supporting SA and detail vision while being acceptable to observers is not known. We conducted research comparing a benchtop dichoptic vision system (DiVS) to a reference binocular system (RBS) using both subjective ratings and a performance test. Subjective ratings were directed at questions involving image quality, viewing comfort and presence or immersion. The performance test required observers to scan the scene to locate a target and then make an identification. Response times were collected for each component of this task

8041-05, Session 1

Evaluation of anti-glare applications for a tactical-helmet-mounted display

J. Roll, N. Trew, M. Geis, P. R. Havig, Air Force Research Lab. (United States)

Monocular Head Mounted Displays (HMDs) provide warfighters with unprecedented amounts of information without negatively affecting situational awareness. The US Air Force recognizes their usefulness, and has included the Vuzix Tac Eye Lt HMD as part of a kit for ground-based, battlefield airmen. Although the HMD increases situational awareness, it also limits binocular vision when worn as designed, directly in front of the eye. To address this limitation, operators have chosen to wear it just above the cheek, angled up toward the eye. However, wearing the HMD in this position exposes the display to glare. Therefore, we tested several film and HMD hood applications for their effect on glare. The first experiment objectively examined the amount of light reflected off the display with each application in a controlled environment. This second experiment used human participants to subjectively evaluate display readability/legibility with each film and HMD hood covering under normal office lighting and under a simulated sunlight condition. In this novel test paradigm, participants had to correctly identify different icons on a map and different words on a white background. Our results indicate that though some applications do reduce glare, they do not significantly improve the HMD's readability/legibility compared with an uncovered screen. This suggests that these post-production modifications will not solve this problem and underscores the importance of employing a user-centered approach early in the design cycle to determine an operator's use-case before manufacturing an HMD for a particular user community.

Return to Contents

8041-06, Session 1

Virtual reality in a cave: limitations and the need for HMDs

P. R. Havig, J. P. McIntire, E. E. Geiselman, Air Force Research Lab. (United States)

In virtual reality (VR) circles a “cave” is a 3 - 6 sided box with displays on each side. It has for many years sufficed as the “immersive” portion of VR mostly due to the insufficient HMDs in the domain. However, current HMDs rival many caves and indeed are taking over. Here we discuss the pros and cons of this advent as well as human factors issues related to VR and the use of HMDs.

8041-07, Session 2

Sensor image augmentation to avoid saturation

K. Funabiki, Japan Aerospace Exploration Agency (Japan); T. Yoshida, NEC Corp. (Japan); K. Tawada, Shimadzu Corp. (Japan); H. Tsuda, Japan Aerospace Exploration Agency (Japan)

Although FLIR image on HUD or HMD is useful for night-time flight, selecting the best parameters of gain and contrast is sometimes troublesome. For example, higher gain setting can reveal the detail of a low temperature object, however, the setting also make other higher temperature objects “mostly-white”, then if there were many high temperature objects in the field of view, the whole FLIR image becomes mostly white. Consequently, if the image is on HMD or HUD, the pilot might hesitate to increase the brightness to avoid the “mostly-white” image.

An algorithm of image augmentation to avoid image saturation was invented. A result of flight experiment using HMD and FLIR camera showed the proposed method is effective in case of both sea and land are equally in the image.

8041-08, Session 2

Transfer alignment from a personal dead reckoning system to a handheld IMU

L. V. Ojeda, J. Borenstein, Univ. of Michigan (United States)

Some applications require the tracking of position and attitude of a hand-held instrument such as a video camera. This presents two challenges: pose estimation for the walking person and relative pose estimation for the handheld instrument.

The first challenge is met by our earlier-developed Personal Dead-Reckoning (PDR) system that uses a foot-mounted IMU to track the position and heading of a walking person inside buildings. Exploiting the rectilinear features of the building, the PDR system provides zero heading errors at steady state in walks of unlimited duration. However, the second challenge is harder to meet because the attitude of the instrument can change arbitrarily. Just adding an additional IMU provides dissatisfactory results because that IMU is subject to accelerometer and gyro drift, which grow into unbounded position and heading errors that cannot be corrected by the same method that works for the foot-mounted IMU.

In order to reduce the effects of drift and other errors in the hand-held IMU, we adopted a method known as Transfer Alignment (TA). Our TA formulation uses the accurate position updates from the PDR system to bound and correct positioning and heading errors of the hand-mounted IMU. TA takes advantage of the fact that the hand-held IMU will always be in near the foot and ultimately follows the same path. The TA error correction for attitude and position is performed by a Kalman filter (KF). We present results of TA applied to two handheld IMUs, a high-grade and a low-grade one.

8041-09, Session 2

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 2010 with the US Government, eMagin made additional improvements in OLED life and developed the first SXGA (1280 X 1024 triad pixels) OLED microdisplay. US Army RDECOM CERDEC NVESD conducted life and performance tests on these displays, publishing results at the 2007, 2008, 2009, and 2010 SPIE Defense and Security Symposia. Life and performance tests have continued through 2010, 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.

8041-10, Session 2

Spatial noise in microdisplays for near to eye applications

D. A. Fellowes, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Spatial noise in imaging systems has been characterized and its impact on image quality metrics addressed primarily with respect to the introduction of this noise at the sensor component. While detrimental, sensor spatial noise is often mitigated through the use of non-uniformity correction algorithms. However, sensor fixed pattern noise is not the only source of fixed pattern noise in an imaging system. Display fixed pattern noise cannot be easily mitigated in processing and, therefore, must be addressed. In this paper, a thorough examination of the amount and the effect of display fixed pattern noise is presented. The specific manifestation of display fixed pattern noise is dependent upon the display technology. The spatial noise characteristics are reported for both transmissive and emissive microdisplays. Utilizing a calibrated 50 MegaPixel camera, US Army RDECOM CERDEC NVESD has developed a micro-display spatial noise data collection capability. Noise and signal power spectra were measured for varying signal amplitudes and used to determine the noise equivalent drive difference (NEDD) of the display as a function of spatial frequency analogous to the noise equivalent temperature difference (NETD) of a thermal sensor. The statistical method of computing the kurtosis of the luminance values of display pixels was used to describe the display operability analogous to the focal plane array operability parameter. The goal of this study is to establish a set of display noise metrics to aid in system level performance modeling in addition to minimizing display cost driven by realistic performance requirements.

8041-11, Session 3

Binocular Scorpion helmet-mounted display

R. Atac, M. Edel, Gentex Corp. (United States)

Gentex Visionix has tested a prototype for a binocular version of its Scorpion HMD. Scorpion uses a 2mm thick transmissive Light Optical

Element display that is fully compatible with night vision goggles. The binocular configuration was found to be comfortable to use and easy to harmonize, due to the low distortion and good contrast of the displays. Sub-pixel drawing also contributes by reducing image differences resulting from the displays being mounted diagonally at opposite angles. Head-borne weight and CG in the two-display system are still excellent, and the pilot's field of regard is not significantly reduced by the additional display. This paper describes Binocular Scorpion from a human factors, implementation and engineering perspective.

8041-12, Session 3

Wide field of view digital night vision head-mounted display

M. P. Browne, SA Photonics (United States)

SA Photonics has developed (with support from the Air Force Research Laboratory, the US Army and Vision Systems International) an innovative wide field of view digital night vision head mounted display (HMD). This HMD has an 80 degree field of view to greatly improve operator situational awareness. By creating an all-digital system, we provide the capability to enhance and record night vision imagery, overlay symbology, and inset video from remote sensors, either mounted on the aircraft or on Unmanned Air Vehicles (UAVs). This HMD has been designed with maximum pilot utility in mind, and is easily stowable without impacting center of gravity or maneuverability of the pilot's head within the cockpit. Because the sensors are digital, they can be located right above the pilot's eyes removing any hyperstereopsis.

We have completed the design of our digital wide field of view HMD. Results of our work will be presented, along with design tradeoffs and future system improvements.

8041-13, Session 3

Full-color, see-through, daylight-readable, goggle-mounted display

C. D. DeJong, Microvision, Inc. (United States)

A Compact See-Though, Full-Color, Daylight Readable Eyewear Display

See-through near-to-eye displays offer an opportunity to present visual information to an individual. The information presented can be used to augment the world the user is seeing. Microvision has developed a see-through, full-color, daylight-readable, monocular display in a goggle form factor. The image source for the display is an Integrated Photonics Module (IPM) that uses modulated red, green, and blue lasers reflecting off a MEMS based bi-axial scanning mirror to create an image. This image is relayed to the eye through a pupil-expanding substrate-guiding optic. The low étendu laser-based display engine is an excellent match for the substrate guided optic for presenting the user with an infinite conjugate image. The paper discusses design considerations and performance characteristics of the eyewear display.

8041-14, Session 3

Development of a dichoptic foveal/peripheral head-mounted display with partial binocular overlap

D. R. Tyczka, M. J. Chatten, J. B. Chatten, Chatten Associates, Inc. (United States); J. O. Merritt, The Merrit Goup (United States); H. L. Task, Task Consulting (United States); D. G. Hopper, B. I. Fath, Air Force Research Lab. (United States)

Today's head-mounted displays (HMD) fall far short of providing truly wide fields of view with visual acuity rivaling direct vision. One reason for this is the enormous pixel count required to achieve high acuity over the entire visual field. In reality, human vision provides high visual acuity only across the very small central foveal region of the visual field; acuity decreases rapidly just a few degrees beyond this region. This presents the opportunity to create, using current technology, an effective vision system that delivers very high-resolution imagery over a narrow central field of view, while simultaneously providing lower-resolution imagery over a very wide peripheral field. Previous foveal/peripheral display systems typically combined the foveal and peripheral views optically in a single eye. A simpler approach may be possible in the form of a dichoptic vision system, wherein each eye receives a separate view. One eye would be presented with high-resolution foveal imagery, while the other would receive the much wider peripheral view. Binocular overlap in the central region would provide some degree of stereoscopic depth perception. It remains to be determined, however, if such a system would be acceptable to users, and if binocular rivalry or other effects would degrade visual task performance compared to conventional HMDs. In this paper, we describe a preliminary dichoptic foveal/peripheral vision system and suggest methods by which its usability and performance can be assessed. This effort was funded by the U.S. Air Force Research Laboratory Human Performance Wing under SBIR Topic AF093-018.

8041-15, Session 3

Head-worn displays for NextGen

R. E. Bailey, J. J. Arthur III, NASA Langley Research Ctr. (United States)

The operating concepts emerging under the Next Generation air transportation system (NextGen) require new technology and procedures - not only on the ground-side - but also on the flight deck. Flight deck display and decision support technologies are specifically targeted to overcome aircraft safety barriers that might otherwise constrain the full realization of NextGen. One such technology is the very lightweight, unobtrusive head-worn display (HWD). HWDs with an integrated head-tracking system are being researched as they offer significant potential benefit under emerging NextGen operational concepts. In the proposed paper, these benefits for NextGen are described. The paper details the recent research results, current HWD technology limitations, and future technology development needed to realize HWDs as a key technology component of NextGen.

8041-16, Session 4

Flight tests with enhanced/synthetic vision system for rescue helicopter

H. Tsuda, K. Funabiki, T. Iijima, Japan Aerospace Exploration Agency (Japan); K. Tawada, Shimadzu Corp. (Japan); T. Yoshida, NEC Corp. (Japan)

JAXA (Japan Aerospace Exploration Agency) is conducting research program named SAVERH (Situation Awareness and Visual Enhancer for Rescue Helicopter) from 2008. In the SAVERH, Tunnel-in-the-Sky and 3D Terrain information incorporated with FLIR image is presented on HMD (Helmet Mounted Display) or HDD (Head Down Display). The SAVERH aims at inventing method of presenting suitable information to the pilot to support search and rescue missions by helicopters. This 'method' contains not only how to display several information to pilot but also what relevant hardware should be. In the past three years, several flight tests were conducted in mountain area, sea area, and night condition to evaluate the display symbology and hardware and to demonstrate the operation concept. As a result, some useful technologies such as a method of presenting Tunnel-in-the-Sky display on HMD were invented and way to display FLIR image easily-to-see with terrain image were obtained. Effectiveness of head-slaved-FLIR in night operation was also demonstrated.

8041-17, Session 4

In-flight evaluation of an optical head motion tracker III

K. Tawada, M. Okamoto, Shimadzu Corp. (Japan)

We presented a new approach for Optical HMT (Head Motion Tracker) past years. In existing Magnetic HMT, it is inevitable to conduct pre-mapping in order to obtain sufficient accuracy because of magnetic field's distortion caused by metallic material around HMT, such as cockpit and helmet. Optical HMT is commonly known as mapping-free tracker; however, it has some disadvantages on accuracy, stability against sunlight conditions, in terms of comparison with Magnetic HMT. Since laboratory experiments in 2008, we have succeeded to obtain good accuracy in direct sunlight condition through day flight (2009) and also confirmed good performance in night flight (2010) by using newly developed optical HMT, which can overcome particular disadvantages by integration with two area cameras, LED markers, image processing techniques and inertial sensors with simple algorithm.

Shimadzu Corp. and JAXA (Japan Aerospace Exploration Agency) are conducting joint research named SAVERH (Situation Awareness and Visual Enhancer for Rescue Helicopter) that aims at inventing method of presenting suitable information to the pilot to support search and rescue missions by helicopters. The Optical HMT has been evaluated through a series of flight evaluation in SAVERH and demonstrated the operation concept.

In this report, we show the capability of the HMT system finally tested through 16 flights including night landing.

8041-18, Session 4

Qualification testing of the Scorpion HMCS for A-10 and F-16

R. Atac, T. Bugno, Gentex Corp. (United States)

Gentex Corporation won the Helmet Mounted Integrated Targeting (HMIT) contract with the Air Guard and Air Reserve in May 2010 along with Raytheon Technical Services Corporation as the prime contractor. The HMIT program involves qualification and installation of the Scorpion HMCS Color HMD in both the A-10C and F-16C Block 30 aircraft types. Qualification tests include all aspects from ejection safety, to NVG and pilot compatibility as well as performance testing. This paper will review the qualification testing results and program status along with any lessons learned.

8041-19, Session 4

The reported incidence of man-machine interface issues in Army aviators using the Aviator's Night Vision System (ANVIS) in a combat theatre

K. L. Hiatt, U.S. Army Research Institute of Environmental Medicine (United States); C. E. Rash, U.S. Army Aeromedical Research Lab. (United States)

Background: Aviators rely on the ANVIS for night operations. Human factors literature notes that the ANVIS man-machine interface results in reports of visual and spinal complaints. This is the first study that has looked at these issues in the much harsher combat environment. Last year, the authors reported on the statistically significant ($p<0.01$) increased complaints of visual discomfort, degraded visual cues, and incidence of static and dynamic visual illusions in the combat environment. In this paper we present our findings regarding increased spinal complaints and other man-machine interface issues found in the combat environment. Methods: A survey was administered to Aircrew deployed in support of Operation Enduring Freedom. Results: 82 Aircrew (representing an aggregate of >89,000 flight hours of which >22,000 were ANVIS) participated. Analysis demonstrated high complaints of almost all levels of back and neck pain. Additionally, the use of body armor and other Aviation Life Saving Equipment (ALSE) caused significant ergonomic complaints when used with ANVIS. Conclusions: ANVIS use in a combat environment resulted in high reports of spinal symptoms and other man-machine interface issues over what was previously reported. Data from this study may be more operationally relevant than that of the peacetime literature as it is de¬rived from actual combat and not training and it may have important implications about making combat predictions based on performance in training scenarios. Notably, Aircrew remarked that they could not execute the mission without ANVIS and ALSE and accepted the degraded ergonomic environment.

8041-20, Session 5

Mask-mounted display (MMD) design considerations for diver operating environment

R. Manley, D. G. Gallagher, W. W. Hughes, C. G. Holmes, Naval Surface Warfare Ctr. Panama City Div. (United States)

Military and Public Safety Divers work in a unique and extreme operational environment characterized by high turbidity and zero visibility. To help conduct underwater security, search, and recovery missions special sensors are used; including imaging sonar, underwater navigation systems, mapping devices, and enhanced underwater video. A visual display system is the necessary means of providing this sensor information to the diver. Unfortunately, handheld displays or displays built into the sensor are virtually useless in the environment characterized by zero visibility.

"Near-to-eye" display systems incorporating micro display technology and its associated optic s provides a workable solution. However, while a step in the right direction these "near-to-eye" systems - whether developed for commercial or military applications - have been designed for land-based (or "topside") environments, and fall far short when simply adapted to a dive mask.

A diver operating underwater with a dive mask in zero visibility presents a singularly unique challenge combining requirements for small physical size, light weight, large eye-relief (stand-off distance), high data content, and minimum power.

The paper will describe the successful design of such a system from the perspective of the diver's unique mission operating environment. The resultant system is a light-weight, binocular, mask-mounted visual display that allows for extended stand-off distance (eye relief), requires no interpupillary or focus adjustments, and provides high data content color information regardless of ambient visibility conditions.

8041-21, Session 5

Has the HMD taken off yet? A look toward the future of HMDs

P. R. Havig, Air Force Research Lab. (United States)

Previously the role, or lack thereof, of HMDs was discussed in terms of why they have taken so long to come online. Here this discussion is renewed in terms of the new batch of HMDs that are being produced. Discussion will be in terms of not only advancements but also new applications areas previously unthought-of for the HMD.

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8042A-01, Session 1

A look at current and future display needs for Air Force applications

P. R. Havig, Air Force Research Lab. (United States)

Keeping up with current technology is a never ending process. In this paper current and future display types are investigated as to their viability as well as how they may "fit" Air Force applications. Further discussion will be on current and future needs of displays with an emphasis on applications areas.

8042A-02, Session 1

Army roadmap for future displays

E. W. Forsythe, U.S. Army Research Lab. (United States)

No abstract available

8042A-03, Session 1

Navy roadmap for future displays

R. O'Connor, Naval Air Systems Command (United States)

No abstract available

8042A-04, Session 2

Flight instrument modifications for helmet-mounted SWIR imaging systems

T. R. Robinson, J. Green, G. J. Grabski, M. A. Jacobson, Esterline Technologies Corp. (United States)

Night vision technology has undergone significant advances in the last two decades. The night vision goggle (NVG) based on GaAs continues to raise the bar for alternative technologies. Resolution, gain, sensitivity have all improved; the image quality through these devices is nothing less than incredible. Panoramic NVGs and ENVGs are examples of recent advances that enhance the capabilities for the war fighter.

Even with these advances, alternative night vision devices based on solid state InGaAs imaging systems are under development for helmet-mounted aviation applications. The InGaAs imaging system offers advantages over the existing NVGs. Two key advantages are; (1) the new system produces digital image data, and (2) the new system is sensitive to energy in the short-wave infrared (SWIR) spectrum.

While it is tempting to contrast the performance of these digital systems to the existing NVGs, the technologies appear less competitive and more synergistic. It is likely, by the end of the decade, both NVGs and SWIR devices will be used by pilots within a cockpit. As such flight decks will need to be compatible with both NVGs and SWIR imaging systems.

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.

Inserting a SWIR imaging device in a cockpit will require similar consideration. A project evaluating flight deck instrument compatibility with SWIR devices is currently ongoing and is described in this paper. This project is sponsored by the Air Force Research Laboratory (AFRL).

8042A-05, Session 2

Light surface display

H. H. Refai, 3DIcon Corp. (United States)

Significant advances in several key technologies over the last decade have led to increasing optimism among researchers and technologists that the generation of images over several layers of screens is both viable and practical. In this paper, we present light surface display that constructs different images over three layers viewable around a180 degree arc. This display contains a variety of particles suspended within its image space (screen), that when excited by two different infrared lasers, illuminate to generate particular images in each layer. These particles include upconversion materials which convert lower energy beams into higher energy visible beams and function as light emitting phosphors. The light surface display consists of a first Digital Light Processing (DLP)-based projection system that launches a first infrared laser beam forming sequential slices of a two dimensional image along the length and width of the image space, and a second DLP-based projection system that launches a second infrared laser beam creating translational layers across the depth of the image space. These two DLP-based projection systems are synchronized together to provide precise translational intersections over all the layers within the image space. We present a new technology that can be utilized to generate different images over three layers within the projection space. This technology can be used in a variety of applications such as rendering a map or terrain in the first layer, aircraft distribution in the second layer and additional information in the third layer for air traffic control applications.

8042A-06, Session 2

Augmented reality maintenance system (ARMS) for complex military assets

K. Osborn, N. M. Rensing, T. C. Tiernan, Radiation Monitoring Devices, Inc. (United States)

Currently, equipment maintenance requires highly trained individuals and is labor intensive, expensive and inefficient. The Marine Corps and DOD use written technical manuals and Interactive Electronic Technical Manuals (IETM) to direct technicians through complex maintenance procedures for land vehicles, radar systems, radio communications systems, and ground-based weapon systems. However, technical manuals are still time consuming and tedious to use, and substantial training is needed to extract the appropriate data, understand the technical details for troubleshooting defective components, and the performance of critical maintenance and repairs. RMD is developing a revolutionary new technology for equipment maintenance based on Augmented Reality (AR). The AR-based maintenance system (ARMS) will guide the equipment maintainer through the entire maintenance process, from the identification of defective components to the detailed repair methodology and the functional test sequence. The delivery of instructions to the maintainer during routine maintenance tasks will all be implemented using an audio headset and a laser projector to superimpose symbology on the system being maintained. Multiple cameras will be used to observe the repairs and collect data on its progress, allowing the ARMS system to provide useful and timely

information without unduly burdening the user. It will augment the abilities of the technician by providing the type of guidance normally associated with an expert human trainer.

8042A-07, Session 2

Performance and development considerations for a new generation of land vehicle displays

J. T. Thomas, General Dynamics Canada Ltd. (Canada)

Land vehicles are relatively small, yet the systems complexity is increasing rapidly to provide needed improvements to situational awareness, vehicle management and weapons systems. Processing loads have increased rapidly and there are more display functions than ever. All must be accommodated in a limited space where electronics competes with weapons and crew comfort. In this paper we will examine a unique system solution for vehicle computing and associated data display that provides system level advantages from a compact COTS base at a cost that is compatible with Army vehicles. We will examine the packaging, operational environment, processing, operator interface and display design options. Finally, we project current solutions into a future with expanded applications that exploits new display, materials and processing technologies into a new, more flexible vehicle display.

8042A-08, Session 3

Hybrid magneto-photonic crystal (MPC) nanotechnology display technology for 3D auto stereo projection and flexible fiber composite display systems

S. C. Ellwood, Jr., C. F. Stirling, Photonica, Inc. (United States)

The advent of digital 3D and the new realism in video and cinema images has created a historic search for a display technology or combination of technologies that can deliver super-realistic 3D images that are bright with no eye-strain, and low cost, in flat screen TVs and digital projectors. Photonica has developed that new technology display system - a hybrid combination of technologies - that has the demonstrated key performance benchmarks needed to deliver the products for which the industry has been searching.

Photonica innovation treats the display or projector as a network of devices. The solution to making a flat screen display larger and cheaper is to scale-up the optics rather than the electronics. Photonica scales-up the optics and uses multiple small electronic components in parallel to drive sectors of the fiber-optic screen. Fiber-optics is cheaper per unit area for a flat screen than what is, in effect, a giant computer chip. In order to increase resolution, more pixels are added to the electronics (chip or display), and optics are used to combine many lower-resolution components. The display video performance is improved by combining multiple sources per final pixel (“pixel signal processing”) to increase final frame rate, contrast, brightness, digital 3D image process, and color gamut, instead of exclusively trying to improve the performance of a single source per sub-pixel or pixel.

Photonica’s technology applications include systems ranging from Pico - to Large Format projectors, and Digital 3D Flat Panel Displays ranging from Flexible, Foldable Tablets to 100” and larger Flat Panel Flexible Screen TV’s.

8042A-09, Session 3

Precise positioning surveillance in 3D using night-vision stereoscopic photogrammetry

J. M. Schwartz, Follow-Me Systems, LLC (United States)

Techniques to derive point clouds from time-of-flight laser scanners are growing in popularity within the scientific, commercial and defense communities. However the devices these techniques rely on are not well suited for covert surveillance due to size, complexity, and active emission of laser-light. Because laser-light can be detected by anti-surveillance methods, even infrared laser scanners are vulnerable to detection in the field. In contrast, the use of passive imaging techniques remains well-suited to covert surveillance and intelligence gathering. By incorporating night-vision and stereoscopic 3-D, new capabilities can extend the value of traditional passive ISR imaging techniques.

In this paper, a close-range photogrammetric method is paired with calibrated high-resolution night-vision cameras and survey-grade GPS equipment to increase the capabilities of traditional passive imaging surveillance. Calibrated camera models and high-accuracy GPS locations are used in order to derive a registered, pixel-based point cloud from the night-vision image pairs. The resulting point clouds are used to determine scene dimensions, generate full 3-D scene models, and extract real-world positions of mission critical objects. Error analysis of the resulting point clouds show this technique delivers position accuracies which rival laser scanning even in near-total darkness. Advances in high-resolution digital imagers currently allow for image acquisition as rapidly as five frames-per-second, therefore the technique is applicable to 3-D stereoscopic video collection as well. Because this surveillance technique does not rely on active laser emissions it is more portable, less complex, less costly, and less detectable than time-of-flight laser scanning.

8042A-10, Session 4

Ultra-high-resolution AMOLED

I. Wacyk, O. F. Prache, A. Ghosh, eMagin Corp. (United States)

AMOLED microdisplays continue to show improvement in both resolution and optical performance, enhancing their appeal for a broad range of near-eye applications such as night vision, simulation and training, situational awareness, augmented reality, medical imaging, and mobile video entertainment and gaming. eMagin’s latest demonstrator for an HDTV+ resolution technology integrates an OLED pixel of 3.2 x 9.6 microns in size on a 0.18 micron CMOS backplane to deliver significant new functionality as well as the capability to implement an HD1080 microdisplay in a 0.87” diagonal device. In addition to the conventional matrix addressing circuitry, the WVGA demonstrator display includes a very low-power, low-voltage-differential-signaling (LVDS) serialized interface to minimize cable and connector size as well as EMI, an on-chip set of look-up-tables for digital gamma correction, and a novel pulse-width-modulation (PWM) scheme that together with the standard analog control provides a total dimming range of 0.01fL to 1000fL in the monochrome version. An internal 10-bit DAC ensures that a full 256 gamma-corrected gray levels are available across the entire dimming range, resulting in a measured dynamic range exceeding 18-bits. This device has been successfully tested for operation at frame rates ranging from 30Hz up to 240Hz. In addition to the high frame rate, an impulse drive mode has been included that demonstrates significant reduction of motion artifacts in high speed scene changes. This paper will describe the operational features and detailed optical and electrical test results of the new WVGA demonstrator microdisplay, and its implications for a HDTV+ format device.

8042A-11, Session 4

Alternatives to flat panel displays in vehicle turrets

G. Nicholson, Naval Surface Warfare Ctr. Crane Div. (United States)

Space is a premium in vehicle turrets. Reducing the footprint of displays inside turrets, frees up space for the warfighter. Traditional military ruggedized flat panel displays cannot reside flush with the curved turret wall and consumes more space than their advertized size. The lack of turret space also makes balancing human factors difficult. To better meet

the warfighter needs, alternatives and incremental upgrades to the flat panel displays in turrets were compiled. Each alternative technology was assessed against the constraints of a turret. Benefits, issues, and predictions to implementation are summarized. Viable alternatives are being developed into suitable options.

8042A-12, Session 4

Microdisplay contributions to system level performance

T. Bacarella, T. Hogan, Kopin Corp. (United States)

We examine the impacts of displays on performance of infrared and fused imaging systems. We present test data for AMLCD and OLED microdisplays over ranges of luminance and temperature. We deconstruct typical system level requirements to present needed display level requirements and present their potential impacts on system level performance. Sensor performance is very well understood as is processing of the imagery and the impact on system level performance, but how the image is conveyed to the user has just as much impact on performance as the sensor and is often neglected in system level performance. This paper seeks to explain the key display parameters that contribute to system level performance of infrared and fused imaging systems. Test data presented will include analysis of display performance variance as a function of luminance and temperature and will include spatial noise, contrast, brightness, uniformity and probability of target detection. Temperatures tested will be typical to ruggedized environments and will range from -40C to +65C. Luminance will be over typical man-portable near to eye brightness ranges.

8042A-13, Session 4

General implications of HUD systems applied to automobile industries

J. A. Betancur Ramírez, G. Osorio Gómez, Univ. EAFIT (Colombia)

Today, HUD technology is consolidating in transportation vehicles as an effective tool of great potential in driving comfort, information access and road security. Therefore, it's necessary to analyze those factors that consolidate these systems in the automobile industry and that let the user to get involved with external factors while driving. Although these products have long been developed in the automotive sector, it is clear the large number of applications that still wait to be explored and the need for research, that is required in this regard. This article has the purpose to analyze, based on the current technology, the factors that have been implemented in these visual systems, with the purpose to establish which are its functions and which are the advantages and disadvantages of these systems, in order to compare their relevance at the moment the system is implemented in a vehicle. To fulfill this objective an optical and perception analysis was proposed through an instrumental set up, with common characteristics to any transportation vehicle, making possible the implementation of the theoretic factors considered. Finally, some recommendations, considerations and conclusions were made, all focused in a proposal of the way that that these systems can be approached.

8042A-14, Session 5

Accounting for human neurocognitive function in the design and evaluation of 360 degree situational awareness display systems

J. S. Metcalfe, DCS Corp. (United States); T. Mikulski, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); S. Dittman, Vorteil Technologies, Inc. (United States)

The current state and trajectory of technology development supporting advanced displays lends a broad informational infrastructure to operators of complex systems. The vast array of display options, both available and emerging, threatens to outstrip the perceptual-cognitive capacities of intended operators, thus limiting their ability to effectively interact with targeted technologies. Therefore, a critical step in designing complex display systems is to find an appropriate match between display capabilities, operational needs, and human ability to utilize complex information. The present work examines a set of evaluation parameters that were developed to facilitate the design of systems to support a specific military need; that is, the capacity to support the achievement and maintenance of real-time, 360° situational awareness (SA) across a range of complex military environments. The focal point of this evaluation is on the reciprocity native to advanced engineering and human factors practices, with a specific emphasis on aligning the operator-system-environment fit. That is, the objective is to assess parameters for evaluation of 360° SA display system suitable for military operations in tactical platforms across the range of current and expected operational environments. The approach is centered on five "families" of parameters, including vehicle sensors, data transmission, in-vehicle displays, intelligent cueing, and human factors. Parameters are examined under the assumption that displays designed to conform to natural neurocognitive processing will enhance and stabilize Soldier-system performance and, ultimately, unleash the human's potential to actively achieve and maintain the awareness necessary for enhanced lethality and survivability in the modern and future operational contexts.

8042A-15, Session 5

A methodology for the assessment of 360° local area awareness displays

C. Manteuffel, M. Jaswa, T. Johnson, J. S. Metcalfe, DCS Corp. (United States); B. J. Brumm, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

In the process of developing new technologies for displaying 360° visual data supporting Local Area Awareness (LAA) in complex environments (e.g. tactical military environments), one important, though often overlooked, area is system evaluation. Without an accurate and reliable evaluation, it is impossible to determine which elements of the new display are useful and which need further development. Evaluating a system properly requires two types of tests: one for testing capabilities (e.g. given a display, what types of threats can be detected and identified?), and another for probing whether a given display configuration is useful (e.g. will the human operator use this more complex interface appropriately in the real world?). While established methodologies exist for the former, the latter often appears as a much less tractable problem. This is primarily because of the difficulties with modeling the complexity of the real world in a simulated environment. This paper presents a methodology for architecting a distributed simulation to support evaluation of a 360° LAA display system for usefulness to human participants within virtual environments. The evaluation that leveraged the methodology ultimately reported several unexpected results due to the its effectiveness; for example, the experiment discovered a much greater "keyhole effect" than expected, where participants focused almost entirely on the forward 180°, even when presented with imagery covering the full 360°. Such results demonstrate the utility of the methodology, particularly for developing evaluations that discover unexpected aspects of operational use in complex environments.

8042A-16, Session 5

Visual tools for human guidance in manual operations

G. Abramovich, K. G. Harding, GE Global Research (United States)

Return to Contents

Various manual tasks can benefit from real time visual aids. Electronic visual aids are finding new applications in such critical areas as remote surgery. But there are more subtle means to guide a person's actions in performing critical assembly or disassembly operations where the operator must keep an eye contact with the hand for safety reasons, or enhanced eye-hand coordination. This paper will explore means of visual guidance that make use of direct optical view, real time graphics overlays, color change effects, and psuedo tactile feedback, and discuss factors that impact their effectiveness. We will discuss our security-related application examples with particular emphasis on human factors considerations and engineering tradeoffs.

8042A-17, Session 5

Head-mounted display (HMD) assessment for tracked vehicles

G. Nicholson, W. Hurley, Naval Surface Warfare Ctr. Crane Div. (United States)

Providing the warfighter with Head Mounted Displays or Helmet Mounted Displays (HMDs) while in turreted vehicles provides a means to visually maintain access to systems information while in a high vibration environment. The high vibration and unique environment of military tracked and turreted vehicles impacts the ability to distinctly see certain information on an HMD, especially small fonts or graphics and information that requires staring, rather than glancing. The military and commercial use of HMDs was compiled from market research, market trends, and user feedback. Lessons learned from previous military and commercial use of HMD products were derived to determine the feasibility of using HMDs in the high vibration of tracked vehicles and the unique environments in which tracked vehicles can be used. The results are summarized into factors including HMD features, reliability and human systems integration domains of training, costs, and human factors. In high vibration environments, certain HMDs must be specified for successful implementation.

8042A-18, Session 6

Non-RF wireless helmet-mounted display and two-way audio connectivity using covert free-space optical communications

M. Strauss, L. Volfson, Torrey Pines Logic, Inc. (United States)

Torrey Pines Logic (TPL) has over 10 years of R&D in its free-space optical communication technology called LightSpeed. TPL is using the LightSpeed technology as the basis to solve cable management problems with user's helmet mounted displays and headsets, and their torso and/or vehicle mounted equipment. The system "cuts" the cables by using light emitting diodes (LED) and photodiodes to send and receive data at rates that can reach 120Mbps burst. TPL built the communication protocols around proprietary waveforms that we created for the transmittal of uncompressed 800x600 30fps full color video and bi-directional audio. The system uses sources in the solar blind range of the atmosphere that both enables use in direct sunlight and significantly limits its signature. With the current sources, range is purposely limited to about 2m. Other frequencies are available to extend the range out to 500m while remaining covert. Using advances in FPGA technology and algorithm development, TPL significantly reduced power consumption so that the system can function on AA batteries for hours or draw power from a USB connection.

TPL built current Phase I prototypes for the Air Force Research Labs and is in the process of finishing up Phase II hardware. Phase I was a proof of concept brassboard that attained all range, throughput, and usability goals. Phase II is a miniaturization and power optimization effort.

8042A-19, Session 6

Evolution of LED backlighting in avionics displays

J. Davis, J. Tchon, Rockwell Collins, Inc. (United States)

Light Emitting Diodes (LEDs) have realized enormous gains in output efficiency over the past 10 years. These gains have created performance improvement and cost reduction opportunities in backlight subsystems for avionics grade displays. Display packaging approaches have evolved to accommodate reduced emitter populations and the specific challenges associated with those component reductions. The objective of this paper is to discuss display packaging design parameters associated with and/or affected by trending LED efficiency gains.

8042A-20, Session 6

ARINC 818 for video and display control

T. Keller, J. A. Alexander, Great River Technology, Inc. (United States)

ARINC 818 is defined as a point to point video link that is used to drive cockpit displays both in military and commercial aerospace applications. In addition to the ARINC 818 video link to a display, a command and control link such as Mil Std 1553 is often needed to carry bezel button or other configuration or control data. Although ARINC 818 was envisioned as a video link, its high speed, low latency and high reliability make it ideal to carry both video and data. A bi-directional implementation of ARINC 818 provides ample bandwidth and messaging capability to eliminate the MIL STD 1553 or ARINC 429 data interface with a single fiber pair. This paper examines the architecture and messaging structure required to include an ARINC 818 return path so that a separate data path is eliminated.

Data packets can be sent as separate containers on the ARINC 818 "video" link or included in the video stream with the Object 0 data. An data messaging architecture is developed for a data dispatcher that handles the data Rx and Tx function and the associated timing that also maintains the 100% quality of service required for the video path.

8042A-21, Session 6

Evolution of low-profile and lightweight electrical connectors for soldier-worn applications

E. Gans, K. S. Lee, T. Jannson, K. Walter, Physical Optics Corp. (United States)

In addition to military radios, modern soldiers carry cell phones, GPS devices, computers, video equipment, and night-vision aids. All of these devices require electrical cables and connectors (for data and power transmission). The current practice is to operate each electrical device via independent power and data cables using conventional cable and connector technology. Conventional cables are stiff and difficult to integrate into a soldier-worn garment, such as a vest. Conventional connectors are tall and heavy since the connectors were designed for ensuring a secure connection to a bulkhead-type panel, and being tall, represent significant snag-hazards in soldier-worn applications. Physical Optics Corporation has designed a new, light-weight and low-profile electrical connector that is far more suitable for soldier-worn applications. When these low-profile connectors are mated, the combined height is less than 0.3 inches - a significant reduction compared to the 2.5 inch average height of conventional connectors. The new connectors operate much like a conventional garment snap. Electrical connections can be made with one hand (gloved or bare) and blindly (without looking). Furthermore, the connectors can be combined into systems that distribute data or power from a central location on the soldier's vest, thus reducing the length and weight of the cables necessary to interconnect the various electronic systems the soldier must carry. The result is a light-weight power and data distribution system offering significant advantages over conventional electrical connectors in soldier-worn applications. This presentation outlines the evolution of the connector to meet various and changing requirements for modern applications.

8042A-22, Session 6

Affordable multisensor digital video architecture for 360 degree situational awareness displays

S. P. Scheiner, DCS Corp. (United States); D. A. Khan, A. L. Marecki, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); D. A. Berman, U.S. Army Night Vision & Electronic Sensors Directorate (United States); D. Carberry, General Dynamics Robotic Systems (United States)

One of the major challenges facing today's military ground combat vehicle operations is the ability to achieve and maintain full-spectrum situational awareness while under armor (i.e. closed hatch). The challenge is complicated by the fact that future ground combat operations will require closed-hatch vehicle systems to carry out complex missions. Thus, the ability to perform basic tasks such as driving, maintaining local situational awareness, surveillance, and targeting will require a high-density array of real time information be processed, distributed, and presented to the vehicle operators and crew in near real time (i.e. low latency). Advances in display and sensor technologies are providing never before seen opportunities to supply large amounts high fidelity imagery and video to the vehicle operators and crew in real time. To fully realize the advantages of these emerging display and sensor technologies, an underlying digital architecture must be developed that is capable of processing these large amounts of video and data from separate sensor systems and distributing it simultaneously within the vehicle to multiple vehicle operators and crew. This paper will examine the systems and software engineering efforts required to overcome these challenges and will address development of an affordable, integrated digital video architecture. The approaches evaluated will enable both current and future ground combat vehicle systems the flexibility to readily adopt emerging display and sensor technologies, while optimizing the War-fighter Machine Interface (WMI), minimizing lifecycle costs, and improving, the survivability of the vehicle crew working in closed-hatch systems during complex ground combat operations.

8042A-23, Session 6

Display technology gaps used with electro-optic sensors

J. E. Fulton, Jr., G. Nicholson, Naval Surface Warfare Ctr. Crane Div. (United States)

The warfighter needs displays to see the information from fielded sensors. Gaps exist between the Electro-Optic sensor information and the optimal display to view that information. An assessment was completed to capture the military display technology gaps by Naval Surface Warfare Center Crane Division's Electro-Optics Technology Division for many DoD Electro-Optics (EO) systems. The results of these gaps have been compiled along with predictions of when or if these gaps will be filled based on commercial market trends.

8042A-24, Session 6

Ultra-mobile rugged computing platforms design considerations

R. Garcia, M. Wright-Johnson, General Dynamics Itronix Corp. (United States); R. Daniels, Air Force Research Lab. (United States)

State of the art ultra mobile computing is designed to be used in many varied and severe environments. Ultra mobile computing platforms including mobile phones, net books and laptops are common products that are used by the general public and increasingly by dismounted military users. Ultra mobile computing is evolving from the traditional office environment applications to use in other severe environments. The natural ultra mobile computing progression would be rugged-ultra-mobile-computing devices. Rugged ultra mobile computing devices that have the same functionality and usage models in severe environments where outdoor elements can be a significant factor, such as rain, heat, cold, dust, shock, drop, vibration, or sunlight.

This paper will discuss the following ultra mobile rugged design considerations:

(1) How outdoor elements can reduce the effectiveness and robustness of commercial grade electronics.

(2) Design considerations to meet outdoor elements.

(3) Ultra mobile visual display environment examples. Operator use in bright sunlight, or low light level NVIS compatibility mode.

(4) Design considerations to meet shock and drop needs, including the use of lightweight but sturdy materials. Dampening materials design considerations will also be discussed.

Conference 8042B: Enhanced and Synthetic Vision 2011

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8042B-25, Session 7

Enhanced/synthetic vision and head-worn display technologies for terminal maneuvering area NextGen operations

J. J. Arthur III, S. P. Williams, L. J. Prinzel III, R. E. Bailey, K. J. Shelton, NASA Langley Research Ctr. (United States)

Adverse weather results in approximately 70% of all flight delays in the National Airspace System (NAS). Air traffic operations in the terminal maneuvering area are particularly affected by instrument meteorological conditions (IMC). Estimates posit that airport throughput may drop as much as a factor of 3 during periods of low visibility that can compound into delays throughout the NAS. Existing technologies and new airport construction marginally reduce the "performance gap" for throughput between IMC and visual meteorological conditions (VMC) at the 35 major US commercial hub airports. For example, a new runway at Atlanta (ATL) increased airport throughput by only 3%. For some airports, construction of new runways is not possible and instead must rely solely on technology innovation to reduce the performance gap.

NASA has been researching innovative technologies for the Next Generation Air Transportation System (NextGen) to provide a "better-than-visual" capability to enable "equivalent visual operations"; that is, equivalent or better VMC operational rates and safety in all weather conditions including IMC. These new technologies build on proven flight deck systems and leverage synthetic and enhanced vision systems. The paper will describe the integration of several complementary flight deck technology concepts including automatic dependent surveillance broadcast (ADS-B 'IN'), head-worn displays with head tracking, synthetic and enhanced vision systems, innovative adaptive symbology and displays, and flight deck interval management. Results from past and present simulation research will be discussed that evaluates these technology concepts for the NextGen terminal maneuvering area, including approaches to very closely spaced parallel runways and four-dimensional surface operations.

8042B-26, Session 7

Helicopter Autonomous Landing System (HALS): an enhanced flight vision system that enables multiship landing, takeoff, and en-route flight in degraded visual environments

J. Cross, D. Howard, C. Chapman, Sierra Nevada Corp. (United States)

Sierra Nevada Corporation has developed the Helicopter Autonomous Landing System (HALS), an enhanced vision system that enables multi-ship landing, takeoff, and enroute flight in Degraded Visual Environments (DVE). A fast-scanning millimeter wave active radar is used to produce real-time terrain and obstacle imagery. The radar imagery is fused with synthetic imagery of the surrounding terrain to form a long-range, wide field-of-view display. A symbology overlay is added to provide aircraft state information and approach and landing guidance cuing to the pilot. The combination of see-through imagery and guidance symbology provide the key information a pilot needs to perform safe flight operations in DVE conditions. HALS has been successfully flight tested in a variety of scenarios, from brown-out DVE landings, to enroute flight over mountainous terrain, to wire/cable detection during low-level flight. This paper discusses the HALS-3 architecture and radar, presents imagery, and summarizes the HALS flight test results.

8042B-27, Session 7

A compact wide-area surveillance system for defence and security applications

J. R. E. Sadler, J. Davis, D. L. Hickman, Waterfall Solutions Ltd. (United Kingdom)

The increased prevalence of Closed Circuit Television (CCTV) systems as part of a solution to homeland security has resulted in the necessity to view multiple simultaneous camera feeds. In some cases the fields of view of the individual cameras overlap lending themselves to combination into a single wide area image. Alternatively there are cases where the cameras are placed to cover a large area but with blind spots between cameras. In these cases, a single sensor unit with a wide field of view can ensure that the CCTV system operator's situational awareness can be greatly enhanced through the provision of a single continuous panoramic imaging system. This paper reports on advances that Waterfall Solutions Ltd (WS) has made in field of wide area surveillance systems and introduces a low profile, wide field of view sensor system, and associated processing, which provides solutions to both of these problems. Within this paper, the SIREN system and its development challenges are described. A number of application examples are provided to illustrate its operation and the system's adaptability and flexibility to a number of real life scenarios.

8042B-28, Session 7

Enhanced and synthetic vision for terminal maneuvering area NextGen operations

R. E. Bailey, L. J. Kramer, L. J. Prinzel III, K. Ellis, K. J. Shelton, J. J. Arthur III, NASA Langley Research Ctr. (United States)

Synthetic and Enhanced Vision System (SEVS) technologies have the potential to provide additional margins of safety and aircrew performance and enable the implementation of operational improvements for low visibility surface, arrival, and departure operations in the terminal environment with equivalent efficiency as visual operations. To meet this potential, research is needed for effective technology development and implementation of regulatory and design guidance to support introduction and use of Synthetic Vision Systems and Enhanced Flight Vision Systems (SVS/EFVS) advanced cockpit vision technologies in Next Generation Air Transportation System (NextGen) operations.

The proposed paper describes the objectives, equipment, and research methods in a pilot-in-the-loop simulation test which evaluated the use of SVS/EFVS in NextGen low visibility ground (taxi) operations and approach/landing operations. Twelve crews flew approach and landing operations in a simulated NextGen Chicago O'Hare environment. Various scenarios tested the potential for EFVS for operations in visibility as low as 700 ft runway visibility range and SVS to enable lower decision heights than can currently be flown today. This work also evaluated these technologies, in isolation or integrated with Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic alerting and Collision Avoidance System (TCAS)-II information, as they may impact flight crew(s) workload, head-down time, and ability to detect potential collisions with objects, obstacles or other traffic.

8042B-29, Session 7

Next generation EFB applications

C. Pschierer, Jeppesen GmbH (Germany)

Electronic Flight Bags (EFB) with several applications like an Airport Moving Map (AMM) are deployed on commercial aircraft like the Boeing 777 and the Airbus A380 for some years. The architecture of these systems is based on RTCA DO-178B certified flight deck software components for centralized database server systems.

The next generation of EFB applications will make even stronger use of a centralized database server to share consistent data between various flight deck applications. This paper describes concepts developed for the EU research project ALICIA.

The approach operation support subsystem will be supported with the experience gained by the design and development of several electronic charting applications, like the Enroute Moving Map (EMM). Main contribution will be the introduction of a map mode overlay mode superimposed by graphical NOTAM information. The taxi operation support subsystem will be supported by the provision of high sophisticated aerodrome mapping data including digital NOTAMs and taxi route display. For the atmospheric awareness subsystem Jeppesen will research the handling of such a kind of dynamic data on the flight deck. Handling comprises the storage of the data as well as their visualization.

8042B-30, Session 8

A comparison of synthetic and human observer approaches to multispectral 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 element that can be “resolved” using the system, which requires a human in the loop to make the assessment. This paper compares the results of a custom-designed software approach to generate an effective resolution value for a sensor with human vision results using the same images. Landolt Cs were selected as the resolution target, which were imaged at multiple distances from multiple sensors. The images were analyzed using the custom software to determine the orientation of the C at each of the distances, which resulted in a probability of correct orientation detection curve as a function of distance. Probability of correct orientation detection as a function of distance was also obtained directly from six subjects that viewed the imagery. These curves were then used to generate a “resolution” value for the sensor using the custom software results and the human subject results. Resolution results for both the software and the human participants were obtained for four different spectral band sensors as well as for fused images from two pairs of sensors. These results and the possible use of this synthetic observer resolution approach are presented and discussed.

8042B-31, Session 8

Millimeter-wave data acquisition for terrain mapping, obstacle detection, and dust penetrating capability testing

S. Schmerwitz, H. Doehler, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); S. A. Jennings, K. Ellis, National Research Council Canada (Canada)

The DLR project ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites) is devoted to demonstrate the usage and evaluate the characteristics of different sensors for helicopter operations within degraded visual environments, such as brownout landing. In cooperation with the NRC flight tests on a Bell 205 were conducted to gather sensor data from a 35 GHz pencil beam radar for different designated use of millimetre-wave data. A set of three different focuses were tested - terrain mapping, obstacle detection and dust penetration. It is planed to evaluate the capability of mmw radar data in fusion with other sensors data for the usage as the only really dust-penetrating sensor for fighting the brownout problem. On the one hand in comparison with other sensors during normal conditions the radar delivers a much worse angular resolution on the other hand it might be the best sensor for remaining on the safe side during a brownout. In this paper the flight trials at NRC will be presented and a description of the radars general capability will be shown. The reader will have a look into the concept of multi-sensor-fusion as attempted in the ALLFlight project.

8042B-32, Session 8

Small-scale anomaly detection in panoramic imaging using neural models of low-level vision

M. C. Casey, Univ. of Surrey (United Kingdom); D. L. Hickman, Waterfall Solutions Ltd. (United Kingdom)

Our understanding of sensory processing in animals has reached the stage where we can exploit neurobiological principles in commercial systems. In human vision, one brain structure that offers insight into how we might detect anomalies in real-time imaging is the superior colliculus (SC). The SC is a small structure that rapidly orients our eyes to a movement, sound or touch that it detects, even when the stimulus may be on a small-scale; think of a camouflaged movement or the rustle of leaves. This automatic orientation allows us to prioritize the use of our eyes to raise awareness of a potential threat, such as a predator approaching stealthily. In this paper we describe the application of a neural network model of the SC to the detection of anomalies in panoramic imaging. The neural approach consists of a mosaic of topographic maps that are each trained using competitive Hebbian learning to rapidly detect image features of a pre-defined shape and scale. What makes this approach interesting is the ability of the competition between neurons to automatically filter noise, yet with the capability of generalizing the desired shape and scale. We will present the results of this technique applied to the real-time detection of obscured targets in visible-band panoramic CCTV images. Using background subtraction to highlight potential movement, the technique is able to correctly identify targets which span as little as 3 pixels wide with a low false alarm rate, despite noise.

8042B-33, Session 8

Real-time image registration and fusion in a FPGA architecture (FIRE)

R. Rickman, T. Waters, L. Swan, Waterfall Solutions Ltd. (United Kingdom)

Real-time Image Registration is a key processing requirement of WS’s image fusion system, FIRE, which combines the attributes of high resolution visible imagery with the spectral response of low resolution Thermal Sensors in a single composite image.

Implementing image fusion at video frame rates typically requires a high bandwidth video processing capability which, within a standard CPU-type processing architecture, necessitates bulky, high power components. FPGA’s offer the prospect of low power/heat dissipation combined with highly efficient processing architectures for use in portable, battery-powered, passively cooled applications, such as hand-held or helmet-mounted systems, such as WS’s FIRE, for example.

The FIRE processing architecture warps the thermal onto the visible image to compensate for the differing optical characteristics of the two sensors prior to forming this composite image.

FIRE uses a multi-resolution approach to produce high quality fused imagery, preserving details from the video sources at different resolutions. FPGA's are particularly well suited to this type of application.

The efficient processing within the FIRE system is highly parallelised and reduces buffering and system processing bottle-necks by performing the registration and fusion calculations 'on the fly' within a pipe-lined architecture.

The FIRE architecture can support complementary processing capability such as highly effective Local Area Contrast Enhancement and Scene Based non-uniformity Correction to improve image quality to yield a cost effective yet high performance system.

8042B-34, Session 8

Investigating attentional tunneling through a flexible experimentation environment and eye tracking

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Although attentional tunneling as a phenomenon is at least known since the late 1970ies it is still an area of high research interest, since it bears connections to current and future applications in head-up and head-down displays. For example, it is still not fully answered to what degree highly dynamic scenarios influence the pilot's ability to keep up with routine tasks, and vice versa, when and whether dynamic scene changes stay unnoticed under high workload.

In order to further investigate attentional tunneling a generic experimentation environment was set up. The core of the environment is DLR's sensor simulation suite F3S. To ensure flexible scenarios, the simulation software can be installed on specialized flight simulators, for example a Vision Station, as well as standard workstations and can be tuned to a simple view simulation with different levels of realism. It allows for a full and dynamic control of experimental scenarios, e.g. possible changes in the environment. For larger scenarios several platforms can be coupled to enable the investigation of team situations. As one of its key features the set-up includes a full eye-tracking solution that is further capable of recording dynamic areas of interest.

Within a first experiment with a student sample F3S was used as a simple view simulation combined with synthetic approach scenarios. Subjects were asked to detect changes whilst flying tunnel-in-the-sky approaches with a head-up display. At the same time eye gaze positions where tracked. This novel approach to the investigation of attentional tunnelling can prove that an environmental change, even though visually perceived, is not necessarily cognitively processed at the same time. It further allows investigating to what degree attention is influenced by dynamic objects and workload.

We present the basic structure of the overall experimental set-up as well as results of the first tests.

8042B-36, Session 8

Efficient reduction of complex noise in passive millimeter-wavelength video utilizing Bayesian surprise

T. N. Mundhenk, J. Baron, R. M. Matic, HRL Labs., LLC (United States)

Passive millimeter wavelength (PMMW) video holds great promise given its ability to see targets and obstacles through fog, smoke and rain. However, current imagers produce undesirable complex noise. This can come as a mixture of fast shot (snow like) noise and a slower forming circular fixed patterns. Shot noise can be removed by a simple gain style filter. However, this can produce blurring of objects in the scene. To alleviate this, we measure the amount of Bayesian surprise in the video. Bayesian surprise is change in time which is abrupt, but cannot be accounted for as shot noise. The shot noise filter is then attenuated in locations of high surprise. This reduces blurring particularly in places where people visually attend since high Bayesian surprise in videos is very salient to observers. Fixed pattern noise is removed after the shot noise using a combination of Non-uniformity correction (NUC) and Eigen Image Wavelet Transformation. The combination allows for online removal of time varying fixed pattern noise even when background motion may be absent. It also allows for online adaptation to differing intensities of fixed pattern noise. The fixed pattern and shot noise filters are all efficient allowing for real time video processing of PMMW video. We show several examples of PMMW video with complex noise that is much cleaner as a result of the noise removal. Processed video clearly shows cars, houses, trees and utility poles at 20 frames per second.

Conference 8043: Three-Dimensional Imaging, Visualization, and Display 2011

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8043-01, Session 1

Towards reliable and reproducible 3D video quality assessment

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Recently, the interest in 3DTV, as one of the emerging multimedia formats, has remarkably increased due the rapid technological development. Furthermore, efforts have been devoted to creation of suitable 3D content, to feed this growing market. However, one of the most important factors for a sustainable success of 3DTV is that it provides an increased quality of experience (QoE) when compared to traditional 2D media formats.

One of the challenges for 3D video is that simply adding depth to a 2D video usually is not enough to create a high quality 3D video improving viewers experience, through a feeling of immersion or presence. Quite the contrary, unrealistic depth cues can almost certainly lead to eyestrain and fatigue.

The goal of this paper is to provide a high-level overview of current approaches for 3D quality assessment and to discuss some of its challenges.

Since human viewers are the final and most important judges of any 3DTV system or service, subjective tests are widely used for quality assessment or optimization. Furthermore, subjective quality scores usually serve as reference for the development and validation of objective quality metrics.

Existing methods can be grouped into psycho-perceptual and user-centered approaches. Conventional psycho-perceptual evaluation methods examine the relation between physical stimuli and sensorial experience in a highly controlled laboratory environment. The overall quality or certain quality attributes are judged with full attention on the evaluation task. User-centered evaluation methods relate the quality evaluation to the use of a system or service. This is achieved by taking into account typical users, required system characteristics, potential usage scenarios context, and goal-related evaluation tasks.

Subjective video quality evaluation according to standardized methods has a long history. Especially the methods described in ITU-R BT.500 are commonly used for assessing 2D video quality. Another method, which has become quite popular, is the subjective assessment methodology for video quality (SAMVIQ). This approach is an adaptation of the DSCQS method with the direct comparison of multiple stimuli in order to provide a more reliable discrimination for low and high quality levels. However, all double and multi stimuli methods have to be considered as artificial, as in realistic scenarios, users usually do not compare different instances of a same content. Although it has been recognized quite early that suitable evaluation criteria have to be defined for 3D video, standard subjective evaluation methodologies are currently lacking. The only attempt so far has been described in ITU-T BT.1438 and states that the methods from ITU-T BT.500 are also applicable in 3DTV scenarios. Therefore, most of the subjective quality tests for 3D video are primarily based on the methodologies developed for 2D video.

Evaluating the quality from a user perspective rather than from a system perspective has become increasingly important in multimedia quality assessment. Several standardization bodies have started to explore possible methodologies for user-centered quality assessment. Although most of such efforts are directed at multimedia data in general, they may also be applied to 3DTV.

One of the promising ideas is to split quality of experience (QoE) into quality of service (QoS), which describes the technical quality of a system, and quality of perception (QoP) which describes the information transfer and the user satisfaction. Instead of collecting only the overall quality scores, recent studies also try to identify the underlying quality factors based on questionnaires or interviews. In order to evaluate the quality of a multimedia system or service in a more realistic context, subjective quality tests are not only conducted in controlled laboratories, but also less controlled field settings. For the user-centered evaluation of 3D quality, some additional aspects need to be considered. The concept of presence can be assessed through questionnaires or qualitative methods. Viewers of 3D content may also experience symptoms like eyestrain, disorientation and fatigue, which are typical in virtual environments. This can be measured subjectively using a simulator sickness questionnaire (SSQ).

Since subjective quality tests are quite time consuming and cannot be used for online quality assessment, objective quality metrics are developed to predict the perceived quality of multimedia data.

Existing visual quality metrics can be split into two big families: model-based, and feature-based. Model-based metrics take the “top-down” approach by modeling the human visual perception and estimating the visibility of artifacts. Feature-based metrics estimate the quality in a “bottom-up” fashion by measuring the strength of visual artifacts through signal processing methods. Depending on the needed reference information, objective quality metrics can be further divided into three categories: full reference (FR) metrics which require an entire reference video, reduced reference (RR) which rely on some features extracted from the reference video, and no reference (NR) metrics that analyze the test video only.

A straightforward way to apply 2D quality metrics to 3D is to estimate the quality for the stereo views separately and to combine them into an overall score. While such an approach may work for impairments, which may affect both channels equally, it will fail for other cases. Besides, spatial and temporal masking effects involved in 2D and 3D vision, are also affected by binocular suppression and inter-channel relations. The binocular suppression theory describes the masking effects between the images perceived by the different eyes and is commonly applied for asymmetric video coding. Furthermore, the overall 3D quality may not only be affected by the quality of the individual channels, but also by the image content or depth structure of the scene. 3D quality metrics are a fairly new research area and only a handful number of methods have been proposed so far. Most are based on well-established 2D metrics and try to incorporate depth information in different ways, and often they do not take into account directly, the special characteristics of 3D perception.

For the development of reliable objective quality metrics it is crucial to understand and to quantify the influence of various 3D artifacts on the perceived quality. Based on that, more accurate models of the human visual system that consider both 2D and 3D perception need to be developed. Furthermore, in order to get reliable quality estimates for a typical context the assessment should be done in realistic scenarios.

This paper will provide several illustrative examples of parameters that affect the quality of 3D video, by providing both qualitative and quantitative results of research carried out by authors in this area.

8043-02, Session 1

Hybrid video encoding schemes for backward-compatible 3DTV services

J. Kim, S. Jeong, J. S. Choi, Electronics and Telecommunications Research Institute (Korea, Republic of)

Since the big hit of 3D movie ‘Avatar’, broadcasting industry is preparing introduction of 3DTV service. There can be many ways to transmit stereoscopic video data and provide 3DTV service. The most simple and convenient one is to use so-called ‘frame-compatible’ format, in which the left and right view images are reduced to a half resolution and combined together to make it a 2D-like data. In this way, we can use the legacy broadcasting system and installed set-top-boxes, without any change, for the 3DTV service. However, it has two major drawbacks: one is degraded video quality and the other is that legacy TVs cannot show

2D video. In order to provide the 3DTV service of full HDTV quality and at the same time 2DTV service to legacy viewers, we need to send two images of full resolution encoded separately. Video coding technology has been improving very much since MPEG-2 standard was adopted for HDTV broadcasting, and we now have new tools with much higher efficiency like AVC and HEVC. Thus, for backward-compatible high quality 3DTV service with minimum bitrate increase, we obviously need to study hybrid video coding schemes and draw parameters for optimal operation.

In this paper, we first present new hybrid coding schemes: MPEG-2 and AVC/HEVC with inter-view prediction and/or joint rate control, and then analyze the performance and properties of the coding schemes to show the quality vs. bit-rate, optimal bit allocations for best subjective 3D quality.

8043-03, Session 1

3D video capturing for multiprojection type 3D display

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We are researching 3D video to establish an ultra-realistic communication system based on advanced 3D image technologies. We developed a multi-view 3D display using high-definition projectors. The displayed 3D images are 70 inches size with resolution of 1,920 (H)×1,080 (V) and a viewing angle of about 40 degrees. However, the displayed 3D images are only computer-generated graphics or still images of real objects. It is not possible to capture and display real moving objects like people that are crucial contents for realistic communications.

To capture 3D video and display real moving objects, we studied a capturing method using a camera array for a multi-projection type 3D display. First, we analyzed the optimum camera arrangements and image signal processing for several multi-projection type 3D displays. We also clarified the relationship between the calibration error and the quality of the reconstructed 3D images and estimated the required accuracy of the camera calibration.

Second, in experiments, we developed a multi-camera system using 30 high-definition video cameras to capture the moving objects. The registrations of captured video were arranged by high-accuracy camera adjustment and geometrically compensated by image processing optimized for the multi-projection 3D display. As experimental results, we successfully captured and displayed the 3D video of the real moving objects in our 3D video system for the first time.

8043-04, Session 1

Fast and accurate algorithms for quadratic phase integrals in optics and signal processing

A. Koc, Stanford Univ. (United States); H. M. Ozaktas, Bilkent Univ. (Turkey); L. Hesselink, Stanford Univ. (United States)

The class of two-dimensional non-separable linear canonical transforms (2D-NS-LCTs) is the most general family of linear canonical transforms, which are important in both signal/image processing and optics. Application areas include noise filtering, image encryption, design and analysis of ABCD systems, etc. In optics, 2D-NS-LCTs can represent not only systems involving anamorphic/astigmatic components and reference surfaces, but also other interesting systems like optical mode converters and resonators. To facilitate and use them in applications, one must obtain a digital computation method and a fast algorithm to calculate the input-output relationships of these transforms. In this paper, we derive an algorithm of ~NlogN time, N being the two-dimensional space-bandwidth product. Despite the highly oscillatory nature of the integral kernel, we manage the sampling rate to ensure that the number of samples used is sufficient, but not much larger than the space-bandwidth product of the input signal so that the algorithm is as efficient as possible. The straightforward method of sampling the input field and the kernel, and then calculating the output field, is not suitable for several reasons. Firstly, due to the highly oscillatory nature of the integral kernel, a naive application of the Nyquist sampling theorem to determine the sampling rate causes an excessively large number of samples and inefficient computation. Second, ignoring the kernel oscillations and determining the sampling rate according to the input field alone may cause an under-representation of the output field in the Nyquist-Shannon sense. To overcome these issues we also develop a space-bandwidth tracking method.

8043-05, Session 2

Research activities on digital holographic 3D displays in Japan

H. Yoshikawa, Nihon Univ. (Japan)

Recently, researches on digital holographic 3D display are getting very active as well as the digital holography for 3D image acquisition. This paper reviews recent research activities in Japan, including digital holographic 3D video displays, digital holographic printers and computer-generated holograms. The holographic video display includes 100 megapixel full-color full-parallax display, horizontal scanning display, enlarged viewing angle display. For the fringe printer, laser plotter and tiling systems are introduced. For the computer-generated hologram, various kinds of hologram types are described as well as fast computation methods.

8043-06, Session 2

Development of electronic holography toward ultra-realistic communication

K. Yamamoto, Y. Ichihashi, T. Senoh, R. Oi, T. Kurita, National Institute of Information and Communications Technology (Japan)

Holography is the technology to reconstruct ideal 3-D objects in space. Therefore, it has long been attracting great deal of attention to use holography for 3-D display. To realize ultra-realistic communication, we have been developing electronic holography system that captures 3-D objects such as human beings under natural light and displays their reconstructed objects by electronic holography. We will introduce our progress and current system in this talk.

One of the systems we will introduce is real-time color holography system for live scene. It includes three blocks. The first block is capture block that uses IP (Integral Photography) to capture color 3-D objects under natural light. It consists of a lens array and a video camera. The second block is processing block that generates holograms rapidly by FFT (Fast Fourier Transform) with random phase adding in RGB planes. The final block is display block that displays holograms to reconstruct color 3-D images. It consists of three LCDs (Liquid Crystal Display) and laser sources with some optical systems.

8043-07, Session 2

Ray-based and wavefront-based holographic displays for high-density light-field reproduction

M. Yamaguchi, Tokyo Institute of Technology (Japan)

For next-generation autostereoscopic 3D displays, the optical reproduction of light-field is promising because it enables to produce highly realistic 3D images. This paper demonstrates two different

approaches for 3D display with high-density light-field reproduction; ray-based and wavefront-based techniques. As a ray-based display though a hard copy 3D image, a holographic 3D printer is introduced, which automatically outputs high-resolution full-parallax holographic stereograms from 3D image data. High-quality full-color 3D images were experimentally obtained with excellent gloss and texture appearances. On the other hand, there is a limitation in ray-based displays, i.e., the resolution of the image far from the display plane is degraded. The wavefront-based holographic display is thus expected to breakthrough such limitation for deep 3D image reproduction. For this purpose, we have proposed a technique for calculating computer generated hologram, in which the wavefront is derived from the light-ray information. This method can reproduce deep 3D images without resolution degradation even though the wavefront is generated from ray information. In the method, the light-rays are sampled numerically at a ray-sampling plane defined near the image location, and they are transformed to the wavefront by using Fourier transforms. Then the wavefront propagation is calculated based on the diffraction theory, resulting in high-resolution display of deep 3D scene, while realistic image is obtained from the light-ray information calculated by conventional rendering techniques for computer graphics. The experimental results of both ray-based and wavefront-based 3D displays are demonstrated by the printed holograms, and the potentials of future holographic 3D displays are discussed.

8043-08, Session 2

Digitized holography: spatial 3D imaging of virtual and real objects

K. Matsushima, Y. Arima, S. Nakahara, Kansai Univ. (Japan)

In classical holography, the object wave of a real object is recorded on light-sensitive films by the interference with reference waves, and the object wave is reconstructed by diffraction by the interference fringe. Recent evolution of computer, image sensor, and micro fabrication technologies make it possible to digitize this whole process. Moreover, recent development of computer algorithms allows us to synthesize the object wave of completely virtual object whose shape and properties are given by the numerical model.

We demonstrate the actual spatial 3D images of virtual and real objects, in addition, the hybrid of that. The holograms more than 6.5 x 6.5 cm2 in dimension reconstruct spatial images with a viewing angle at least 37 degree in full-parallax. These holograms are made of chrome-coated glass used for photo masks and fabricated by a laser lithography system. Therefore, the fabricated holograms are chemically stable without suffering aging-degradation.

The object waves for virtual 3D model are numerically synthesized by polygon-based algorithm developed for computation of several giga-sampled wave-fields of occluded 3D scenes within several tens hours. The wave-fields emitted by real-existent objects are captured by using a technique of synthetic aperture digital holography. The captured wave-fields have a cross section more than 8 x 7 cm2 and the sampling interval less than 1 micro meter.

These wave-fields are optically reconstructed by the principle of holography. As a result, the produced spatial 3D images give a strong sensation of depth and reality, which never has been caused by conventional 3D systems.

8043-09, Session 3

View-dependent lightfield composition

K. Utsugi, M. Yamasaki, T. Koike, M. Oikawa, Hitachi, Ltd. (Japan)

We have developed a method for use with autostereoscopic display systems called “Extended integral photography based on overlaid multiple projections (IPOP).” We applied the proposed method to a new autostereoscopic display system (12-inch, 24 projectors) and were able to construct a 4D light field viewable at wide angles (more than 75 degrees for both vertical and horizontal) on a display plane. Conventional integral photography imaging methods require high-cost device components, i.e., a high-density and high-definition micro lens array and a display panel of extremely high-resolution. Our method uses a multi-projector system in which each element projector is one that is commercially available. These projectors individually display integral images on a coarse lens array screen and the integral photography images from each projector are then observed as independent overlaid image comprised of light spots in the elemental micro lens. The total system provides superimposed scalable high-resolution images by increasing the number of projectors. This full-fledged full parallax display not only generates an accurate representation of 3-d geometry but also substantializes view-dependent display images. Another of our current goals is describing a new principle of representation and postproduction process of a view-dependent 3-d image editing for this display. In this presentation, we also explain techniques and applications for the view-dependent composition of light field images for full parallax autostereoscopic displays. We use the autostereoscopic display to present our application examples of how view-dependent information presentation and concealment, texture, and BRDF representation via motion parallax perform in the auto-stereoscopic environment.

8043-10, Session 3

Fully programmable display parameters in integral imaging by smart pseudoscopic-to-orthoscopic conversion

M. Martinez-Corral, H. Navarro, G. Saavedra, Univ. de València (Spain); R. Martinez-Cuenca, Univ. Jaume I (Spain); B. Javidi, Univ. of Connecticut (United States)

Previously, we reported a digital technique for formation of real, non-distorted, orthos-copic integral images by direct pickup. However the technique was constrained to the case of symmetric image capture and display systems. Here, we report a more general algorithm which allows the pseudoscopic to orthoscopic transformation with full control over the display parameters so that one can generates a set of synthetic elemental images that suits the characteristics of the Integral-Imaging monitor and permits control over the depth and size of the reconstructed 3D scene.

8043-11, Session 3

3D integral imaging with unknown sensor positions

X. Xiao, M. Daneshpanah, M. Cho, B. Javidi, Univ. of Connecticut (United States)

Integral imaging is a 3D sensing and imaging technique which can be applied in many diverse fields. In integral imaging, multiple 2D intensity images are captured by a microlens array or a pinhole array. Conventional 3D integral imaging systems require that all the sensor positions in the image capture stage are known. But in certain image pick up geometries, it may be difficult to obtain accurate measurement of sensor positions such as sensors on moving platforms and/or randomly distributed sensors. In this paper, we present a 3D integral imaging method with unknown sensor positions. In the proposed method, all the sensors are randomly distributed on a plane with parallel optical axes. More, only the relative position of any two sensors is needed whereas all other sensor positions are unknown. We combine image correspondences extraction, camera perspective model, two view geometry and computational integral imaging 3D reconstruction techniques to estimate the unknown sensor positions. The experiment results executed both in lab and outside show the feasibility of the proposed method in 3D integral imaging. Furthermore, the experiments indicate that the quality of reconstructed images by using the proposed sensor position estimation algorithm can be improved compared to the ones by using the physical measurements of the sensor positions.

8043-12, Session 3

Method of enlarging horizontal viewing zone in integral imaging

M. Miura, J. Arai, M. Okui, Japan Broadcasting Corp. (Japan); F. Okano, Japan Broadcasting Corp. (Japan) and NHK Engineering Services (Japan)

Integral imaging can provide binocular parallax and smooth motion parallax along both horizontal and vertical direction without special glasses. A horizontal viewing zone of reconstructed images is generally equal to a vertical viewing zone. However, it is suitable for specific application that the horizontal viewing zone is larger than the vertical viewing zone. We present a method enlarging a horizontal viewing zone and resolution in integral imaging. On the method enlarging the horizontal viewing zone, we created specially-shaped elemental images. On the method enlarging the horizontal resolution, we allocated more pixels of an elemental image to horizontal direction with an additional optical mask. The horizontal viewing zone can be enlarged with a lens array with shorter focal length as original depth of reconstructed images maintains. We confirmed that the horizontal viewing zone was enlarged by the presented method.

8043-13, Session 3

Realization of precise depth perception with coarse integral volumetric imaging

H. Kakeya, S. Sawada, Univ. of Tsukuba (Japan)

In this paper realization of precise depth perception using coarse integral volumetric imaging (CIVI) is discussed. CIVI combines multiview technology based on integral imaging with volumetric technology by layering display panels to show volumetric elemental images, where DFD algorithm is applied to realize smooth inter-panel connection. In CIVI the size of the elemental lenses are larger than major conventional integral imaging displays so that the viewer can observe dozens of pixels through each lens. With this configuration the viewer can see the pixel edges of real/virtual image generated by the lenses. When multiple panels are set at different depths from the elemental lens, layered real/virtual images are observable from the viewer. As the focus of the viewer can be induced at different depths with this configuration, vergence-accommdation conflict is expected to be reduced. In this paper the authors carry out psychophysical experiments to verify that vergence-accommdation conflict is reduced and depth perception of the viewer is improved by combining multiview and volumetric technologies. Besides the problem of perceptual distortion due to vergence-accommodation conflict, optical distortion has to be taken into account to realize precise depth perception with CIVI. Since CIVI generates real/virtual images optically, distortion of the image can cause distortion of 3D space to be presented. To attain presentation of undistorted 3D space with CIVI, the authors simulate the optics of CIVI and propose an algorithm to show undistorted 3D space by compensating the optical distortion on the software basis.

8043-14, Session 4

Development of three types of multifocus 3D display

S. Kim, D. Kim, Korea Institute of Science and Technology (Korea, Republic of)

Three types of multi-focus(MF) 3D display are developed and possibility about monocular depth cue is tested. The multi-focus means the ability of monocular depth cue to various depth levels. By achieving multi-focus function, we developed 3D display system for each eye, which can satisfy accommodation to displayed virtual objects within defined depth. The first MF 3D display is developed via laser scanning method, the second MF 3D display uses LED array for light source, and the third MF 3D display uses slated LED array for full parallax monocular depth cue. The full parallax MF 3D display system gives omnidirectional focus effect. Two or four parallax images generate omnidirectional focus effect. The proposed 3D display systems have a possibility of solving eye fatigue problem that comes from the mismatch between the accommodation of each eye and the convergence of two eyes. The monocular accommodation is tested and a proof of the satisfaction of the full parallax accommodation is given as a result of the proposed full parallax MF 3D display system. We achieved a result that omni-directional focus adjustment is possible via only two parallax images.

8043-15, Session 4

The effect of stereoscopic display luminance and ambient illuminance on physiological measurement and image quality

P. Wang, K. Chen, S. Hwang, National Tsing Hua Univ. (Taiwan); C. Chen, Industrial Technology Research Institute (Taiwan)

When people watch 3D-Ready TV, the display luminance as well as the ambient illumination is important factors for image quality and physiological comfort.

In this research, an experiment in the multi-view stereoscopic display is conducted. The independent variables are the display luminance with low, middle, and high levels, and the ambient illumination with low and high levels. The dependent variables are subjective physiological comfort assessment, subjective image quality evaluation, and objective visual fatigue measurement. The purpose of the experiment is to find out the appropriate combination of display luminance and ambient illumination for viewers with the most comfort and the best image quality.

The result shows that the display luminance significantly affects the degree of "eye strain" and "seeing the object clearly" of the subjective physiological comfort assessment. As for the subjective image quality evaluation, the ambient illumination statistically influenced viewers' stereoscopic feelings and the display luminance significantly affected viewers' harmonic feelings of 3D pictures. However, no evidence is found that the display luminance, the ambient illumination, and the interaction effects are significant on the objective visual fatigue measurement. Among the six combinations of the display luminance and the ambient illumination, viewers will feel the most comfortable and get the best image quality in the high display luminance and the high ambient illumination.

The outcome of the experiment is expected to find out the optimal display luminance and ambient illumination combination for designers' guidelines and users' references as viewing 3D displays.

8043-16, Session 4

Field of view extension in integral imaging using frequency division multiple access technique: numerical analysis

Z. Kavehvash, K. Mehrany, Sharif Univ. of Technology (Iran, Islamic Republic of); S. Bagheri, IBM Thomas J. Watson Research Ctr. (United States)

Integral imaging could be considered as one of the prospective methods for recording and displaying 3D images based on its distinct features. But there exists some challenges regarding the implementation of this method while one of the most important ones is the field of view and resolution limitation of this method. The reason lies in the limited space of each elemental image and thus the potential of interference between them in case of increasing their field of view or resolution. To solve this problem, multiple access approaches have been proposed and analyzed in our previous work. In this work we investigate using frequency division multiple access (FDMA) idea for solving this problem. The detailed theoretical implementation has been analyzed and numerical results have been obtained for making the results more comprehensive. The

used performance metric was the amount of similarity between the output image and the original image. Simulation results show an increase of more than ten percent in the performance of the 3D reconstructed images using the proposed method.

8043-17, Session 4

Bright 3D display, native and integrated on-chip or system-level

S. C. Ellwood, Jr., C. F. Stirling, Photonica, Inc. (United States)

Photonica pioneered use of magneto-optics and hybrid technologies in visual display systems. The Photonica solution creates arrays addressing hi-speed, solid-state modulators up to 1K times faster that DMD/DLP, yielding high frame-rate and extremely high net native resolution allowing for full-duplication of right eye and left eye modulators at 1080p, DCI 2K, and other specified resolution requirements. The technology enables high-transmission (brightness) per frame. In one version, each integrated chip component (integrated image-engine assembly) processes binocular (or binocular+/multi-viewing angle) frames simultaneously, employing simultaneous right eye/left eye channels, either polarization-based or “Infitec” color-band based channels, as well as pixel-vector based systems. In another version, a multi-chip, massively parallel signal-processing architecture integrates pixel-signal channels to yield simultaneous binocular (or multi-view) frames. This may be combined with on-chip integration. Channels are integrated either through optics elements on-chip or through fiber network or both. Photonica innovation includes the development of periodic vertical structures for display, using conventionally deposited periodic photonic crystal films in the nanometer scale to achieve greater Faraday rotation and dynamic range than single layer films, improved transmission spectrum, and improved color filtering. In addition, large-scale integration of planar magneto-photonic elements, scaling to X-Y array of planar pixels, and magnetic addressing of each element, are enabled by novel optical solutions. The use of periodic planar magneto-photonic pixel modulators and micro- and nano-patterned magneto-photonic materials are created using standard semiconductor based lithographic patterning, but in particular lend themselves to nano-imprint fabrication methods.

8043-18, Session 5

Application issues in the use of depth from (de)focus analysis methods

M. Daneshpanah, K. G. Harding, G. Abramovich, GE Global Research (United States); A. Vemury, U.S. Dept. of Homeland Security (United States)

Recovering 3D object information through analyzing image focus (or defocus) has shown to be a potential tool in situations where only a single viewing point is possible. Precise modeling and manipulation of imaging system parameters, e.g. depth of field, modulation transfer function and sensor characteristics, as well as lighting condition and object surface characteristics are critical for effectiveness of such methods. Sub-optimal performance is achieved when one or more of these parameters are dictated by other factors. In this paper, we will discuss the implicit requirements imposed by most common depth from (de)focus analysis methods and offer related performance predictions. We also describe how a priori information about the objects of interest can be used to improve performance in realistic applications of this technology.

8043-19, Session 5

Automated modified composite pattern single image depth acquisition

C. Casey, L. Hassebrook, Univ. of Kentucky (United States)

The use of structured light illumination techniques for three-dimensional data acquisition is, in many cases, limited to stationary subjects due to the multiple pattern projections needed for depth analysis. Traditional Composite Pattern (CP) multiplexing utilizes sinusoidal modulation of individual projection patterns to allow numerous patterns to be combined into a single image. However, due to demodulation artifacts, it is often difficult to accurately recover the subject surface contour information. On the other hand, if one were to project an image consisting of many thin, identical stripes onto the surface, one could, by isolating each stripe center, recreate a very accurate representation of surface contour. But in this case, recovery of depth information via triangulation would be quite difficult. The method described herein, Modified Composite Pattern (MCP), is a conjunction of these two concepts. Combining a traditional Composite Pattern multiplexed projection image with a pattern of thin stripes allows for accurate surface representation combined with non-ambiguous identification of projection pattern elements. In this way, it is possible to recover surface depth characteristics using only a single structured light projection.

The technique described utilizes a binary structured light projection sequence (consisting of four unique images) modulated according to Composite Pattern methodology. A stripe pattern overlay is then applied to the pattern. Upon projection and imaging of the subject surface, the stripe pattern is isolated, and the composite pattern information demodulated and recovered, allowing for 3D surface representation. Additionally, we introduce techniques which, when implemented, allow fully automated processing of the Modified Composite Pattern image.

8043-20, Session 5

Efficient reconstruction of 3D images from photon starved integral imaging using preconditioned PMLEM

D. Aloni, Ben-Gurion Univ. of the Negev (Israel)

Reconstruction of three dimensional (3D) images from photon starved integral images was successfully achieved by applying several methods including: maximum likelihood estimation, Bayesian estimation, and statistical estimation involving truncated Poisson statistics. Here we present a new estimation approach implementing preconditioned Penalized Maximum Likelihood Expectation Maximization (PMLEM). We show that PMLEM outperforms the previously obtained results. Reconstruction from integral imaging with average counts as low as 10-5 counts per pixels are presented.

8043-21, Session 5

3D sensing and visualization of micro-objects using axially distributed image capture

D. Shin, M. Cho, B. Javidi, Univ. of Connecticut (United States)

There has been great interest in three-dimensional (3D) microscopy to sense, visualize and to extract 3D information from micro-objects. A number of approaches to implement 3D microscopy have been reported with holography and integral imaging for 3D visualization of micro-objects. In general, holography requires a coherent light source and recording of an interference pattern, and may lead to production of speckle effects. On the other hand, integral imaging can operate with an incoherence source. However, 3D microscopy based on integral imaging may compromise the resolution of the reconstructed image due to the distortion, aberration, and low numerical aperture of microlens array.

In this paper, we propose a 3D sensing and visualization of micro-objects using an axially distributed image capture system. Axially distributed image capture is capable of providing high-resolution 3D reconstructed images since it does not use a micro lens array. In the proposed method, the micro-object is optically magnified and the axial images of magnified micro-object are recorded using axially distributed image capture. The camera is moved along a common optical axis and multiple in focus longitudinal images of the micro-object are recorded with the camera in

Return to Contents

different longitudinal positions. The recorded 2D images of the 3D objects are referred to as elemental images. The recorded elemental images are used to visualize the 3D scene using the computational reconstruction algorithm based on ray back-projection. Preliminary experimental results are presented.

8043-22, Session 5

Three-dimensional imaging of objects in scattering medium by using statistical image processing

M. Cho, B. Javidi, Univ. of Connecticut (United States)

In this paper, three-dimensional (3D) imaging of objects in scattering medium is presented. Synthetic Aperture Integral Imaging (SAII) technique is used to record multiple images with different perspectives. Each recorded image is degraded by light scattering. This degradation function can be modeled by Gaussian Theory. The unknown parameter mean of Gaussian distribution can be estimated by using Maximum Likelihood Estimation (MLE). The effects of scattering can be remedied by using estimated degradation function and statistical image processing techniques such as histogram stretching and matching. 3D scene can be visualized by computational 3D reconstruction algorithms of integral imaging. To show the ability of 3D object visualization in scattering medium, experimental results are presented.

8043-23, Session 6

HR3D: high-rank 3D display using content-adaptive parallax barriers

D. R. Lanman, R. Raskar, Massachusetts Institute of Technology (United States)

We optimize automultiscopic displays built by stacking a pair of modified LCD panels. To date, such dual-stacked LCDs have used heuristic parallax barriers for view-dependent imagery: the front LCD shows a fixed array of slits or pinholes, independent of the multi-view content. While prior works adapt the spacing between slits or pinholes, depending on viewer position, we show both layers can also be adapted to the multi-view content, increasing brightness and refresh rate. Unlike conventional barriers, both masks are allowed to exhibit non-binary opacities. It is shown that any 4D light field emitted by a dual-stacked LCD is the tensor product of two 2D masks.

Thus, any pair of 1D masks only achieves a rank-1 approximation of a 2D light field. Temporal multiplexing of masks is shown to achieve higher-rank approximations. Non-negative matrix factorization (NMF) minimizes the weighted Euclidean distance between a target light field and that emitted by the display. Simulations and experiments characterize the resulting content-adaptive parallax barriers for low-rank light field approximation.

8043-24, Session 6

Comparisons of perceived images from three different stereo camera arrangements

J. Son, S. Yeom, D. Lee, Daegu Univ. (Korea, Republic of); M. Park, Korea Institute of Science and Technology (Korea, Republic of)

Stereoscopic image is regaining its popularity due to the commercially available stereoscopic TV based on high speed LCD and shutter glasses, and mobile devices with stereoscopic image display. However, it has been known that stereoscopic images are always subject to distortions whenever the photographing and viewing conditions are not the same. Since the amount of distortions in the perceived image are different for stereoscopic image pairs from different stereo camera arrangements such as parallel, converging and diverging, proper selection of a camera arrangement for a specific device can minimize the distortion and enhance the depth sense. Compared with the parallel and converging arrangements, the diverging is developed recently. Its perceived image characteristics are almost opposite to that of the converging. It can be used for the mobile device where space is limited to install a stereo camera with a wide inter-camera distance. In this paper, the characteristics of the perceived images for the camera arrangements are analyzed for possible application to a specific device, and to compensate puppet theater effect and stereoscopic vision deficiency.

8043-25, Session 6

Compensation of stereoscopic crosstalk in 3D display by equalizing gamma characteristics

D. Kim, S. A. Chestak, Samsung Electronics Co., Ltd. (Korea, Republic of)

Perfect displaying of stereoscopic 3D image requires both correct displaying of gray-levels and minimization of ghosting, caused by crosstalk between left and right channels. Correspondence between the input gray level and output luminance displayed by the display system is defined by gamma characteristic, standardized for each display application.

Ghosting in the disparity region of 3D image also can be described in terms of gamma characteristics. Whereas the background and foreground regions of 3D image are always displayed in accordance with specified gamma characteristic, the disparity regions in presence of crosstalk are displayed with distorted gray levels. Ghosting at different input gray levels can be expressed by the difference between the distorted and undistorted gamma characteristics. Known methods of crosstalk compensation are focused just on minimizing the crosstalk. A method of gray-to-gray crosstalk compensation, presented in the paper, minimizes the difference between gamma characteristics in the background (foreground) regions of 3D image and in the disparity regions. Experimentally we demonstrated compensation of residual crosstalk in time sequential stereoscopic system by substituting each gray level of input stereoscopic images with modified gray level while keeping the gamma characteristic similar to that of 2D display.

8043-26, Session 7

Virtual touch on 3D-images based on embedded optical sensor array system

Y. Huang, G. Wang, S. Tung, M. Ma, National Chiao Tung Univ. (Taiwan); H. Tseng, J. Lo, C. Kuo, AU Optronics Corp. (Taiwan)

We proposed a virtual 3D-touch system, which can detect the 5-axis (x, y, z, theta, phi) 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.

8043-27, Session 7

Applications of liquid crystal lens for autostereoscopic 2D/3D display based on tablet personal computer

S. Liu, Chunghwa Picture Tubes, Ltd. (Taiwan)

This work designs a liquid crystal (LC) lens which uses LC to make a gradient index (GRIN) lens, to achieve switching between general 2D and autostereoscopic 3D display. Since tablet personal computer (PC) has recently become popular consumer electronics, we develop some novel 3D display applications on this product.

In this paper, first, we discuss principles of the 3D technique, and simulate LC properties of the LC lens and optical tracing of the 3D display. To analyze some important LC lens parameters, such as different rubbing direction compared with electrodes orientation, various cell gap and electrode structures with lens performance, and diverse LC lens types with optical effect for a high 3D quality, we obtain the optimal design from the simulations.

Second, we develop some novel 3D applications by using the LC lens. One is 2D and 3D coexistence display; at the same time, it shows a regular 2D and autostereoscopic 3D display on different regions of 3D panel. Another is two orientations 3D display; with this design, there is no up and down, so it shows high quality 3D image orientation with every turn. The other is free movement 3D display without pseudo-stereoscopy; applied the driving voltage on designate electrodes, the LC lens could change its position of focal point, and the 3D viewing zone will be changed, too. As it applies a human face detector to catch observer position, a no pseudo-stereoscopy 3D display will be achieved.

Finally, the performance of the above designs is verified through the measurement results for angular luminance and 3-D crosstalk. We believe that using LC lens to develop 3D applications in tablet PC has a great potential in the future.

8043-28, Session 7

A method for taking a right scaled depth sense in multiview autostereoscopy: using a recomposed hybrid object space based on the actual images by both multi Z-depth and common cameras

K. Lee, S. Kim, Korea Institute of Science and Technology (Korea, Republic of)

In stereoscopy, depth distortion is a serious problem to provide the correct depth sense of the object when the reconstructed depth image was displayed and perceived. The numerous studies have been reported to solve the problem but they did not give us a general solution because the causes inducing problem are cross linked between the stereoscopic system and observational constraints. In this paper, we suggested a way that the objective space transformation as the distorted objective space to make a perceived scaled depth sense using a hybrid camera system consisted of a depth camera and common cameras as a tool of multi-views actual images acquisition. In detail, the constraints can be altered to the amount of inversed distortion likes the transformed objective space. Firstly, we have taken a Z-map of multi views by Z-depth cameras having a same interval then divide and recompose the depth layers in virtual space by the linear relationship between the perceived scaled depth and the objective space before transformed. Secondly, we did re-map the color information of the objective space taken by the common cameras to the replaced depth layers. Consequently we can perceive the right scaled object depth sense without a depth distortion regardless of any size of display because we have already considered all of constraints in both systematic and observational term to provide the scaled depth. We respect this investigation to advanced stereoscopic circumstance such as the tele-operating Medical surgery, Military and Educations.

8043-29, Session 7

3D imaging and wavefront sensing with a plenoptic objective

J. M. Rodríguez-Ramos, Univ. de La Laguna (Spain); R. López López, Instituto de Astrofísica de Canarias (Spain); J. P. Lüke, J. G. Marichal-Hernández, F. Rosa González, Univ. de La Laguna (Spain)

Plenoptic cameras have been developed the last years as a passive method for 3d scanning. Several superresolution algorithms have been proposed in order to increase the short resolution of the lightfield acquisition when using microlenses arrays. A number of multiview stereo algorithms have also been applied in order to extract depth information from plenoptic frames. Real time developments have been implemented using specialized hardware as Graphical Processing Units (GPUs) and Field Programmable Gates Arrays (FPGAs), thanks to their parallel nature.

The terrestrial atmosphere degrades the telescope images due to the diffraction index changes associated to the turbulence. These changes require a high speed processing, 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.

In this paper, we will present not only our own implementations related with the cited in the above paragraphs, but also our new developments: a) a portable plenoptic objective to transform every conventional 2d camera in a 3D plenoptic camera, and b) the plenoptic camera used as a wavefront phase sensor for adaptive optics (OA).

These advances allow a wide versatility for the plenoptic sensors, and this constitutes a short contribution to relate the wave optics and the computer vision as many authors claim.

8043-30, Session 8

Inverse problem approach for digital hologram reconstruction

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Digital holography (DH) is increasingly used for its time-resolved three-dimensional (3D) imaging capabilities. A 3D volume can be numerically reconstructed from a single hologram. Applications of DH range from experimental mechanics, biology, and fluid dynamics. Improvement and characterization of the 3D reconstruction algorithms is a current issue.

Over the past few years, numerous algorithms for the analysis of holograms have been proposed. They are mostly based on a common approach for hologram processing: digital reconstruction based on the simulation of the hologram diffraction. They suffer from artifacts intrinsic to holography: twin-image contamination of the reconstructed images, image distortions for objects located close to the hologram borders. The analysis of the reconstructed planes is therefore penalized by these defects. In contrast to this approach, the inverse problem perspective does not transform the hologram and performs object detection by matching a model of the hologram and sometimes using a priori constraints. This technique extracts more information from the hologram and solves two essential problems: the improvement of the axial accuracy and the enlargement of the reconstructed field beyond the physical limit of the sensor size (out-of-field reconstruction). The drawback of this approach is a computation load heavier than that of the classical techniques which can be solved using the power of parallel hardware architecture of GPU.

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8043-31, Session 8

Three-dimensional imaging of dynamic phenomena in micro-objects using phase contrast digital holographic interference microscopy

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Imaging of transparent micro-objects objects, especially living cells, becomes a challenging problem since such objects do not appreciably change the amplitude of the electromagnetic radiation interacting with it. Phase contrast techniques can be used to overcome this hurdle. Digital holography is one of the most effective tools for phase contrast microscopic imaging of transparent objects and it yields the three dimensional profile of the object under investigation. Another advantage of digital holography is that of numerical focusing, allowing one to focus on to any desired object plane. Since the numerical reconstruction of holograms yields the complex amplitude of the object wavefront, it can be used to reconstruct the phase profile of the object wavefront. From this phase information, three dimensional optical path length profile of the object under study is obtained. The variation of the obtained optical path length with time provides the morphological changes occurring to the object. This morphological change is related to the effect of the external agencies acting upon the object. To negate the effect due to imaging optics holograms, with and without the object are recorded and the reconstructed phases are compared. Since here propagation distances involved are of the order of millimeters, angular spectrum propagation approach towards scalar diffraction theory is used for the numerical reconstructions. This method has the added advantage that it can separate out the different diffracted beams in the frequency spectrum and hence there will not be overlap between any of the three beams in the reconstructions.

8043-32, Session 8

Quantitative analysis of three-dimensional biological cells using interferometric microscopy

N. T. Shaked, A. P. Wax, Duke Univ. (United States)

Live biological cells are three-dimensional microscopic objects that constantly adjust their sizes, shapes and other biophysical features. Wide-field digital interferometry (WFDI) is a holographic technique that is able to record the complex wavefront of the light which has interacted with in-vitro cells in a single camera exposure, where no exogenous contrast agents, such as fluorescent dyes, are required. From the recorded complex field, the fully quantitative phase profiles of cells can be obtained. However, simple quasi-three-dimensional holographic visualization of the cell phase profiles need not be the end of the process. Quantitative analysis should permit extraction of numerical parameters which are useful for cytology or medical diagnosis. Using a transmission-mode interferometric setup, the resulting phase profile represents the multiplication between the integral refractive index and the thickness of the sample. These coupled variables, the refractive index and the thickness, may not be distinct when acquiring the phase profiles of dynamic cells. Many morphological parameters which are useful for cell biologists are based on the cell thickness profile rather than on its phase profile. This lecture will present methods to decouple the cell thickness and its refractive index using the WFDI-based phase profile. We will also present a novel approach, called whole-cell-imaging, which is able to extract useful numerical parameters on the cells even in cases where decoupling of cell thickness and refractive index is not possible or desired. Experimental results obtained in our laboratory for various types of biological cell systems will be presented throughout the lecture.

8043-33, Session 8

Integration of microscopic holograms based on view compensation

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Digital holography is a 3-D imaging technology that provides phase information. It has been used for microscopy in many applications as 3-D surface recognition, biophotonics and so on. However, it is not easy to obtain accurate information when objects have right angle shapes and measured vertically. To make ease the condition an object is rotated to obtain 3-D information in trading off some shape view, but if several holograms are taken for the same object at different views the trade-off information can be reconstructed by topographic compensation. This paper suggests a method of integrating microscopic holograms using view compensation. View compensation is processed by feature extraction and object motion compensation.

8043-34, Session 8

Phase contrast imaging using digital holography

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Phase shifting common path digital holography can be used to overcome the stability problems created by mechanical shocks and temperature fluctuations in the general type of digital holographic set up such as Mach-Zehnder set up.[1,2,3]. However, these optical setups involve many optical components and very difficult to produce accurate phase shifts. We propose a new method to carry out phase contrast imaging using in-line digital holography. The proposed method uses the principle of diffraction from a phase grating which is displayed on SLM placed at the Fourier transform plane of a lens . The first order diffracted light from this grating is collected by a lens which then forms an image on a CCD for image visualization. The un-scattered light through the sample (dc component) acts as the reference beam for the common path interferometer. A phase grating is displayed on the SLM and a circular area corresponding to the dc spot is chosen. The grating within this circular area is shifted with respect to the rest of the region. This will introduce an amount of phase-shift between the light diffracted from these two different regions. Thus controlled amount of phase-shifts can be obtained by shifting the phase grating with pre-calculated steps. One can easily use the four step phase shifting method to retrieve the phase distribution of the specimen. Proof-of-concept experiments have been carried out using simple objects such as human hair, optical fiber etc.

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8043-35, Session 8

Dual wavelength digital holography phase unwrapping by linear regression

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In digital holographic microscopy, the superposition of an object and reference wave is recorded by a CCD camera. The hologram, reconstructed numerically, contains information about the entire optical field allowing for both intensity and phase imaging to be performed. Phase imaging of objects with optical height variation greater than the wavelength of light is ambiguous and results in phase being wrapped. Previously, a technique based on comparison of two phase images of the same object recorded at different wavelengths has been introduced. This dual wavelength technique generates an extended range "beat" wavelength phase image, but also greatly increases the uncertainty of measurements. Therefore, the beat wavelength phase image is used to subsequently adjust one of the original single wavelength phase images in order to reduce the uncertainty. By comparing the two phase images directly, our dual-wavelength linear regression method avoids the unnecessary step of generating the beat wavelength phase image, so the two phase images can be accurately unwrapped via pixel by pixel comparison. Our unwrapping method can process complex topologies, computationally fast and also the limitations on the total optical height are significantly relaxed. We demonstrate the results of phase unwrapping using our method on objects that are a few wavelengths high, where the measurement uncertainty is kept low. We also show that in the case of objects that are many wavelengths high this method is capable of producing a phase map free of discontinuities, which would have been impossible to unwrap using a "traditional" dual-wavelength phase unwrapping.

8043-36, Poster Session

3D abnormal behavior recognition in power generation

J. Su, Harbin Univ. of Science and Technology (China); Z. Wei, North China Electric Power Univ. (China)

This paper peoposed an abnormal behavior recognition method in power generation. Because color and shape were fixed, it adopted edge detecting method using color to recognize object in worker. It used geometric character of skeleton and its angle to express sequence of three-dimensional human behavior data and used Semi-join critical step Hidden Markov Model, weighing probability of critical steps' output to reduce the computational complexity. It selected some skeleton frames from 3D behavior sample to form a critical step set which was a bridge linking 2D observation behavior with 3D human joints feature. In the beginning of recognition progress, it found the best match for every frame of 2D observed sample in 3D skeleton set. After that, 2D observed skeleton frames sample would be identified as a specifically 3D behavior by behavior-classifier. Effectiveness is demonstrated by experiments in similar power generation environment.

8043-38, Poster Session

Reconfiguration methods of viewing zone in mobile auto-stereoscopic display

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Generally, auto-stereoscopy has a shortcoming as a fusible stereo condition. Since, in moving state, the viewer cannot keep a viewing distance between viewer and mobile auto-stereoscopic display panel. Thus the distance will be an important constraint for embodying a good fusible stereo in this paper.

The first problem is the viewer's parallel movement which is defined as the parallel direction of mobile auto-stereoscopic display panel. In previous works, the first problem was solved by dynamic barrier type has been reported one solution and other types of solution using image processing also has been reported. At this time, a resolution of each viewpoint image is not changed.

Then, other problem is the viewer's normal directional movement to the display. A method of image mapping algorithm is used to solve it. However, it has two disadvantages which are a low resolution of nth view image. So, this solution is not suitable to second problem.

For this reason, we proposed a new method for adjusting the distance making suitable fusible stereo despite movement.

Equitation of parallax barrier design is used in this solution. So, in our proposed method, the changing barrier position is used in proportion to a distance between display panel and viewer position in order to above problem. Uniform image resolution is advantage of the new method.

8043-39, Poster Session

Digital holographic microscopy of optically trapped three-dimensional microstructures

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Digital holographic microscopy provides a non-destructive and quantitative phase contrast imaging that is suitable for high resolving investigations of living cells. On the other hand, for many applications including cell analysis the immobilization of the sample under study is a crucial task. Optical trap is an elegant candidate to immobilize the micro samples. In this work, digital holographic microscopy is integrated with an optical trapping setup. This combination is of particular advantage for quantitative visualization of three dimensional structures that are trapped by laser beam. The recored hologram by CCD can be post-processed to three-dimensionally reconstruction of the trapped objects.

8043-40, Poster Session

Three-dimensional speckle-noise reduction by using computational integral imaging and statistical point estimator

I. Moon, Chosun Univ. (Korea, Republic of); B. Javidi, Univ. of Connecticut (United States)

A 3D approach to speckle-noise reduction of objects in coherent imaging by use of computational integral imaging (II) and a parametric point estimator is overviewed. Using multiple image channels in II, the elemental image set of a 3D object having random speckle-noise patterns are recorded from different perspectives. The speckle-noise-reduced 3D image of the original object has been numerically reconstructed from the recorded elemental image set by ray back propagation algorithm to an arbitrary image reconstruction plane using a parametric point estimator. Optical experiments to verify the performance of the speckle-noise reduction method are overviewed.

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8044-01, Session 1

Ground jammer localization with two satellites based on the fusion of multiple parameters

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GPS receivers, radar receivers and communication systems are subject to long-range (150 - 200 km) jamming and require anti-jam techniques for successful operation. A jammer emitter transmits signals falling in the target receiver's working bandwidth with a power much larger than the target receiver's desired signal, and floods the target receiver's desired signal. Anti-jam techniques include spread spectrum, antenna technique, localizing and destroy, etc. In this paper, we present a localization method based on the fusion of time-difference-of-arrival (TDOA), frequency and direction of arrival (DOA) using an extended Kalman Filter (EKF). In the proposed technique, the jammer's DOA's with respect to the two satellites are first fused to provide a coarse estimation of the jammer position, and then the coarse position is used as the initial value for the fusion of DOA's and TDOA for refining the jammer position. Simulations show that the proposed method can provide high localization accuracy for anti-jamming.

8044-02, Session 1

Track splitting for improved tracking performance in a cluttered environment using PDAF

X. Tian, Y. Bar-Shalom, Univ. of Connecticut (United States); E. P. Blasch, K. D. Pham, Air Force Research Lab. (United States); G. Chen, DCM Research Resources LLC (United States)

For tracking a target in a heavily cluttered environment, the Probabilistic Data Association Filter (PDAF) is very efficient and can significantly reduce track losses. However, the uncertainty in the measurements' origin may cause significant degradation in the tracking accuracy of the PDAF, and the PDAF will diverge when the clutter density is above a certain threshold [1]. In this paper we explore the technique of splitting the track of the target into sub-tracks running in parallel. Each sub-track occupies a portion of the uncertainty region of the original track. As a result, the sub-tracks maintained using PDAF will be more selective over the incoming measurements (including detection and false alarms), and have less loss in tracking accuracy. The splitting of the track will incur a significant amount of additional computation cost. The problem of how to do this most effectively to improve the tracking performance will be addressed. Due to the simplicity of the PDA algorithm and the hugely improved parallel processing capability of computer systems, the proposed algorithm is very promising in practical tracking applications.

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8044-03, Session 1

Scheduling of a constellation of imaging satellites with usage constraints

P. J. Shea, N. Nasgovitz, Black River Systems Co. (United States)

The problem of automated scheduling a constellation of satellites to achieve maximum information content is a challenging problem. This optimization problem is further complicated when one attempts to meet collection requirements on various sites all while operating within a power budget. The goal of this research is to find the schedules for a set of satellite sensors that observe a set of fixed ground locations while incorporating visibility, solar angles, time of day, site priority, goal time between collects for each site, and satellite power. Our solution approach utilizes a top-down approach that accounts for information over the entire scheduling window. The higher layers use relaxed satellite information in ever decreasing time windows, while the lowest resolution scheduling layer uses a Lagrangian relaxation based approach which incorporates the power constraint in the objective function. The final step of our approach is to search locally for better solutions using a k-switch local search method to improve on the optimization objective function. This paper will focus on the technical discussion of the hierarchal approach and generation of the final solution via Lagrangian relaxation. We will provide performance results for our approach using simulated data and sensors.

8044-04, Session 1

Fusion of radar and satellite target measurements

M. S. Farber, D. Blaty, G. Moy, C. D. Nealy, The Aerospace Corp. (United States)

An important issue for a ballistic missile defense system (BMDS) is the ability to fuse the information gathered by various sensor systems. In particular, it may be necessary in the future to fuse measurements made using ground based radars with passive measurements obtained from satellite-based EO/IR sensors. This task can be challenging in a multi-target environment in view of the widely differing resolution elements between active ground-based radar and an observation made by a sensor at long range from a satellite platform. Additionally, each sensor system will have a residual pointing bias which has not been calibrated out. The problem is further compounded by the possibility that an EO/IR sensor may not see exactly the same set of targets as microwave radar. Recently, with the launch of the MDA sponsored STSS demonstrator satellites, this issue has taken on increased interest. In order to better understand the problems involved in performing the fusion of metric information from EO/IR satellite measurements with active microwave radar measurements, we have undertaken a study of this data fusion issue and of the associated data processing techniques. In this paper, we present the results of this analysis. To carry out this analysis, we have made use of high fidelity simulations to model the radar observations from a missile target and the observations of the same simulated target, as gathered by a constellation of satellites. The results of fusing the tracks from the two sensing systems are given, along with the ability to estimate the bias of the individual systems. Parametric dependencies of results are presented.

8044-05, Session 2

Optical payload for the STARE Mission

L. M. Simms, V. J. Riot, W. H. De Vries, B. J. Bauman, D. W. Phillion, S. S. Olivier, A. J. Pertica, S. Nikolaev, Lawrence Livermore National Lab. (United States)

Space-based Telescopes for Actionable Refinement of Ephemeris (STARE) is a nano-sat based mission designed to better determine the trajectory of satellites and space debris in orbit around earth. In this paper, we give a brief overview of the mission and its place in the larger context of Space Situational Awareness (SSA). We then describe the

details of the central optical payload, touching on the optical design, the characterization of the on-board image sensor, and several areas where risk mitigation is required for our Cubesat based prototype. Finally, we discuss the on-board star and satellite track detection algorithm to be used on target images acquired during the lifetime of the mission.

8044-06, Session 2

Upstream data fusion of multiple optical sensors for improved tracking and discrimination of geosynchronous satellites

A. J. Newman, C. H. Michaelis, E. M. Klatt, N. L. Mehta, T. S. Spisz, E. G. Kahn, The Johns Hopkins Univ. (United States)

The Johns Hopkins University Applied Physics Laboratory recently completed a project sponsored by the Air Force Space and Missile Systems Center to investigate the operational utility of applying upstream data fusion (UDF) techniques to detection and tracking of dim Resident Space Objects (RSOs) and discrimination of closely-spaced RSOs using space surveillance sensor data. The UDF process taps data at the sensor source and bypasses the data reduction and detection thresholding of the legacy single-sensor processing stovepipes. It then exploits the upstream data by tuning detection sensitivity to respond to faint signatures and discriminating between the true targets and consequent large number of false candidates by fusing data across complementary sensor phenomenologies, diverse view geometries, and different times. In addition, processing of raw (or nearly raw) sensor data allows the UDF algorithms to extract and exploit metric data and error statistics with the highest possible precision, as well as exploit attribute data that is not normally reported in traditional processing chains. The UDF algorithms use Bayesian evidence accrual techniques to gradually discriminate true objects from false alarms as more data is processed. The project executed a ten day triple-site collection campaign using three geographically separated High Accuracy Network Determination System (HANDS) optical sensors at Albuquerque, NM, Maui, HI, and Kwajalein Atoll, Marshall Islands. The UDF prototype processed raw imagery, detected a variety of geosynchronous satellites, and fused the extracted measurement data to track the satellites with order of magnitude better accuracy than available from the Space Catalog and discriminate closely-spaced geostationary satellites that are commonly cross-tagged by current operations.

8044-08, Session 2

Compressive sensing for space imaging applications

S. P. Chin, The Johns Hopkins Univ. Applied Physics Lab. (United States); L. Kennell, U.S. Naval Academy (United States); A. Carr, D. Blodgett, The Johns Hopkins Univ. Applied Physics Lab. (United States); T. D. Tran, D. T. Nguyen, The Johns Hopkins Univ. (United States)

We show that some of the recent progress on compressive sensing (CS), a new approach to data acquisition in which analog signals are digitized not via uniform sampling but via measurements using more general, even random, test functions, are applicable to the imaging needs for SSA. In stark contrast with conventional wisdom, CS theory predicts that given an a priori knowledge of sparsity, we can combine “sub-Nyquist-rate sampling” with digital computational power for efficient and accurate signal acquisition and image reconstruction. We show that this CS theory is indeed applicable and useful in digital hololographic system -in that it allows us to reduce the number of focal plane arrays by 50% without losing essential features of the images, and suggest a way that such a technique may be applicable for space applications in which, in order to move to longer ranges, a larger CCD array needs to be fabricated using an array of smaller CCD arrays. Additionally, there many SSA situations that need to limit the number of pixels that are collected in order to maintain the computation feasibility of processing space images in a reasonable amount of time. Compressive sensing offers a path to sparsely sample the objects from a distance and produce images with resolution comparable to the fully populated array.

8044-09, Session 2

Homography-based change detection for space-based satellite inspection

R. Buffington, J. E. McInroy, Univ. of Wyoming (United States)

In order to perform space situational awareness, it is necessary to maintain surveillance of objects in Earth orbit. A system of space-based imaging sensors could make much more detailed inspections of the existing Resident Space Objects (RSOs). However, in order to preserve bandwidth, it is desirable to send the groundstation only a subset of all images which are taken by the inspection system.

This paper presents a change detection algorithm which can detect changes in the appearance of an RSO. A new inspection image is compared to a previously taken base image. In each image, the translation vector and rotation matrix between the camera and the RSO, or pose, is slightly different. Assuming that the points making up each image of the RSO are within a single plane, it is possible to generate a planar homography which is a linear mapping between the two images. The homography is used to estimate the rotation and translation between the camera coordinate systems. This knowledge can be used to warp the inspection image so that it appears as though it was taken from the same coordinate system as the base image. Finally, basic morphological image processing and image thresholding techniques are used to perform change detection.

The algorithm was evaluated by applying it to raytraced inspection images exhibiting varying lighting and pose conditions. Simulation results show that the algorithm can reliably detect damage or other geometrical changes to the RSO.

8044-10, Session 2

Change detection for visual satellite inspection using pose estimation and image synthesis

R. Buffington, J. E. McInroy, Univ. of Wyoming (United States)

Satellites are subject to harsh lighting conditions which make visual inspection difficult. Automated systems which detect changes in the appearance of a satellite can generate false positives in the presence of intense shadows and specular reflections.

This paper presents a new algorithm which can detect visual changes to a satellite in the presence of these lighting conditions. The position and orientation of the satellite with respect to the camera, or pose, is estimated using a new algorithm. Unlike many other pose estimation algorithms which attempt to reduce image reprojection error, this algorithm minimizes the sum of the weighted 3-dimensional error of the points in the image. Each inspection image is compared to many different views of the satellite, so that pose may be estimated regardless of which side of the satellite is facing the camera. The features in the image used to generate the pose estimate are chosen automatically using the scale-invariant feature transform.

It is assumed that a good 3-dimensional model of the satellite was recorded prior to launch. Once the pose between the camera and the satellite have been estimated, the expected appearance of the satellite under the current lighting conditions is generated using a raytracing system and the 3-dimensional model. Finally, this estimate is compared with the image obtained from the camera.

The ability of the algorithm to detect changes in the external appearance of satellites was evaluated using several test images exhibiting varying lighting and pose conditions. The test images included images containing shadows and bright specular reflections.

8044-11, Session 3

Pursuit-evasion orbital game for satellite interception and collision avoidance

D. Shen, DCM Research Resources, LLC (United States); K. D. Pham, Air Force Research Lab. (United States); G. Chen, DCM Research Resources, LLC (United States); E. P. Blasch, Air Force Research Lab. (United States)

This paper develops and evaluates a pursuit-evasion orbital game approach for satellite interception and collision avoidance. Using a coupled zero-sum differential pursuit-evasion game, the pursuer minimizes the satellite interception time and evader tries to maximize interception time for collision avoidance. For the satellite interception problem we design an algorithm for pursuer and one for collision avoidance, where the game solution controls the evader satellite. The interception-avoidance (IA) game approach provides a worst-case solution, which is the robust lower-bound performance case.

We divide our IA algorithm into two parts: first, the pursuer will rotate its orbit to the same plane of the evader, and second, the two spacecrafts will play a zero-sum pursuit-evasion (PE) game. A two-step setup saves energy during the PE game because rotating a pursuer orbit requires more energy than maneuvering within the orbit plane. To rotate the pursuer orbit plane, we utilize a series of small delta-v's less than a given vmax. For the PE orbital game, an optimum open loop feedback saddle-point equilibrium solution is calculated between the pursuer and evader control structures. Using the openloop feedback control rule, each player will calculate their distributed control track state. Numerical simulations are performed to demonstrate the orbital game theoretic approach for satellite interception and collision avoidance.

8044-12, Session 3

A trust-based sensor allocation algorithm in cooperative space tracking problems

D. Shen, G. Chen, DCM Research Resources, LLC (United States); K. Pham, E. P. Blasch, Air Force Research Lab. (United States)

Sensor allocation is an important and challenging problem within the field of multi-agent systems. The sensor allocation problem involves deciding how to assign a number of objects or cells to a set of sensor agents. Generally, in order to make efficient allocations, we need to design protocols that consider both the task performers' costs for the service and the associated probability of success (POS). In our problem, the costs are used sensor resource, and the POS is the object detection probabilities for a given coverage area for given effort criteria. Usually, POS may be perceived differently by different agents because they typically have different standards or means of evaluating the performance of their counterparts (other sensors in the search and tracking problem). Given this, we turn to the notion of trust to capture such subjective perceptions. In our approach, we develop a trust algorithm to construct a novel mechanism that motivates sensor agents to reveal their private information. Then we model the sensor allocation optimization problem with trust-in-loop and solve it using integer-programming. Numerical simulations are performed to demonstrate trust-based sensor allocation algorithm in cooperative space object tracking problems.

8044-13, Session 3

Detection and tracking of LEO collision events using space-based sensors

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In this paper, we present collision event modeling, detection, and tracking using space based Low Earth Orbit (LEO) EO/IR constellation of platforms.

The implemented test bed is based on our previous work on dispersed and disparate sensor management for tracking Resident Space Objects (RSOs). The known RSOs LEO trajectory parameters are tracked by using a first order state perturbation model and the estimates are updated using Monte Carlo sampling techniques. Using multi-hypothesis testing, we estimate if the tracked RSO is on a collision trajectory with a satellite. Trajectories that can lead to a collision are then constantly observed and tracked using observations from EO/IR sensors located on LEO platforms.

The developed algorithms are tested and evaluated on a simulated testbed.

Open problems and future work are discussed.

8044-14, Session 3

Sensor management for collision alert in orbital object tracking

P. Xu, H. Chen, Univ. of New Orleans (United States); D. Shen, G. Chen, DCM Research Resources LLC (United States); K. D. Pham, E. P. Blasch, Air Force Research Lab. (United States)

Given the increasingly dense environment in both low-earth orbit (LEO) and geostationary orbit (GEO), a sudden change in the trajectory of any existing resident space object (RSO) may cause potential collision damage to space assets. With a constellation of EO/IR sensor platforms and ground radar surveillance systems, it is important to design optimal estimation algorithms for updating nonlinear object states and allocating sensing resources to effectively avoid collisions among many RSOs. Previous work in RSO collision avoidance often assumes that the maneuver onset time or maneuver motion of the space object is random and the sensor management approach is designed to achieve efficient average coverage of the RSOs. Few attempts have included the inference of an object's intent in the response to an RSO orbital change. We propose a game theoretic model for sensor scheduling and assume the worst case intentional collision of an object orbital change on one of the known space objects. The intentional collision results from maximal exposure of an RSO's path. The resulting sensor management scheme achieves robust and realistic collision assessment, alerts of impending collisions, and identifies early RSO orbital change lethal maneuvers. We also consider information sharing among distributed sensors for collision alert and an object's intent identification when an orbital change has been declared. We compare our scheme with the conventional (non-game based) sensor management (SMgt) scheme using a LEO-to-LEO space surveillance scenario where both the observers and the unannounced and unplanned objects have complete information on the constellation of vulnerable assets. We demonstrate that with adequate information sharing and optimal sensor management estimation, the distributed SMgt method can achieve the performance close to that of centralized SMgt one in identifying unannounced objects and making early warnings to the RSO for potential collision so that proper collision avoidance action can be taken.

8044-15, Session 4

Fast relative guidance approach for autonomous rendezvous and docking control

M. DeVelle, Y. Xu, Univ. of Central Florida (United States); K. Pham, Air Force Research Lab. (United States); G. Chen, DCM Research Resources LLC (United States)

Relative guidance for autonomous rendezvous and docking is a key technology for many current and future space missions, such as the unmanned on-orbit service. In these missions, it is normally required that the chaser spacecraft can plan a trajectory to the target rapidly, while

controlling the chaser's attitude to align the docking port with that of the target.

To date, many methods have been proposed and applied in rendezvous and docking missions. For example, impulsive maneuver based trajectory design methods based on Lambert's problem or the Clohessy-Wiltshire-Hill's (CWH) equations are proposed. These methods are easy to be implemented, and robust, although the solution might not be optimal. Also continuous thrust methods based on the Pontryagin maximum principal, direct method, and b-spline techniques have been investigated to achieve quasi-optimal orbital rendezvous trajectories. More recent a hybrid method has been proposed to minimize fuel using both continuous and impulsive thrusters. Furthermore, safety has been considered when designing rendezvous trajectories.

This paper will present a recently developed bio-inspired virtual motion camouflage methodology with high order discretization methods to compute the near optimal orbit and attitude trajectories for relative guidance of rendezvous and docking missions rapidly. In this approach, the dimension of the optimization parameters and the computational cost of the online trajectory planning can be reduced significantly. Multiple simulations for either circular or non-circular target orbit cases with the consideration of nonlinear attitude motion planning for docking will be provided to demonstrate the capabilities of the algorithm.

8044-16, Session 4

Control of an industrial robot for hardware-in-the-loop simulation of satellite docking

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Autonomous docking to a flying object in space is a difficult and risky operation hence, the docking system of a servicing spacecraft has to be thoroughly tested and verified before a real space mission can be launched. Ground-based verification of contact-dynamics responses of a spacecraft to a general 3-D physical contact in microgravity condition is very difficult. The traditional test technologies have difficulties in testing full 6-DOF contact dynamics of large and complex space systems. Robotics based hardware-in-the-loop (HIL) simulation is gaining more interest for this purpose. In a HIL simulation system, the system dynamics of a spacecraft including the microgravity condition is predicted by a mathematical model of the multibody dynamical system, because it is very difficult to physically produce a full 6-DOF on-orbit dynamic motion of large satellites on the ground but it is rather easier to accurately model and simulate such dynamics on a computer. On the other hand, contact dynamics is represented by the real hardware interception because such contact action is very difficult to accurately model and simulate on a computer. Therefore, the HIL simulation concept is a combination of both math-model based software simulation and hardware based physical test.

German Aerospace Center (DLR) is developing a new HIL simulation facility called European Proximity Operations Simulator (EPOS). The unique features of the facility, in comparison with the existing HIL simulation systems, are that it uses two heavy-payload industrial robots which can handle a payload up to 250 kg and it allows one robot to approach the other from 25-meter distance away until zero distance. This paper describes a study of how to control the industrial robots used by EPOS to match the impedance of the simulated satellite system, so that the simulated docking behavior will be more realistic. Control of a giant industrial robot to have the same impedance property as a satellite in space is a large challenge because the industrial robot does not have a joint torque control capability and its low-level control software is inaccessible. The problem is solved by developing an admittance control strategy.

8044-17, Session 5

A suborbital flight experiment for validating a satellite inertia identification method

G. Martinez, I. Ferrel, P. Xie, O. Ma, New Mexico State Univ. (United States)

A group of NMSU undergraduate students is developing an autonomous suborbital flight experiment, which is designed to validate a recently developed robotics-based method for identifying the inertia property of a satellite. The method was originally developed at NMSU and studied using computer simulation [1]. However, it has not been experimentally validated because accurately testing the dynamics of a flying body in a full 6-degree-of-freedom (6-DOF) microgravity condition on the ground is too difficult and costly. This flight experiment is one of the steps toward an accomplishment of such a 6-DOF microgravity test of the new inertia identification method.

The student team has designed a manual version of the experiment system and flew it onboard NASA's C-9 microgravity aircraft in 2009 [2]. It was found that the microgravity condition simulated by the parabolic flight was too short in time and too rough in accuracy for a complete experiment. Therefore, they proposed to fly the experiment on a suborbital vehicle which will hopefully provide a better microgravity condition. Their experiment proposal won the first place in a student project contest sponsored by the 2010 Next-Generation Suborbital Researchers Conference, Feb.18-20, 2010, Boulder, Colorado. As a part of the award package the conference sponsors offered the students a free flight opportunity with their suborbital vehicle provided by Masten Space Systems, Inc. The launch date is in the April 2011 timeframe.

Although the experimental condition with a suborbital vehicle will be better, new challenges arise because the vehicle is unmanned and the payload compartment is unpressurized. This means that the experiment system shall be automatic and also qualified for the thermo and vacuum condition of the suborbital flight. The paper will introduce the innovative design of the experiment system and show how it meets the mission goal and the suborbital flight requirements.

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8044-18, Session 5

Spaceborne telescopes on a budget: paradigms for producing high-reliability telescopes, scanners, and EO assemblies using heritage building blocks

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By starting with established and flown hardware (high TRL), and implementing a concurrent engineering environment and seamless team, a mission architect can achieve high reliability and high performance while operating under constrained cost and short implementation schedule. We will describe methods used by the telescope team on the recent WISE mission to manage cost and realize aggressive schedules. We believe these lessons may be evoked for telescopes addressing defense, security and sensing, as well as those for NASA science.

8044-19, Session 5

The isotropic behavior of an anisotropic material: single crystal silicon (SCSi)

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Single crystal silicon (SCSi), with its diamond cubic crystal structure, is completely isotropic in most properties important for space optics. For example, thermal and optical properties are completely isotropic. The elastic and mechanical properties however are direction dependent. But we show that in spite of this, near-isotropic behavior can be achieved with component designs that utilize the maximum elastic modulus in directions with the highest loads.

The most significant anisotropic property of SCSi is the Young's modulus of elasticity. Literature values vary substantially around a value of 145 GPa. The truth is that the maximum value is 169 GPa in the crystallographic direction, higher than that of many materials such as aluminum and invar. And since Poisson's ratio in this direction is an extremely low 0.064, distortion in the plane normal to the load is insignificant. While the minimum modulus is 130 GPa, a calculated average value, such as the Reuss average used for polycrystalline Si, is close to the maximum at approximately 160 GPa. So that he minimum modulus is almost irrelevant.

It is clear then that near-isotropic elastic behavior can be achieved in SCSi components in spite of anisotropic elastic properties when designs utilize this unique behavior.

8044-20, Session 6

Is space the ultimate high ground?

G. J. Meyer, U.S. Air Force (United States)

Military experts often refer to space as the ultimate high ground under the premise that placing systems in orbit give advantages consistent with the military doctrine of high ground. Although space provides the ultimate "observation post", it has none of the other advantages traditionally associated with high ground. Army Field Manual 34-130 states the advantages of holding key terrain, commanding avenues of approach, and using cover and concealment as additional benefits of high ground. Yet none of these additional advantages accrue to systems in orbit. Finally, international restrictions and reciprocity concerns limit the employment of weapons in space nullifying many of the advantages of the "high ground" of space.

8044-21, Session 7

Narrow ion-beam figuring: a figuring tool that enables new optical systems solutions

U. Mueller, J. Stone, B. Peters, L-3 Communications Tinsley Labs. Inc. (United States); T. P. Greene, NASA Ames Research Ctr. (United States)

Previously difficult or impossible shapes can now be placed on visible imaging optical surfaces using Narrow Ion Beam Figuring (NIBF). This technique, unlike classical Ion Beam Figuring (IBF), does not roughen the surface. Furthermore, the method can be used to take optical surfaces to sub-nanometer surface errors and to sub-microradian slope errors. A specific set of applications uses NIBF surfaces at a reimaged pupil plane to impart special characteristics on image creation. Such optics has steep local slope changes that can only be machined by a small tool. Therefore L-3 Tinsley developed the adjustable focus process with tool diameters of less than one mm. Under a contract with NASA Ames a Phase-induced amplitude apodization (PIAA) asphere with extreme slopes was fabricated. Such high-contrast imaging systems are being considered for terrestrial exoplanet searches. To qualify the system for the fabrication process verification samples were developed, that allow the effective spatial frequency range to be evaluated. The resulting improvements to the PIAA are shown.

8044-22, Session 7

Fiber Bragg-grating true-time delay-based multi-RF-beam steering

R. J. Black, B. Moslehi, Intelligent Fiber Optic Systems Corp. (United States); A. Siahmakoun, S. C. Granieri, Rose-Hulman Institute of Technology (United States)

Typical beam-former architectures for receiving multiple simultaneous-independent RF beams involve a True Time Delay (TTD) network to process each beam and are thus very component intensive, costly and require elaborate interfaces/interconnects. Adding the challenges inherent in large size phased array antennas requiring a high degree of pointing accuracy and steering through a wide range of angles would also contribute to exponential growth in components and parts for the beam-forming network. To alleviate such problems, we have designed a novel high-speed, cost-effective and programmable TTD processor/network shared by all beams. A wavelength routing technique is used for beam-steering RF beams in Receive mode. The new architecture implements TTD through a set of fiber Bragg grating (FBG) arrays that controls all antenna elements. In this approach the direction of incident RF beam is determined by the wavelength of the optical carrier through FBG delay lines that select the optical path of each carrier in the C-band for each Transmit/Receive (T/R) element of the antenna. A two-channel two-bit beam-former is experimentally demonstrated and measurements are performed for receive mode and for RF signals. The beam-pattern results show that independent RF beams can be steered successfully using our wavelength-routing technique.

8044-23, Session 7

Radiation-resistant fiber optic gyroscope for space applications

B. Moslehi, Intelligent Fiber Optic Systems Corp. (United States); R. Yahalom, InFiber Technology (United States); R. J. Black, F. Faridian, Intelligent Fiber Optic Systems Corp. (United States); T. Ooi, A. Corder, U.S. Army Space and Missile Defense Command (United States)

Compact, inexpensive, advanced gyroscopic components that can operate in high radiation over large temperature variations as well as the high shock and vibration that accompany launch are essential for next generation space systems. In particular, Inertial Measurement Units (IMUs) that can provide high-resolution stabilization and accurate inertial pointing knowledge are needed. Interferometric Fiber-Optic Gyroscopes (IFOGs) are proving to be a leading technology for tactical and navigational systems. They have performance that is significantly better than MEMS gyroscopes, and , being free of moving parts, have high reliability and a long life compared to the mechanical gyroscopes and dithered ring laser gyroscopes. However, the available architectures limit the potential size and cost of the IFOG. In this paper, we present a new open loop Fiber-Optic Gyroscope (FOG) design, which includes innovative elements and packaging approaches that can substantially reduce size, weight and power (SWAP), providing also the desired radiation immunity and ruggedization to survive stressing thermal space and launch environments asrequired for next generation space systems.

8044-24, Session 8

A thermal infrared hyperspectral imager for small satellites

S. T. Crites, P. G. Lucey, R. Wright, Univ. of Hawai'i (United

States)

The small satellite market and launch opportunities for these satellites are growing, opening a new niche for earth observations exploiting new technologies in focused, short lifetime missions. These low-cost, short-lived missions 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 parts and allowing early-career scientists and engineers to gain experience working on these projects. The Thermal Hyperspectral Imager (THI) is a low-cost COTS based sensor funded by the NASA EPSCOR (Experimental Project to Stimulate Competitive Research) program, and will demonstrate the ways in which a university's scientific program and instrument development can fit into this niche. THI is a low-mass, power efficient thermal hyperspectral imager that will be integrated with a space-qualified pressure vessel to enable the use of COTS components, and will be compatible with small satellite platforms. The sensor is based on a Sagnac interferometer that was developed under DoD and NASA technology development programs and uses an uncooled 320x256 microbolometer array similar to the focal planes used by the LCROSS instrument on the Lunar Reconnaissance Orbiter. The sensor will collect calibrated radiance data at thermal infrared (TIR, 8-14um) wavelengths in 230-meter pixels with 20 wavenumber spectral resolution from a 400-km Earth orbit.

8044-25, Session 8

A 30 frames-per-second 18-million pixel image sensor for space applications

P. P. K. Lee, J. D. Newman, A. P. Sacco, J. A. Nieznanski, ITT Corp. Geospatial Systems (United States)

ITT Geospatial Systems has developed and space-qualified a visible band interline Charge Coupled Device (CCD) image sensor with 18 million pixels using commercial fabrication technology. The sensor is comprised of an 4320 (H) x 4144 (V) array of 8 micron square pixels. With multiple analog outputs each operating at 20 MHz the sensor will support 30 frames per second continuous video capture. The pixel incorporates pinned photodiode, vertical overflow drain and microlens to achieve low dark current, lag-free imaging with high-speed global electronic shutter at high quantum efficiency (QE). The vertical and horizontal CCD's are true two-phase designs which support integrate while read operation. The sensor chip is mounted on an Aluminum Nitride co-fired ceramic package optimized for electrical signal integrity, thermal and optical stability. The architecture supports quadrant redundancy. The complete Detector Chip Assembly (DCA) has been space-qualified to a Technology Readiness Level (TRL) of 6 with Total Ionization Dose of 25 Krad. The sensor exceeds 12-b of dynamic range and 31% QE with less than 5 W of total power. The non-linearity is measured to be 1.5% while the global non-uniformity is less than 2%. The low defect density of the CCD sensor allows high resolution video imaging in a space environment.

8044-26, Session 8

A study of image quality for imagery generated by standard and hybrid intensity interferometers

J. Murray-Krezan, P. N. Crabtree, Air Force Research Lab. (United States)

Intensity interferometry holds tremendous potential for remote sensing of space objects. Whereas spatial resolution of imagery obtained from earth-based observatories is typically limited by both the size of the primary mirror and atmospheric effects, intensity interferometers (IIs) are relatively unaffected by atmospheric distortions and their effective apertures can be substantially larger than is practical for traditional observatories. Image quality is explored for both a standard II telescope array and a hybrid system combining the II outputs with other sensing modalities, such as partially resolved imagery from a traditional imaging telescope. Partially resolved imagery provides an additional constraint for the phase retrieval process required to generate imagery from II measurements. The benefits of this additional a priori information are explored, and when combined with standard constraints such as non-negativity and compact support should include faster convergence, increased sensitivity, and/or greater resolution or image quality. Although the quality of imagery generated by post-processing the II correlation measurements has been explored previously in terms of the modulation transfer function, this is just one metric by which imagery may be judged. We explore other suitable image quality metrics and discuss common aberrations.

8044-27, Session 8

Holographic weapons sight as a crew optical alignment sight

N. Merancy, Booz Allen Hamilton Inc. (United States); B. Dehmlow, L-3 Communications EOTech (United States); J. P. Brazzel, NASA Johnson Space Ctr. (United States)

Crew Optical Alignment Sights (COAS) are used by spacecraft pilots to provide a visual reference for lateral relative position during rendezvous and docking operations to a target spacecraft. NASA's Orion vehicle, which is currently under development, has not included a COAS in favor of automated sensors, but the crew office has requested such a device be added for situational awareness and contingency support. The current Space Shuttle COAS was adopted from Apollo heritage, weighs several pounds, and is no longer available for procurement which would make re-use difficult. In response, a study was conducted to examine the possibility of converting a commercially available weapons sight to a COAS for the Orion spacecraft. The device used in this study was the XPS series Holographic Weapon Sight (HWS) procured from L-3 EOTech. This device was selected because the targeting reticle can subtend several degrees, and display a graphic pattern tailored to docking operations. Evaluations of the COAS were performed in both the Orion low-fidelity mockup and rendezvous simulations in the Reconfigurable Operational Cockpit (ROC) by crewmembers, rendezvous engineering experts, and flight controllers. These evaluations determined that this unit's size and mounting options can support proper operation and that the reticule visual qualities are as good as or better than the current Space Shuttle COAS. The results positively indicate that the device could be used as a functional COAS and supports a low-cost technology conversion solution.

8044-28, Session 8

Navigation Doppler lidar sensor for precision altitude and vector velocity measurements: flight test results

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An all fiber Navigation Doppler Lidar (NDL) system is under development at NASA Langley Research Center (LaRC) for precision descent and landing applications on planetary bodies. The sensor produces high-resolution line of sight range, altitude above ground, ground relative attitude, and high precision velocity vector measurements. Previous helicopter flight test results demonstrated the NDL measurement concepts, including measurement precision, accuracies, and operational range. This paper discusses the results obtained from a recent campaign to test the improved sensor hardware, and various signal processing algorithms applicable to real-time processing. The NDL was mounted in an instrumentation pod aboard an Erickson Air-Crane helicopter and flown over vegetation free terrain. The sensor was one of several sensors tested in this field test by NASA's Autonomous Landing and Hazard Avoidance Technology (ALHAT) project.

8044-29, Session 8

POSE algorithms for automated docking

R. T. Howard, A. Heaton, NASA Marshall Space Flight Ctr. (United States)

POSE (relative position and attitude) can be computed in many different ways. Given a sensor that measures bearing to a finite number of spots corresponding to known features of a spacecraft, a number of different algorithms can be used to compute the POSE. LIDAR is expected to be used on orbit with more frequency (ORION, Dragon, and others are baselining LIDAR sensors for use in automated maneuvering.) This paper explores several algorithms for potential use with a flash LIDAR sensor, utilizing both simulated data and flight data from a video sensor. Comparisons of the results are shown.

8044-30, Session 9

Manipulability analysis of a two-link space robot using differential geometry method

Y. Zhang, H. Sun, Q. Jia, J. Song, Beijing Univ. of Posts and Telecommunications (China)

Space robot is a special robotic system which is expected to perform important tasks in space, like servicing satellites. However, the application of space robots in space creates a number of technical challenges because of the dynamic coupling between manipulator and base. The dynamics coupling between manipulator and base will affect the performance of the manipulator. This phenomenon makes it difficult to control the manipulator, adversely affects the manipulator's manipulability.

For the dynamic coupling characteristic of the space robot , the researching method of robot used on ground can not be directly applied to the space robot. Although reaearchers developed manny methods to study the space robot, earch of these methods has it's limitations.

In this paper, morden differential geometry method is applied to study the motion characteristic of space robot. The kinematic model of the space robot is constructed by using the moving frame method. Based on this kinematic model, a volume element concept which is an invariant is developed to evaluate the manipulability and disturbance of a space robot system. In the contruction process of volume element, the momentum conservation is also considered. By using the volume element concept, a two link space robot is used to discuss the application of this researching metod, and the manipulability of manipulator and it's influence on the base are analyzed.

In comparison to other researching method, this differential geometry method is shown to be useful in performing manipulability and disturbance analysis for space robot in a zero-gravity environment and is more directly and intelligible than the other methods. This method is a new theoretical approach in space robot research which is largely theoretical at this point in time.

8044-31, Session 9

Dynamic analysis of a spherical mobile robot in rough terrains

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In this article, the dynamic equations of a spherical mobile robot, named BYQ-III, are derived by utilizing the Lagrange method. There is no simplification throughout the whole dynamic analysis and the derived dynamic equations can be used for more precise studies of spherical mobile robots' behavior. Considering any possible differentiable function for the terrain's curve, only assuming that the spherical shell will remain in contact with the ground and the elastic effect of the spherical shell is ignored, the effect of the terrain's roughness is completely described in the dynamic equation evaluation. Although there are complicated and nonlinear relations between the spherical shell and rough terrain, proper choice of generalized coordinates leads to the general closed form dynamic equations of motion, and finally results in the effective reduction of simulation time. But there is no need for the numerical method to solve the complex dynamic equation due to the closed form derivation. In the dynamic equation all variables are highly coupled together and their individual effect cannot be decoupled exactly. From this proposed complete model a simplified model for controller design can be extracted and the proposed model description can give an insight about the performance of different controllers of the spherical robots' motion. Simulations with the same initial conditions on a flat surface and rough terrain show that a rough terrain has a considerable effect on the dynamic behavior of the spherical robots. And as the unevenness of the terrain increases, its effect in the dynamic analysis becomes greater and cannot be neglected.

8044-32, Session 9

Mechanical analysis about the spherical mobile robot on the moon environment

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The movement of the spherical robot on lunar environment is analyzed. A model is created by lunar gravity environment, lunar soil and spherical robot. The interaction of lunar soil and spherical robot shell is the focused studies. Mechanical equation of spherical robot is established under the conditions of rest and motion. Mathematical modeling is finished by the software of Matlab. The curve of the relationship of subsidence and resistance of spherical mobile robot when it is at rest and resistance, traction, motor torque of spherical mobile robot when it is moving is found. And then the model of lunar soil is created by the software of ANSYS, the model of spherical robot is created by the software of Pro-E, Send these two models into the software of ADAMS to simulate the interaction of lunar soil and spherical robot at conditions that the robot is rest and moving. Some disperse points of subsidence and corresponding value of resistance, traction, motor torque of the spherical mobile robot have been got. Curves of the relationship of subsidence and resistance of spherical mobile robot when it is at rest and resistance, traction, motor torque of spherical mobile robot when it is moving is made by fitting curve use these points by the software of Matlab. Then compare these curves made by these disperse points with corresponding curves of mechanical equation of spherical mobile robot. They are generally conformable. So the equation of spherical mobile robot is verified. This will be a base for the further study of the Spherical mobile robot using on lunar.

8044-33, Poster Session

An active co-phasing imaging testbed with segmented mirrors

W. Zhao, Beijing Institute of Technology (China)

An active co-phasing imaging testbed with high accurate optical adjustment and control within nanometer order was set up to validate the algorithms of piston and tip-tilt error sensing and real-time adjusting, and also study synthetic aperture optics theory and co-phasing imaging quality evaluation. Modularization design was adopted. The primary mirror is spherical and divided into three sub-mirrors. One of them was fixed and worked as reference sub-mirror, the others were adjustable respectively to the fixed sub-mirror in three freedoms (piston, tip and tilt) by using sensitive micro-displacement actuators in the range of 15mm with resolution of 3nm. The method of two dimension dispersed fringe analysis was used to sense the piston error between the adjacent

sub-mirrors in the range of 200μm with a repeatability of 2nm. And the tip-tilt error was gained with the method of centroid sensing. Co-phasing image could be realized by adjusting the errors measured above with the sensitive micro-displacement actuators driven by a computer. And then, if an expanded aim was inserted in the path, the imaging quality could be observed. The process of co-phasing error sensing and adjusting could be monitored in real time by a scrutiny module set in this testbed. A FISBA interferometer was introduced to evaluate the co-phasing performance, and finally a total residual surface error of about 50nm rms was achieved, in which the error of about 16nm was contributed by the piston.

8044-34, Poster Session

Performance analysis of ground-to-satellite free-space optical communications

T. Benoy, Cochin Univ. of Science & Technology (India)

The possibility of using high data rate optical transmitters for satellite communication channels have generated a great deal of interest in ground to satellite airborne laser communication links(lasercom) .Free space optical communication is the technology used for future communication.It has many advantages compared to radio wave and micro wave communication systems.

Although many works have been done on the field of free space optical communication for terrestrial communication links few works have been done in the field of FSO based satellite communication systems.

In this project we are considering the effects of Scintillation i.e the temporary redistribution of intensity within the beam which is a result of the chaotic flow of air and from the thermal gradients within the optical path caused by the variation in temperature and density of the air.

Zones(often referred to as eddies)of different sizes and densities act as lenses scattering light off its original path(beam wander).

Different parts of the beam then travel in different path lengths and hence recombine constructively and destructively at any particular moment and results in the spatial as well as temporal redistribution of signal and consequently the lowering of the received optical power.

The treatment of temporal scintillation statistics is rather complicated and we stick mainly to the spatial part.

Here the main aim of this work is to analyze the performance of the communication system based on the laser beam parameters and few additional variables like the zenith angle,antenna height,atmospheric turbulence etc.

The variation of performance with various modulation schemes has also been investigated.

Mathematical modeling has been done with MATLAB using the Hufnagel-Valley(HV 5/7)model for atmospheric turbulence.

The problem at hand is to analyze the performance of the FSO system based on the beam parameters and tweak the other parameters(like zenith angle) to obtain better results and to obtain the BER vs. SNR curves for various modulation schemes taking the assumption of weak atmospheric turbulence.

8044-35, Poster Session

Carbon/carbon for satellite applications

M. M. Meftah, Ctr. National de la Recherche Scientifique (France)

PICARD is a French space scientific mission and was successfully launched on June 15, 2010 aboard a Russian DNEPR launcher. CC is used in the SODISM instrument which stands for Solar Diameter Imager and Surface Mapper: an imaging telescope accurately pointed, and a CCD (Charge-Coupled Device) used to measure the solar diameter and shape with an accuracy of a few milliarcseconds.

SPIE Defense, Security+Sensing

8045-34, Session 1

Results from MAST joint experiment 3.1

J. G. Rogers III, Georgia Institute of Technology (United States) and Univ. of Pennsylvania (United States); A. Cunningham, M. Paluri, H. I. Christensen, Georgia Institute of Technology (United States); N. Michael, V. Kumar, Univ. of Pennsylvania (United States); L. H. Matthies, J. Ma, Jet Propulsion Lab. (United States); F. Dellaert, Georgia Institute of Technology (United States)

This paper will describe the results of a Joint Experiment performed on behalf of the MAST CTA. The system developed for the Joint Experiment makes use of three robots which work together to explore and map an unknown environment. Each of the robots used in this experiment is equipped with a laser scanner for measuring walls and a camera for locating doorways. Information from both of these types of structures is concurrently incorporated into each robot's local map using a graph based SLAM technique.

The Distributed-Data-Fusion algorithm is used to efficiently combine robot's local map into a shared global map. Each robot computes a compressed local feature map and transmits it to neighboring robots, which allows each robot to merge its map with the maps of its neighbors. Each robot caches the compressed maps from its neighbors, allowing it to maintain a coherent map with a common frame of reference.

The robots utilize an exploration strategy to efficiently cover the unknown environment which allows collaboration on an unreliable communications channel. As each new branching point is discovered by a robot, it broadcasts the information about where this point is along with the robot's path from a known landmark to the other robots. When the next robot reaches a dead-end, new branching points are allocated by auction. In the event of communication interruption, the robot which observed the branching point will eventually explore it; therefore, the exploration is complete in the face of communication failure.

8045-35, Session 1

Autonomous navigation with teams of aerial robots

N. Michael, Univ. of Pennsylvania (United States)

There are many examples in nature where large groups of individuals are able to maintain three-dimensional formations while navigating in complex environments. This paper addresses the development of a framework and robot controllers that enable a group of aerial robots to maintain a formation with partial state information while avoiding collisions. The central concept is to develop a low-dimensional abstraction of the large teams of robots, facilitate planning, command, and control in a low-dimensional space, and to realize commands or plans in the abstract space by synthesizing controllers for individual robots that respect the specified abstraction.

The fundamental problem that is addressed in this paper relates to coordinated control of multiple UAVs in close proximity. We develop a representation for a team of robots based on the first and second statistical moments of the system and design kinematic, exponentially stabilizing controllers for point robots. The selection of representation permits a controller design that is invariant to the number of robots in the system, requires limited global state information, and reduces the complexity of the planning problem by generating an abstract planning and control space determined by the moment parameterization. We present experimental results with a team of quadrotors and discuss considerations such as aerodynamic interactions between robots.

8045-36, Session 1

Vision-aided landing and ingress of a micro-air-vehicle using a monocular camera

R. Brockers, Jet Propulsion Lab. (United States); P. Bouffard, Univ. of California, Berkeley (United States); J. Ma, L. H. Matthies, Jet Propulsion Lab. (United States); C. Tomlin, Univ. of California, Berkeley (United States)

Micro air vehicles for urban reconnaissance missions will be greatly enhanced by capabilities for autonomous landing for persistent stare and for autonomous ingress into buildings. We describe the design of vision and control capabilities for these functions. To achieve initial capability, we assume the landing site is a planar surface above a planar background (e.g. flat roof seen against flat ground) and that the ingress point is a rectangular opening in a planar surface (e.g. door or window in a flat wall). To provide these capabilities with a compact sensor suite, we use monocular visual feature tracking and multi-planar homography to find the planar surfaces. Our algorithms are implemented on a quadrotor UAV in our lab, where aircraft position and velocity are determined by a Vicon motion capture system. Feature points on the landing pad are triangulated and centroided to generate a 3-D waypoint for the control system to target for landing. Windows or doors are detected by finding pairs of parallel line segments in the plane of a perceived wall, with feature points seen between the line segments at distances beyond the wall. Real-time performance is achieved with these algorithms running in an embedded Pentium processor on the aircraft. We show live demonstration results from experiments in our lab.

8045-37, Session 1

Estimation of vehicle velocity and proximity via wide-field integration of optic flow

J. S. Humbert, S. Gerardi, A. Hyslop, Univ. of Maryland, College Park (United States)

Wide-Field Integration (WFI) of optic flow, a method for information extraction modeled on the spatial decompositions of specialized inter-neurons in the insect visuomotor system, can provide useful information about the proximity and relative speed of a vehicle with respect to objects in the environment. In this paper, it is shown how weighted summations of optic flow measurements can be used as static estimators of vehicle proximity and velocity. A two step approach is presented for the selection of weighting patterns that accounts for uncertainty in the environment as well as noise in the measurements, and employs LQR to produce feedback gains. Stability is proven via local asymptotic analysis and the quadrotor MAV is simulated in an urban-like environment.
WFI has potential for implementation using analog VLSI, making it an attractive option for small, payload-constrained aerial platforms.

8045-38, Session 1

Compact beam scanning 240GHz radar for navigation and collision avoidance

K. Sarabandi, M. Vahidpour, M. Moallem, J. R. East, Univ. of Michigan (United States)

Autonomous small robotic platforms require a suite of sensor to navigate and function in complex environment. Due to limited space, onboard power, and processing capability these sensors must be low mass, compact in size, low power, and run with minimal processing

requirement. Whereas optical camera and stereo vision can significantly assist in navigation and obstacle detection, their operation is severely hampered in the dark and in poor atmospheric conditions (dust, smoke, haze, rain). We are developing a compact and low-power imaging mm-wave radar system operating at Y-band to allow navigation and obstacle detection in conditions that make the use of passive optical sensors difficult or impossible. The radar system is being fabricated and assembled using silicon micromaching technique with the overall mass of 5 grams, peak power of 200 mW, and operational power of 6.7 mW for one frame per second update rate, filed of view of 50 degrees , angular resolution of 2 degrees, range resolution of 30cm, and range of 400m. The beam steering is accomplished by frequency scanning and the range resolution is obtained from the standard FMCW technique utilizing a chirped signal waveform with step discontinuities. This paper will present the overall architecture of this radar system in addition to the phenomenological investigation of scattering from obstacle in indoor environment. It is also shown how radar images taken from indoor scenes can be interpreted and utilized to create the interior layout of a building as the radar platform navigates through the corridors.

8045-39, Session 2

New techniques for efficient flexible wireless transceivers in nanometer CMOS

M. Flynn, Univ. of Michigan (United States)

Nanometer CMOS processes have proven to be surprisingly effective for analog and RF design. New design techniques have greatly improved the efficiency of ADCs and RF interfaces and also enabled new flexibility. Moving to techniques that are more digital in nature allows fast and easy changes in architecture and performance. Furthermore, from the standpoint of energy efficiency there can be fundamental advantages to processing signals in the digital domain. This paper discusses digital dominant nanometer CMOS transmitter and receiver schemes that are the basis of flexible efficient wireless transceivers for the MAST platforms. A mostly digital fractional-N PLL modulator scheme can be adapted to different constant-envelope modulation schemes. As an example 2.4GHz OQPSK and GSMK signal have been demonstrated with one prototype device. A multi-mode receiver architecture, which exploits a filtering-ADC, can adapt to wireless signals over a frequency range spanning from 500MHz to 3.5GHz. A prototype receiver has been demonstrated with 900MHz and 2.4GHz 802.15.4 communication and also tested with WiFi signals. This receiver, implemented in 65nm CMOS occupies a die area of only 0.4mm2 and consumes as little as 5mW. New ADC architectures exploit the speed of scaled CMOS processes. For example a 12b 50MS/s hybrid-successive approximation pipeline ADC consumes only 3.5mW and achieves a FOM of 52fJ/conv.step.

8045-40, Session 2A

Reconfigurable firmware-defined radios synthesized from standard digital logic cells

D. D. Wentzloff, M. Faisal, Y. Park, Univ. of Michigan (United States)

Radio frequency (RF) front-end circuits designed today for operation in the 1GHz to 10GHz range are almost exclusively fabricated in CMOS processes for reduced cost. This includes LNAs, mixers, oscillators, ... all the components that enable radios to communicate wirelessly. Traditional design of these RF components relies on precise RF models, high-quality passives, and time-consuming custom layout. CMOS logic has become so fast, it is now realistic to implement full-swing logic from standard cell libraries that switch at >10GHz speeds. Logic has become so small, it is also realistic to fit 1000's of gates in the same area occupied by one RF inductor. In this paper, we describe RF circuits and architectures to realize the same functionality of phase- and frequency-discriminating RF front-ends, but do so using only logic gates as the core building blocks. Results from an ultra-wideband transmitter and time-to-digital converter implemented in 65nm CMOS will be shown that were synthesized from only digital logic gates. By implementing these all-digital architectures in a reprogrammable sea-of-gates on a single integrated circuit, a reconfigurable, firmware-defined RF front-end can be achieved. Also in this paper, a firmware-defined demodulator for FM radio is described that has been implemented in a field programmable gate array (FPGA) without requiring an analog-to-digital converter. All analog receiver circuits have been implemented using only logic gates, and synthesized on the FPGA. When combined with a frequency-selective RF front-end, this radio can demodulate FM radio signals using a fraction of the number of gates compared to software-defined radios using digital signal processing.

8045-41, Session 2A

Radio signal strength tracking and control for robotic networks

B. M. Sadler, P. Yu, J. Twigg, U.S. Army Research Lab. (United States)

Radio signal strength (RSS) is a reasonable proxy for link quality, but its accurate estimation requires frequency and spatial diversity due to fluctuation caused by fading. We consider a Rayleigh/Rician fading model, and gather RSS measurements during motion in a complex environment to enable gradient estimation. Using the RSS gradient, we develop control laws to track active sources. These may be used to establish and preserve connectivity among collaborative autonomous agents, to locate and approach radio sources, as well as deploying agents to assist mobile ad hoc networks (MANETs).

8045-42, Session 2A

Enhanced ad hoc wireless connectivity in complex environment using small radio repeater systems

K. Sarabandi, Y. Song, J. Oh, Univ. of Michigan (United States)

Ad hoc communication among small robotic platforms in complex indoor environment is further challenged by three limiting factors: 1) limited power, 2) small size antennas, and 3) near-ground operation. In complex environments such as indoor scenarios often times the line-of-sight communication cannot be established and the wireless connectivity must rely on multi-path propagation. As a result, the propagation path-loss is much higher than free-space, and more power will be needed to obtain the need coverage. Near ground operation also leads to increased path-loss. To maintain the network connectivity without increasing the required power a novel high gain miniaturized radio repeater is presented. Unlike existing repeater systems, this system utilizes two closely spaced low profile miniaturized planar antennas capable of producing omnidirectional and vertical radiation patterns as well as a channel isolator layer that serves to decouple the adjacent antennas. The meta-material based channel isolator serves as an electromagnetic shield, thus enabling it to be built in a sub-wavelength size of 0.001 cubic wavelength, the smallest repeater ever built. Also wave propagation simulations and measurements have been conducted to determine the required gain of such repeaters so to ensure the signal from the repeater is the dominant component. A prototype of the small radio repeater is fabricated to verify the design performance through a standard free-space measurement setup.

8045-01, Session 3

Safe operations of unmanned systems for reconnaissance in complex environments

J. Kott III, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); E. Mottern, General Dynamics Robotic Systems (United States)

The Safe Operations of Unmanned systems for Reconnaissance in Complex Environments (SOURCE) program is developing and will demonstrate Perception, Intelligence, Control and Tactical Behavior technologies that are required for autonomous collaborative unmanned systems. Soldiers will be utilized to conduct safe operation testing scenarios in cluttered dynamic urban 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 first major SOURCE experiment is scheduled for August 2011 at Ft. Hood

8045-02, Session 3

Stereo vision-based terrain perception using thermal infrared sensors

A. L. Rankin, L. H. Matthies, A. Huertas, M. Bajracharya, Jet Propulsion Lab. (United States); G. Sherwin, General Dynamics Robotic Systems (United States)

The ability to perform off-road autonomous navigation at any time of day or night is a requirement for some unmanned ground vehicle (UGV) programs. Because there are times when it is desirable for military UGVs to operate without emitting strong, detectable electromagnetic signals, a passive only terrain perception mode of operation is also often a requirement. Thermal infrared (TIR) cameras can be used to provide day and night passive terrain perception. TIR cameras have a detector sensitive to either mid-wave infrared (MWIR) radiation (3-8µm) or long-wave infrared (LWIR) radiation (8-15µm). With the recent emergence of high-quality uncooled LWIR cameras, TIR cameras have become viable passive perception options for some UGV programs. The Jet Propulsion Laboratory (JPL) has used a stereo pair of TIR cameras under several UGV programs to perform stereo ranging, terrain mapping, tree-trunk detection, pedestrian detection, negative obstacle detection, and water detection based on object reflections. In addition, we have evaluated stereo range data at a variety of UGV speeds, evaluated dual-band TIR classification of soil, vegetation, and rock terrain types, analyzed 24 hour water and 7 hour mud TIR imagery, and analyzed TIR imagery for hazard detection through smoke. Since TIR cameras do not currently provide the resolution available from megapixel color cameras, a UGV's daytime safe speed is often reduced when using TIR instead of color cameras. In this paper, we summarize the terrain perception strengths and limitations provided by a stereo pair of TIR cameras mounted to a UGV.

8045-03, Session 3

Robot training through incremental learning

R. E. Karlsen, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); G. Witus, Wayne State Univ. (United States); S. T. Hunt, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

The real world is too complex and variable to directly program an autonomous ground robot's control system to respond to the inputs from all of its environmental sensors. To be effective, autonomous robots therefore need to learn how to adaptively respond to sensor input. Due to the vast amounts of information that can be generated by sensors such as LADAR and video, intelligent control systems need to learn incrementally, discarding prior data. And systems need to perform this function of generating and updating internal models in real-time. There should be little difference between the training phase and the execution phase; the system should be continually learning or engaging in "life-long learning". In this paper, we present research into incremental learning systems, such as neural networks, Bayes classifiers, and fuzzy c-means clustering. We compare system performance by comparing an incremental or "on-line" training mode with training in batch mode, where all the data is presented to the system at the same time. We want a system that would also allow the experience learned by multiple robots to be pooled together to quickly increase the rate of learning. The learning algorithms are tested on terrain understanding and "learning through teleoperation" databases.

8045-04, Session 3

Safeguarding tele-operation using an automotive radar sensor

J. Giesbrecht, Defence Research and Development Canada (Canada)

This paper reports on the results of integrating a commercially available radar sensor to aid the users of a tele-operated unmanned ground vehicle. Users of tele-operated vehicles have limitations in detecting potentially damaging obstacles, such as the field of view of the camera being used, and the ability of the operator to distinguish objects in a cluttered scene. Furthermore, the user has no way to determine the distance to objects in the scene. The radar system developed aids the operators in two ways: 1) to alert the operator to potentially dangerous obstacles, and 2) to increase the operator's situational awareness by providing range to objects in the environment. A description of the algorithms and hardware used is presented, as well as results of field testing.

8045-05, Session 3

High-frequency imaging radar for robotic navigation and situational awareness

D. J. Thomas, U.S. Army Tank-Automotive and Armaments Command (United States)

With increasingly available high frequency radar components, the practicality of imaging radar for mobile robotic applications is now practical. Navigation, ODOA, situational awareness and safety applications can be supported in small light weight packaging. Radar has the additional advantage of being able sense through aerosols, smoke and dust that can be difficult for many optical systems. The ability to directly measure the range rate of an object is also an advantage in radar applications. This paper will explore the applicability of high frequency imaging radar for mobile robotics and examine a W-band 360 degree imaging radar prototype. Indoor and outdoor performance data will be analyzed and evaluated for applicability to navigation and situational awareness.

8045-06, Session 3

Pedestrian and car detection, classification, and tracking for unmanned ground vehicle using 3D lidar and monocular camera

K. Cho, Univ. of Science & Technology (Korea, Republic of); S. Baeg, Korea Institute of Industrial Technology (Korea, Republic of); K. M. Lee, H. S. Lee, LG Innotek (Korea, Republic of); S. Park, Korea Institute of Industrial Technology (Korea, Republic of)

This paper describes object detection, classification and tracking for an Unmanned Ground Vehicles (UGVs) using a 3D Light Detection And Ranging (LIDAR) and a monocular camera. For safe driving of the UGVs, pedestrians and cars should be detected on their moving routes. We employed a 3D LIDAR named KIDAR-B25, which has been developed by LG Innotek Consortium in Korea. It is optically coupled using horizontal and vertical scanning mechanism. KIDAR-B25 provides two scanning modes; precision and real-time modes. In the precision scanning mode, one frame consists of 80 vertical and 5,760 horizontal step points data, acquired every 5 sec. The real-time mode data has 8 vertical and 5,760 horizontal step points data every 0.2 sec. The KIDAR-B25 acquired both 3D LIDAR space data and image space data simultaneously, and processed them. In the LIDAR space, we reached break points with the LIDAR data using Linear Kalman Filter followed by median filter and extracted a set of an object Region of Interest(ROI). In the image space, we extracted the feature data from the ROI image using the Haar feature method. Finally it is classified as a pedestrian or car using database which is trained with Adaboost algorithm. To verify our system, we made an experiment on the real-time performance of our system, which was mounted on the UGV, through field tests in an urban area.

8045-07, Session 4

Some recent advances and remaining challenges in bipedal walking robots and exoskeletons

J. E. Pratt, Institute for Human and Machine Cognition (United States)

No abstract available

8045-08, Session 4

Aladdin: a semi-autonomous door opening system for EOD-class robots

J. Craft, J. Wilson, Honeybee Robotics (United States); W. H. Huang, M. R. Claffee, E. Phillips, iRobot Corp. (United States)

Opening doors using an EOD-class robot is difficult because of limited feedback from available monocular cameras, the kinematic limitations of EOD-class robot arms, and the complexity of the task. There are several parts to this task: approaching the door, reaching for the doorknob, grasping and turning the doorknob, pulling the door open, and driving through the doorway. Honeybee Robotics and iRobot have been working together to design hardware and software solutions to this problem. Our hardware solution involves a gripper that incorporates passive compliance to simplify the grasping and manipulation challenges; this passive compliance allows a robot to turn the doorknob and pull the door open without precision control to align freedoms of the arm with the doorknob's prescribed path. On the software side, we have developed assistive behaviors to reduce the time a teleoperator takes to complete this task. These behaviors include preprogrammed positioning, doorknob targeting, and auto-reach behaviors. We have implemented our system on an iRobot 510 PackBot and conducted detailed measurements to quantify the performance improvements that our system affords. This paper describes the design of our system and our results.

8045-10, Session 4

Human-like characteristics for high-degree of freedom robotic door opening end effector

J. Gray, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); F. Campagna, RE2, Inc. (United States)

In the field of military Unmanned Ground Vehicles (UGV's), military units are forced to sweep largely populated cities and towns in search of hostile enemies. These urban types of operations are referred to as MOUT (Military Operations on Urban Terrain). During urban operations, these UGV's encounter difficulties when opening doors. Current manipulator end effectors have these difficulties, because they are not designed to mimic human hand operations.

This paper explains the mechanical nature of the Modular Universal Door Opening End-effector (MUDOE). MUDOE is a result of our development research to improve robotic manipulators ability to negotiate closed doors. The presented solution has the ability to mimic human hand characteristics when opening doors. The end-effector possesses an ability to maintain a high Degree of Freedom (DoF), and grasp the doorknob by applying equally distributed forces to all points of contact.

8045-12, Session 4

Dexterous manipulation for non-line-of-sight articulated manipulators

J. Hu, Y. Lim, Hstar Technologies (United States)

Hstar Technologies is developing a bimanual, highly dexterous humanoid robotic system that will be strong enough to load and unload goods from commercial containers, operate safely around humans, with dexterity sufficient to unlock and open cargo doors. This session will discuss the technology and application challenges of Hstar's 'A mobile Dexterous Manipulator (D-Man)' project, and present a solution architecture that we believe will prove applicable to a wide range of uses.

The Hstar D-Man product line brings autonomous robotic operation to warehouse and shipping material handling, creating significant opportunities for cost reduction, the reduction of worker injury, and in the battlefield, unmanned materiel loading and unloading, protecting military personnel from hostile fire and potential injury or death.

D-Man is designed for non-line-of-sight robotic operation under telepresence control, leveraging core features of Hstar's robotic nursing assistant (RoNA) system. These include human-safe arm compliance, strength to pick up and move 300 pound objects, and an omni-directional mobile platform with robotic navigation control, augmented by semi-autonomous ISO container door opening, and dexterous manipulation of shipping boxes. D-Man incorporates innovative electric motor hydraulic transmission series elastic actuator (SEA) technology, an advanced robotic hand and robust perception sensors.

This session will highlight diverse challenges relating to designing and implementing a robust, autonomous freight handling system, including:system architecture for telepresence and direct control; human-safe high velocity, high strength manipulators; dexterous manipulation and stable posture control, supporting both high strength lifting and semi-autonomous door-opening; telepresence and direct control architecture; and safety monitoring and intervention.

8045-14, Session 4

Modular intelligent manipulation for high-DOF robotic arms

J. Gray, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); D. Rusbarsky, D. J. Peters, RE2, Inc. (United States)

The field of mobile manipulation for military applications has made significant advances since America went to war in 2001. The arms used on today's military robotics are rugged and proven but lack fine control and available degrees of freedom. Users control these arms through individual joint movements. The upcoming generation of manipulators have increased capabilities through additional degrees of freedom and the ability to place the end effector through inverse kinematics (flying the end effector). As systems continue to advance and the number of degrees-of-freedom exceed 6, the problem becomes under-constrained and there will be multiple ways of positioning an end effector at a particular point/orientation. In addition to increasing the number of degrees of freedom for manipulators, there is significant research under way to provide the operator with haptic feedback on the robot's environment. This type of feedback provides the operator with increased situational awareness and can help the operator add constraints to the high degree-of-freedom arms.

Under a research efforts sponsored by the U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC), we are exploring technologies that can be used to provide an operator with the ability to more intuitively control high-degree of freedom arm while providing the operator with haptic feedback to more effectively interact with the environment. This paper will highlight the results of the research as well as early test results on a number of prototype systems currently in development. We will demonstrate advantages and disadvantages of some of the leading approaches to intuitive control and haptic feedback.

8045-15, Session 4

Sensor-based redundancy resolution for a mobile robotic manipulator

N. Xi, Michigan State Univ. (United States)

Mobile manipulators offer both mobility and dexterity for robotic manipulations. They are widely used in various military and civilian applications including space exploration, demining, hazardous material handling, manufacturing and services. However the planning and control of a mobile manipulator are challenging because of its high redundancy resulted from multiple degrees of freedom of the manipulator and the mobile platform. The existing planning and control methods are usually rely on off-line motion planning algorithms to solve the redundancy problem. The off-line approach requires the precise knowledge of the tasks and the environment. However, these cannot be always satisfied, especially while working in a unstructured environment and facing high task uncertainties. Unfortunately, this is a typical application scenario for a mobile manipulator in defense and security applications. This paper presents a new sensor-based on-line redundancy resolution method for a mobile manipulator. The key idea is to model the task space coordinates of the mobile manipulator using Elbow angle in addition to the traditional position and orientation. The task and environment constraints including robot payload, kinematics and dynamics workspace and obstacles avoidance can be molded using the augmented task space coordinates. More importantly, the augmented task coordinate will be directly related to on-line sensory measurements. As a result, the redundancy can be resolved under given optimization criteria. The method has been implemented and tested on a mobile manipulator consisted of a 4-wheel mobile base and a 7-DOF robot arm. The experimental results have clearly demonstrated the efficiency and effectiveness of the proposed method.

8045-09, Session 5

JEFX 10 demonstration of cooperative hunter killer UAS and upstream data fusion

B. K. Funk, A. J. Newman, J. C. Castelli, A. S. Watkins, C. B. McCubbin, J. D. Barton, C. K. Peterson, J. T. DeSena, D. A. Dutrow, P. A. Rodriguez, S. J. Marshall, The Johns Hopkins Univ. (United States)

The Johns Hopkins University Applied Physics Laboratory deployed and demonstrated a prototype Cooperative Hunter Killer (CHK) Unmanned Aerial System (UAS) capability and a prototype Upstream Data Fusion (UDF) capability as participants in the Joint Expeditionary Force Experiment 2010 in April 2010. The CHK capability was deployed at the Nevada Test and Training Range to prosecute a convoy protection operational thread. It used mission-level autonomy (MLA) software applied to a networked swarm of three Raven hunter UAS and a Procerus Miracle surrogate killer UAS, all equipped with full motion video (FMV). The MLA software provides the capability for the hunter-killer swarm to autonomously search an area or road network, divide the search area, deconflict flight paths, and maintain line of sight communications with mobile ground stations. It also provides an interface for an operator to designate a threat and initiate automatic engagement of the target by the killer UAS. The UDF prototype was deployed at the Maritime Operations Center (MOC) at Commander Second Fleet, Naval Station Norfolk to provide intelligence analysts and the ISR commander with a common fused track picture from the available FMV sources. It consisted of a video exploitation component that automatically detected moving objects, a multiple hypothesis tracker that fused all of the detection data to produce a common track picture, and a display and user interface component that visualized the common track picture along with appropriate geospatial information such as maps and terrain as well as target coordinates and the source video.

8045-11, Session 5

Dynamic replanning on demand of UAS constellations performing ISR missions

D. W. Stouch, E. Zeidman, W. Callahan, Charles River Analytics, Inc. (United States); K. McGraw, U.S. Army Engineer Research and Development Ctr. (United States); J. Serrin, Charles River Analytics, Inc. (United States)

Unmanned aerial systems (UAS) have proven themselves to be indispensable in providing intelligence, surveillance, and reconnaissance (ISR) over the battlefield. Constellations of heterogeneous, multi-purpose UAS are being tasked to provide ISR in an unpredictable environment. This necessitates the dynamic replanning of critical missions as weather conditions change, new observation targets are identified, aircraft are lost or equipment malfunctions, and new airspace restrictions are introduced. We present a method for generating coordinated mission plans for constellations of UAS with multiple flight goals and potentially competing objectives, and updating them on demand as the operational situation changes. We use a fast evolutionary algorithm-based, multi-objective optimization technique. The updated flight routes maintain continuity by taking into account where the ISR assets have already flown and where they still need to go. Both the initial planning and replanning take into account factors such as area of analysis coverage, restricted operating zones, maximum control station range, adverse weather effects, military terrain value, and sensor performance. Our results demonstrate that by constraining the space of potential solutions using an intelligently-formed air maneuver network with a subset of potential airspace corridors and navigational waypoints, it is possible to ensure global optimization for multiple objectives by taking into account the situation both before and after the replanning is initiated. We employ sophisticated visualization techniques using a geographic information system to help the user 'look under the hood' of the algorithms and understand the effectiveness and viability of the generated ISR mission plans and identify potential gaps in coverage.

8045-13, Session 5

All weather sense and avoid system (AWSAS) for all UAS and manned platforms

V. M. Contarino, R-Cubed Engineering, LLC (United States)

For decades, military and other national security agencies have been

denied unfettered access to the National Air Space (NAS) because their unmanned aircraft lack a highly reliable and effective collision avoidance capability. The controlling agency, the Federal Aviation Administration, justifiably demands “no harm” to the safety of the NAS. To overcome the constraints imposed on Unmanned Aircraft Systems (UAS) use of the NAS, a new, conformable collision avoidance system has been developed - one that will be effective in all flyable weather conditions, overcoming the shortfalls of other sensing systems, including radar, lidar, acoustic, and EO/IR, while meeting form factor and cost criteria suitable for Tier II UAS operations. The system also targets Tier I as an ultimate goal, understanding the operational limitations of the smallest UASs may require modification of the design that is suitable for Tier II and higher. The All Weather Sense and Avoid System (AWSAS) takes into account the FAA’s plan to incorporate ADS-B (out) for all aircraft by 2020, and it is intended to make collision avoidance capability available for UAS entry into the NAS as early as 2013. When approved, UASs can fly mission or training flights in the NAS free of the constraints presently in place. Upon implementation this system will achieve collision avoidance capability for UASs deployed for national security purposes and will allow expansion of UAS usage for commercial or other civil purposes. This work has been funded by ONR and is undergoing flight testing in May 2011.

8045-16, Session 5

Biologically-inspired approaches for self-organization, adaptation, and collaboration of heterogeneous autonomous systems

M. L. Steinberg, Office of Naval Research (United States)

This paper presents a survey of recent theoretical and experimental progress in the development of biologically-inspired approaches for complex search and coverage problems with multiple, heterogeneous autonomous systems. The focus is on approaches that may address ISR problems that can quickly become mathematically intractable or otherwise impractical to implement using traditional optimization techniques as the size and complexity of the problem is increased. These problems require dealing with complex spatio-temporal objectives and constraints at a variety of levels from motion planning to task allocation. There is also a need to ensure solutions are reliable and robust to uncertainty and communications limitations. First, the paper will provide a short introduction to the current state of relevant biological research as relates to collective animal behavior and the underlying neural and cognitive mechanisms. Second, the paper will describe research on largely decentralized, reactive, or swarm approaches that have been inspired by biological phenomena such as schools of fish, flocks of birds, ant colonies, and insect swarms. Next, the paper will discuss approaches towards more complex organizational and cooperative mechanisms in team and coalition behaviors in order to provide mission coverage of large, complex areas. Relevant team behavior may be derived from recent advances in understanding of the social and cooperative behaviors used for collaboration by tens of animals with higher-level cognitive abilities such as mammals and birds. Finally, the paper will briefly discuss challenges involved in user interaction with these types of systems.

8045-17, Session 5

Migration strategies for service-enabling ground control stations for unmanned systems

J. B. Kroculick, Winifred Associates (United States)

Future unmanned systems will be integrated into the Global Information Grid (GIG) and support net-centric data sharing, where information in a domain is exposed to a wide variety of GIG stakeholders that can make use of the information provided. Adopting a Service-Oriented Architecture (SOA) approach to package reusable ground control station functionality into common control services provides a number of benefits including enabling dynamic plug and play of components depending on changing mission requirements, supporting information sharing to the enterprise, and integrating information from authoritative sources such as mission planners with the ground control station’s data model. It would also allow the wider enterprise community to use the services provided by unmanned systems and improve data quality to support more effective decision-making.

We explore current challenges in migrating ground control stations that control multiple types of vehicles to a Service-Oriented Architecture (SOA). Service-oriented analysis involves reviewing legacy systems and determining which components can be made into a service. Existing ground control stations provide audio/visual, navigation, and vehicle health and status information that are useful to C4I systems. However, many were designed to be closed systems with proprietary software and hardware implementations, message formats, and specific mission requirements. An architecture analysis can be performed that reviews legacy systems and determines which components can be made into a service. A phased SOA adoption approach can then be developed that improves system interoperability.

8045-29, Session 5

Autonomous sustain and resupply: what is the future?

G. S. Broten, Defence Research and Development Canada (Canada)

As autonomous ground vehicles (UGVs) acquire more capabilities, their possible military roles have become a topic of much speculation. Given a UGVs’ limited sensing capabilities and the resulting lack of situtational awareness, behind the front line roles have been posited as an attractive option. A role in autonomous convoying has been researched, but only in support of traditional human manned convoys. As UGVs gain more and more capabilities, there is the open question of how to applied these capabilities to the sustain and resupply problem. Defence R&D Canada - Suffield, in conjunction with Simon Fraser University has conducted research that investigate these issues.

Under autonomous resupply, a fleet of UGVs co-ordinate their actions to service a group of consumers. The consumer could be other autonomous vehicles, manned vehicles or static sites. The supply UGVs must also monitor their internal expendables and ensure that they have sufficient resources on hand. In its generalized form, the UGV fleet is heterogeneous with individual vehicles having varying performance characteristics and offering differing resupply capabilities. Consumers are also heterogeneous, and demand the delivery of various commodities, in varying quantities. The resupply point may be a specified geographical location or it could be a point negotiated between the consumer and the supplier. Finally, at supply sites, supply vehicles acquire goods for either personal usage or to offer as goods to other consumers.

This research produced a novel theoretical analysis of the sustain and resupply problem, which lead to new concepts in sustain and rendezvous methods for UGVs teams. These concepts have been investigated via large scale simulations. These extensive simulations have shown that large UGV teams can self-organize conveys to deliver goods while ensuring each UGV sustains its own expendables.

8045-17, Session 6

Little dog learning tractive and compressive terrain characteristics

B. L. Digney, Defence Research and Development Canada (Canada)

In recent years research into legged locomotion across extreme terrains has increased. Much of this work was done under the DARPA Learning Legged Locomotion program that utilized a standard little dog robot platform and prepared terrain test boards with known geometric data. While path planing using geometric information is necessary, acquiring and utilizing tractive and compressive terraincharacteristics is equally important. This paper will describe methods and results for learning tractive and compressive terrain characteristics with the little dog robot.

The estimation of terrain traction and compressive/support capabilities using the mechanisms and movements of the robot rather than dedicated instruments is the goal of this research. The resulting characteristics may differ from those of standard tests, however they will be more useful to the locomotion controller's given that they are obtained in the physical context of the actual robot and actual movement. For example, Figure~ref{fig:tractive} shows the robot test and results for learning tractive characteristics of ice (a) and layered paper (b) in contact with the little dog's rubber feet while doing a push up and forward manoeuvre. The results of Figure~ref{fig:tractive} (c) and (d) both show clear slip points, but the results for the paper (d) show a horizontal compliance before the slip. This may be due to the terrain or to the robot, but either way it is very important to know and may not have been discovered with an isolated standard friction test. Compliance results are shown in Figure~ref{fig:compressive} for 6~cm thick sponge (a) and simulated rubble (b). Results show a clear hysteresis for the sponge (c) and a varying level of foot penetration until it achieves purchase for the rubble (d).

The full paper will elaborate on the methods used, present additional results and describe how these captured characterizes are parametrized, learned and utilized by foot placement planners. Future work will be discussed on how these methods can be interwoven with other purposeful actions of the robot and lessen the need for direct terrain probing actions.

8045-18, Session 6

Driver-assist behaviors for high-speed small UGVs

B. M. Yamauchi, iRobot Corp. (United States)

Currently deployed small UGVs operate at speeds up to around 6 mph and have proven their usefulness in explosives ordnance disposal (EOD) missions. As part of the TARDEC-funded Stingray Project, iRobot is investigating techniques to increase the speed of small UGVs so they can be useful in a wider range of missions, such as high-speed reconnaissance and infantry assault missions. We have developed a prototype Stingray PackBot, using wheels rather than tracks, that is capable of traveling at speeds up to 18 mph. A key issue when traveling at such speeds is how to maintain stability during sharp turns and over rough terrain. We are developing driver assist behaviors that will provide dynamic stability control for high-speed small UGVs using techniques such as dynamic weight shifting to limit oversteer and understeer. We are also developing behaviors for high-speed obstacle avoidance that will be integrated with stability control. These driver assist behaviors will enable operators to use future high-speed small UGVs in high optempo infantry missions and keep warfighters out of harm's way.

8045-19, Session 6

Fusion of visual odometry and inertial data for enhanced, real-time egomotion estimation

V. E. Perlin, D. B. Johnson, M. M. Rohde, Quantum Signal LLC (United States); R. E. Karlsen, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

Visual odometry (VO) systems have been widely researched and demonstrated to yield highly precise motion estimates, yet adoption in actual fielded systems has been very limited. This is likely due in large part to the critical sensitivity of such systems to even brief occlusions of the camera's field of view. VO is also sensitive to other factors that influence image quality, including harsh or low lighting and inclement weather.

To mitigate these sensitivities, the authors have developed a prototype VO system that integrates a low cost inertial measurement unit (IMU). IMUs provide data that is complementary to visual sensing. They have been shown to improve precision and robustness of VO compared to stand-alone solutions. IMUs are excellent at measuring rotational speeds and can help disambiguate rotation from translation, which is difficult for VO in certain scene geometries. Furthermore, IMUs are not sensitive to feature-poor environments and are not subject to occlusion. Thus they can provide continuous position estimates when VO might be unreliable.

In this paper, the authors describe the new system and fusion solution: a novel, low-dimensional loose-coupling scheme with several advantages. Results of multiple performance characterization experiments (on rough terrain and smooth roadways at speeds of up to 75 miles per hour) are also presented. The prototype system is shown to perform at a very high level (distance error < 1%, yaw drift rate ~2 degrees per minute) in multiple configurations, including different optics and different vehicles. Directions for further improvements are also presented.

8045-20, Session 6

Design, modelling, implementation, and intelligent fuzzy control of a hovercraft

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A Hovercraft is an amphibious vehicle that hovers just above the ground or water by air cushion. The concept of air cushion vehicle can be traced back to 1719. However, the practical form of hovercraft nowadays is traced back to 1955. The objective of the paper is to design, simulate and implement an autonomous model of a small hovercraft equipped with a mine detector that can travel over any terrains. A real time layered fuzzy navigator for a hovercraft in a dynamic environment is proposed. The system consists of a Takagi-Sugeno-type fuzzy motion planner and a modified proportional navigation based fuzzy controller. The system philosophy is inspired by human routing when moving between obstacles based on visual information including the right and left views from which he makes his next step towards the goal in the free space. It intelligently combines two behaviours to cope with obstacle avoidance as well as approaching a goal using a proportional navigation path accounting for hovercraft kinematics. MATLAB/Simulink software tool is used to design and verify the proposed algorithm.

8045-21, Session 7

Human leader and robot follower team without GPS and without line of sight

S. Kwanmuang, J. Borenstein, L. V. Ojeda, Univ. of Michigan (United States)

This paper describes our functional navigation system that allows a robot to follow a walking human, without line-of-sight and without GPS. Conventional solutions use vision and other sensors on the robot to track and follow the leader at a distance of just a few meters. This approach requires almost constant line-of-sight between the robot and the human and requires the follower not to lag by more than a few meters.

In contrast, our system does not require line-of-sight at all and allows the follower to lag behind the leader by up to one minute, regardless of the number and severity of obstructions between them and limited only by the range of the RF-based communication link between them. Our system uses our already well-developed personal dead-reckoning (PDR) system on the leader and conventional dead-reckoning capabilities (based on odometry and a simple MEMS-based IMU) on the follower.

Our solution is far from trivial. This is because the two dead-reckoning systems each incur unbounded heading and position errors. Thus, the leader's virtual trail of foot steps becomes increasingly false and misleading, while the robot develops its own growing errors in following that already false trail. Our solution is based on the observation that the absolute accuracy of the leader's and follower's dead-reckoning systems is not so important. What is important is that their position and heading errors be exactly the same. The paper describes our approach to implementing such error synchronization, along with experimental results.

8045-22, Session 7

Methods for UGV teleoperation with high latency communications

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This paper reports on the initial development and testing of a suite of complementary control methods for Unmanned Ground Vehicle (UGV) teleoperation with high-latency communications. The methods included latency protection, predictive displays, and supervisory control. Latency protection mitigates against typical types of high-latency teleoperation input errors. The latency protection methods included filtering the joysick commands, limiting the commanded rates as a function of latency, and emergency stop when the operator commands and Operator Control Unit (OCU) navigation video were out of phase. Predictive displays indicate to the operator the current state of the UGV, i.e., the state after all of the latent commands are executed (latent commands are those that have been issued but whose effects do not yet appear in the OCU display). We implemented two alternative predictive display methods: augmented reality using iconography to indicate the effects of the latent commands, and virtual reality which warps the image to show the view to reflect the latent commands. Supervisory control methods for "point and go" control allowed the operator to specify simple, short-range objectives that the UGV can accomplish on its own, without advanced sensing, path planning, etc. We implemented and demonstrated these methods on a Man-Transportable Robotic System (MTRS) model currently in use for Explosive Ordnance Disposal.

8045-24, Session 7

SUGV waypoint following

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

Currently, the 3000+ robotic systems fielded in theater are entirely teleoperated systems. This constant dependence on operator control introduces several problems, including a large cognitive load on the operator and a limited ability for the operator to maintain an appropriate level of situational awareness of his surroundings. One solution to reduce the dependence on teleoperation is to develop autonomous behaviors for the robot to reduce the strain on the operator.

Waypoint following is one example of an autonomous behavior that allows the robot to follow a designated path defined by latitude, longitude coordinates with limited operator involvement. There are a variety of different algorithmic approaches to accomplishing this task. In this paper two approaches are explored: a naïve approach which attempted to navigate by following a sequential list of waypoints fed to it either by an operator or a control program, and a more advanced approach which attempted to refine the list of waypoints by generating intermediate waypoints based upon an a priori map of the area.

In this paper, the implementation details of both of these methods on a small unmanned ground vehicle (SUGV) will be described, along with preliminary results of several experiments. Further, the costs of building an a priori map will be contrasted with the benefits of what is expected to be a more efficient system.

8045-25, Session 7

Energy efficient path planning for skid-steered autonomous ground vehicles

A. Sharma, N. Gupta, E. G. Collins, Jr., The Florida State Univ. (United States)

It is important to minimize the energy consumption of autonomous ground vehicles (AGVs) deployed in real world missions. One of the ways that this can be accomplished is to choose the vehicle's motion to minimize the mechanical and electrical energy usage required by the vehicle's motion. This paper considers energy efficient motion planning for skid-steered AGVs, an important and large class of all terrain vehicles. A skid-steered vehicle can be either tracked or wheeled and is characterized by two features. First, the vehicle steering depends on controlling the relative velocities of the left and right side wheels or tracks. Second, all wheels or tracks remain parallel to the longitudinal axis of the vehicle and vehicle turning requires slippage of the wheels or tracks. An experimentally verified power consumption model for skid-steered vehicles has been recently developed based on the "exponential friction model," which yields power consumption predictions that are far more accurate than those obtained using Coulomb's friction model. At a given velocity the power consumption is essentially a function of the vehicle turning radius. This paper demonstrates energy efficient motion planning using Sampling Based Model Predictive Control (SBMPC), a recently developed motion planning algorithm. In this research SBMPC uses the kinematic model of the skid-steered vehicle to determine feasible vehicle paths and the power model to compute the energy consumption along a given path. The results demonstrate the importance of considering energy consumption in the motion planning process.

8045-26, Session 7

Lessons to improve testing for countermine robotic systems

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The dismounted countermine mission faces a complex challenge: how to integrate capabilities to find and eliminate surface laid and buried explosive hazards with existing robot system technologies. The purpose is to keep robot operator(s) at a safe standoff distance in both complex and urban terrains including confined areas and subterranean environments. This paper presents what we learned in subsystem testing done in the past, and the lessons we need to learn about the challenges of achieving total mission success. We identify three components of a robotic countermine system: move to threat area, maneuver sensor head, and prosecute the kill chain (detect, mark, and neutralize hazards). Each of these is essential, yet attention tends to focus on the third one. The focus here is on lessons from the other two components. What lessons come from moving a countermine robot to the area of expected threats? What sensor head maneuvers are necessary to increase the probability of detection (Pd) and lower the false alarm rate (FAR) for hazards? This paper presents qualitative and anecdotal data from subsystem testing during the past two years. Lessons we learn from such a holistic approach provide a foundation for realizing a countermine robot and elucidate the path forward for system-level testing for a countermine robot.

8045-16, Session 8

An improved particle filter approach for multiple target detection and tracking

W. Lu, G. Zhang, S. Ferrari, Duke Univ. (United States); R. O. Fierro, I. Palunko, The Univ. of New Mexico (United States)

The problem of target moving behavior modeling and tracking has a number of applications, such as unmanned craft monitoring, wild animal observation, and suspect surveillance. In this paper, a modified particle filter with a new sampling method is proposed for target moving behavior recognition with a limited number of measurements containing high noise. We assume that target trajectories consist of a sequence of straight line segments in which the slope and intercept need to be inferred. The transition between adjacent line segments is assumed to obey Markov property. The transition function as well as the segment slope and intercept are updated based on the previous estimation and

new target position measurement. When the sensor loses the target, it explores the workspace based on the latest knowledge. The tracking objective is to keep the geometric distance between the sensor platform and the target sensor field of view in a predefined range, and to minimize energy consumption due to sensor movements. A potential field method is constructed for the purpose of navigating the sensor toward the target and keeping a certain distance from the target. A novel control law based on the target position and velocity together with the estimated transition function as the input is developed to track the targets. The convergence of the target moving behavior modeling algorithm and the tracking algorithm are proven via Lyapunov stability theory. The algorithms will be validated via numerical simulations and experimentally verified on a heterogeneous multi-sensor testbed including quadrotors and ground vehicles.

8045-27, Session 8

A cell decomposition approach to pursuit and evasion with adversarial agents

G. Foderaro, B. Bernard, S. Ferrari, Duke Univ. (United States)

Submitted for G. Hudas and F. Lewis session on Intelligent Behaviors.

This paper presents a probabilistic optimization approach using geometric cell decomposition to obtain the optimal path for an intelligent agent against non-deterministic adversaries in a simultaneous motion discrete sweeping problem. This approach focuses on regions of interest where agents have restricted movement, such as in urban locations or inside buildings, and allows for online path optimization capable of adapting to these dynamic environments. Cell decomposition maps a continuous environment to a graphical representation of the state and control spaces. A modified decision tree is constructed from the map, and actions are chosen to optimize an objective function. Cell decomposition is a popular technique for robotic path planning, mobile sensor networks, and path exposure, but many approaches focus solely on navigation and obstacle avoidance. The methodology presented here additionally considers goals relevant to sensing objectives. In many sensing applications, invaders are modeled by a Markov motion process with known transition probability functions. The approach given in this paper uses non-parametric modeling of the evolving probability distribution for adversary position and motion between observations. Although solving the dual pursuit and evasion problem is intractable in many cases, the cell decomposition and non-parametric modeling techniques used in this paper are often capable of finding the minimax solution due to significant reductions in the size of the state space. The theoretical results are validated through numerical Monte Carlo simulations involving multiple pursuers and a single evader.

8045-28, Session 8

Trust dynamics in multi-agent coalition formation

D. G. Mikulski, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States) and Oakland Univ. (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 G. Hudas and F. Lewis session on Intelligent Behaviors.

Trust is an attitude we all intuitively understand, but may find difficult to express rationally. We rely on our ability to trust others whenever we need to gauge something that we cannot ever know precisely. Thus, trust provides us with a highly versatile heuristic that helps us deal with uncertainty, allowing us to reduce the complexity within arbitrary situations involving risk, vulnerability, and interdependence. Our optimism to believe that things will behave consistently motivates our use of trust, even if it exposes us to undesirable possibilities.

Trust is critical for successful cooperation between selfish agents in coalitions. It encourages less defensive monitoring, increased information sharing, and increased cooperative reciprocity. However, trust also exposes each agent to vulnerabilities associated with betrayal. This duality between efficiency and vulnerability presents dilemmas in cooperative dynamics by challenging agents to intelligently choose between team interests and self interests.

In this paper, we present a rigorous treatment of coalition formation based on trust interactions in multi-agent systems. Current literature on trust in multi-agent systems primarily deals with trust models and protocols of interaction in non-cooperative scenarios. Here, we use cooperative game theory as the underlying mathematical framework to study the trust dynamics between agents as a result of their trust synergy and trust liability in cooperative coalitions. We rigorously justify the behaviors of agents for different classes of games, and discuss ways to exploit the formal properties of these games for specific applications, such as unmanned cooperative control.

8045-30, Session 8

X-band radar for UAV-borne MAV target recognition

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Submitted for G. Hudas and F. Lewis session on Intelligent Behaviors.

Increased use of Miniature (Unmanned) Aerial Vehicles (MAVs) is coincidentally accompanied by a notable lack of sensors suitable for enabling further increases in levels of autonomy and consequently, integration into the National Air Space (NAS). The majority of available sensors suitable for MAV integration are based on infrared detectors, focal plane arrays, optical and ultrasonic rangefinders, etc. These sensors are generally not able to detect or identify other MAV-sized targets and, when detection is possible, considerable computational power is typically required for successful identification. Furthermore, performance of visual-range optical sensor systems can suffer greatly when operating in the conditions that are typically encountered during search and rescue, surveillance, combat, and most common MAV applications. However, the addition of a miniature radar system can, in consort with other sensors, provide comprehensive target detection and identification capabilities for MAVs. This trend is observed in manned aviation where radar systems are the primary detection and identification sensor system. Within this document the design of a miniature, lightweight X-Band radar system for use on a miniature (710mm rotor diameter) rotorcraft is described. Moreover, the algorithms utilized to accurately identify a miniature helicopter are explored. In addition, the system performance is evaluated to determine the effective detection and identification ranges. Finally, an analysis of potential MAV navigation and collision avoidance behaviors is performed to determine the effect of integrating radar systems into MAV-class vehicles.

8045-31, Session 8

Building entity models through observation and learning

R. D. Garcia, Motile Robotics Inc. (United States); R. Kania, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); M. Fields, U.S. Army Research Lab. (United States); L. E. Barnes, Univ. of South Florida (United States)

To support the missions and tasks of mixed human/robot teams, future robotic systems will need to adapt to the dynamic behaviors of both teammates and adversaries. One of the essential elements of this adaptation will be the ability to exploit both long and short-term temporal data. This will allow robotic systems to predict, anticipate, and influence future behaviors of both teammates and adversaries. It will also enable the system to optimize its own behavior in order to increase mission success.

This work is a preliminary step to developing online entity behavior models through a combination of observations and learning techniques. As knowledge is extracted from the system through sensor and temporal feedback, agents within the robotic system attempt to develop and exploit a basic movement model for an adversary. For the purpose of this work, extraction and exploitation are performed through the use of a discretized two-dimensional game. The game consists of a predetermined number of agents attempting to keep an unknown adversary agent from penetrating their territory. The agents utilize temporal data coupled with past adversary observations to hypothesize the probable locations of the adversary throughout the game and thus optimize their guarding locations.

Results are presented by comparing the success metrics of an untrained agent with the success metrics of an agent dynamically extracting and exploiting observed data.

8045-32, Session 8

Neuro-optimal control of helicopter UAVs

D. J. Nodland, Missouri Univ. of Science and Technology (United States); A. Ghosh, National Metallurgical Lab. (India); J. Sarangapani, Missouri Univ. of Science and Technology (United States)

Helicopter UAVs can be extensively used for military missions as well as in civil operations, ranging from multi-role combat support and search and rescue, to border surveillance and forest fire monitoring. The helicopter UAVs are underactuated nonlinear mechanical systems and the controller design of such systems can be very challenging. Nevertheless, this paper presents an optimal controller design for the regulation of an underactuated helicopter using adaptive critic neural network framework. The online approximator-based controller learns the infinite-horizon continuous-time Hamilton-Jacobi-Bellman (HJB) equation and then calculates the corresponding optimal control input that minimizes the HJB equation forward-in-time. In the proposed technique, optimal regulation is accomplished by a single neural network (NN) with a second NN necessary for the virtual controller. Both of the NNs are tuned online using novel weight update laws. The stability of the overall closed-loop system is established using Lyapunov methods. Simulation results are included to demonstrate the effectiveness of the proposed control design in hovering applications especially for sensing explosives.

*"Submitted for G. Hudas and F. Lewis session on Intelligent Behaviors"

8045-44, Poster Session

Development of an autonomous positioning and navigation spherical robot

K. Hou, H. Sun, Q. Jia, Y. Zhang, Beijing Univ. of Posts and Telecommunications (China)

In this paper, we provide an autonomous positioning and navigation spherical robot. Due to the character of flexible movement and anti-dumping, the published literature about spherical robots has grown enormously during the last several years. Based on the spherical robots developed in our laboratory, we design an autonomous positioning and navigation system for the spherical robot, which can be widely used in the fields of environment monitoring, military reconnaissance and scientific research. Firstly, the mechanical structure and control system of the spherical robot in our laboratory are described particularly. The performance parameters of the movement also are given. Secondly, the autonomous positioning and navigation system is presented. In this system, the GPS (global positioning system) navigation and visual navigation are used coordinately to realize their own advantages to improve the accuracy and reliability. The GPS navigation is applied for the long distance, while the visual navigation is used at close quarters. Thirdly, because a large number of positions and image information data need to be addressed in the main processor, the optimization of the process is presented, which can make the whole movement more reliable and smooth. The process of the system is introduced in detail, which includes five main steps to realize the function. Fourthly, in the visual navigation system, a simple image identification based on wavelet analysis to reduce image data processing amount is given, which can improve identification accuracy and efficiency. Finally, the experimental data and results in the spherical robot show feasibility of the autonomous positioning and navigation system.

8045-33, Session 9

High-fidelity physics-based simulation of a UGV reconnaissance mission in a complex urban environment

C. Goodin, J. D. Priddy, C. L. Cummins, B. Q. Gates, Jr., P. J. Durst, T. R. George, U.S. Army Engineer Research and Development Ctr. (United States)

The U.S. Army Engineer Research and Development Center (ERDC) is working with various partners to pursue research focused on supporting the development of increased levels of autonomy for unmanned ground vehicles (UGV) in defense applications. The research is being conducted under the Safe Operations of Unmanned systems for Reconnaissance in Complex Environments (SOURCE) Army Technology Objective (ATO), and the principal SOURCE partners include the U.S. Army Tank Automotive Research, Development and Engineering Center and the Army Research Lab. Under the SOURCE ATO, the ERDC is developing the Virtual Autonomous Navigation Environment (VANE) which will enable virtual performance evaluations of UGV with autonomous driving capability. The VANE incorporates vehicle mobility, terrain physics, and sensor models in a simulation tool for UGV. An initial demonstration of the VANE for an urban reconnaissance mission has recently been completed. In the demonstration, a mid-sized UGV was autonomously driven from a forward operating base (FOB) into an urban environment representative of a typical middle-eastern city. Reconnaissance was performed on a pre-selected target and the UGV returned to the FOB. The closed loop simulation included physics based LIDAR, CCD, GPS, and IMU sensor models as well as high fidelity vehicle-terrain interactions. The results of the simulation and the potential impact of similar simulations on the development and integration of UGV autonomy will be presented.

8045-34, Session 9

Light weight, portable operator control unit using an Android-enabled mobile phone

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There have been large gains in the field of robotics, both in hardware sophistication and technical capabilities. However, as more capable robots have been developed and introduced to battlefield environments, the problem of interfacing with human controllers has proven to be just as challenging. Particularly in the field of military applications, controller requirements can be stringent and can range from size and power consumption, to durability and cost. To this end, a light weight, inexpensive controller was created based on a mobile phone running the Android operating system. It was designed to control an iRobot Packbot through the Army Research Laboratory (ARL) in-house Agile Computing Infrastructure (ACI). The hardware capabilities of the mobile phone, such as Wi-Fi communications, touch screen interface, and the flexibility of the Android operating system, made it a compelling platform.

This controller offers many benefits over traditional Operator Control Units (OCUs). Such OCUs tended to resemble laptops and as such, were heavy, bulky, and had greater power requirements. The Android based OCU offers a more portable package and can be easily carried by a soldier along with normal gear requirements. In addition, the one hand operation of the Android OCU allows for the Soldier to keep an unoccupied hand for greater flexibility.

To validate the Android OCU as a capable controller, experimental data was collected evaluating use of the controller and a traditional OCU

interfaced with an Xbox 360 controller. Initial analysis suggests that the Android OCU performed positively in qualitative data collected from participants.

8045-35, Session 9

Practical robotic self awareness and self knowledge

D. W. Gage, XPM Technologies (United States)

This paper argues for a particular set of practical cognitive capabilities for humanoid robots and also for other robotic systems including unmanned vehicles of all types. After we stitch together the hardware and functional software components of the system, we need to (metaphorically speaking) “attach the electrodes,” which, in a practical sense, means to implement and integrate additional software to provide a level of self-awareness and self-knowledge. The notion is that a robot should develop and maintain a “sense” of its own (piecewise) continuous existence through time and space, that it should in some sense “get a life.” This represents a thrust distinct from the focus of a number of other current high-profile projects such as PR2, iCub, or MDS.

Self-awareness includes the ability to survive and work through unexpected power glitches while executing a task or mission: to “instantly” reboot, to safeguard itself in real time, to quickly recover its state, and to return to the task at hand as quickly as possible. Self-knowledge includes an extensive world model including a model of self and the purpose context in which it is operating (deontics). The architecture must support proactive self test and subsystem and behavior monitoring and calibration, and maintain a “personal” health/repair history. This will support an alternative model for system test and evaluation -- continuously measuring system performance throughout the entire product lifecycle, instead of limited-scenario formal structured testing prior to deployment. It will include episodic memory, and a system “lifelog,” with its supporting “life-logic” inference structure. It will also factor in multiple modes of Human Robotic interaction (HRI) - peer-to-peer, multi-level intervention, etc.

8045-36, Session 9

Microrobotic surveillance: discrete and continuous starbots

M. Mayyas, W. H. Lee, H. E. Stephanou, The Univ. of Texas at Arlington (United States)

This paper focuses on robotic technologies and operational capabilities of multiscale robots that demonstrate a unique class of Microsystems with the ability to navigate diverse terrains and environments. We introduce two classes of robots which combine multiple locomotion modalities including centimeter scale Discrete and Continuous robots which are referred here by D-Starbot and C-Starbot, respectively. The D-Starbot is based on novel mechanisms that allow shape reconfiguration to accomplish tasks such as lowering and raising to go over and under obstacles as well as squeezing through small voids. The C-Starbot is a new class of foldable robots that is generally designed to provide a high degree of manufacturability. It consists of flexible structures that are built out of composite laminates incorporating Microsystem technologies. The C-Starbot is designed to emulate and combine multiple locomotion modalities such as walking, running, crawling, gliding, clinging, climbing, flipping and jumping. The first generation of C-Starbot has centimeter scale structure that consists of flexible flaps each being coupled with muscle-like mechanism.

Untethered D-Starbot designs are prototyped and tested for multifunctional locomotion capabilities in indoor and outdoor environments. We present foldable mechanism and initial prototypes of C-Starbot capable of hopping and squeezing at different environments. To better understand the kinematic performance of such a class of robots, the large elastic deflection of robot’s arm is obtained for pulling force acting at variable angles and under payload and friction forces.

8045-37, Session 9

Novel locomotion via biological inspiration

R. D. Quinn, A. Boxerbaum, A. Hunt, Case Western Reserve Univ. (United States); L. Palmer, Univ. of South Florida (United States); H. Chiel, Case Western Reserve Univ. (United States); R. Bachmann, BioRobots, LLC (United States); E. Diller, Case Western Reserve Univ. (United States)

Animal behavioral, physiological and neurobiological studies are providing a wealth of inspirational data for robot design and control. Several very different biologically inspired mobile robots will be described. A robot called DIGbot is being developed that moves independent of the direction of gravity using Distributed Inward Gripping (DIG) as a rapid and robust attachment mechanism observed in climbing animals. DIGbot is an 18 degree of freedom hexapod with onboard power and control systems. Passive compliance in its feet, which is inspired by the flexible tarsus of the cockroach, increases the robustness of the adhesion strategy and enables DIGbot to execute large steps and stationary turns while walking on mesh screens. A Whegs robot, inspired by insect locomotion principles, is being developed that can be rapidly reconfigured between tracks and wheel-legs and carry GeoSystems Zipper Mast. The mechanisms that cause it to passively change its gait on irregular terrain have been integrated into its hubs for a compact and modular design. The robot can move smoothly on moderately rugged terrain using its tracks and run on irregular terrain and stairs using its wheel-legs. We are also developing soft bodied robots that use peristalsis, the same method of locomotion earthworms use. We present a technique of using a braided mesh exterior to produce fluid waves of motion along the body of the robot that increase the robot’s speed relative to previous designs. The concept is highly scalable, for endoscopes to water, oil or gas line inspection.

8045-38, Session 9

Zipper mast for enhanced communications and surveillance

G. Woodruff, Geo Systems, Inc. (United States); G. Witus, Turing Associates, Inc. (United States); P. Muench, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

Geosystems has been advancing innovations in zipper mast technology under a Phase II SBIR project with the US Army RDECOM/TARDEC. The zipper mast knits together three bands of spring steel into a rigid, retractable mast. Recent advances include design of the zipper tooth structure, material processing, cable management, use of composites and novel lightweight alloys, environmental sealing, and stabilization technologies. This paper reports test results covering surveillance camera and communications RF simultaneous operation, environmental testing, reliability testing, and field operational testing on robotic and manned platforms.

8045-39, Session 9

Small unmanned aerial platform for geospatial data collection and analysis

E. Levin, A. V. Sergeyev, Michigan Technological Univ. (United States)

Michigan Tech developed small unmanned aerial platform (SUAV) to research possibilities of geospatial data collection and analysis. Specifically, remotely controlled SUAV platform was deployed to identify mapping accuracy and verify applicability of such platform exploitation for surveillance. Imagery obtained from SUAV platform deployed uncalibrated cameras model and vary from 20 to 5 centimeters in ground sampling distance (GSD). Geometrical sensor modeling quality and object's measurements accuracy results are the most important characteristics for identifying platform suitability in surveillance application scenarios.

SUAV platform is equipped with autopilot and capable to accommodate a payload up to 11 pounds. Experiments were performed deploying 12MP Cannon Rebel EOS camera, which was a subject to calibration procedures. Surveying grade GPS equipment was used to prepare ground calibration sites. Work on processing of the obtained datasets encompasses: sensor modeling, single photo resections with image co-registration, mosaicking, and finally 3D terrain models generation. Comparison of the results obtained from the SUAV to respective results obtained from rigorous and traditional on-the-ground measurements provides an excellent opportunity for accuracy estimation and quality assurance to identify numerically limitations on potential target detection capability.

8045-40, Session 9

Laser power beaming for defense and security applications

T. Nugent, Jr., J. Kare, LaserMotive (United States)

Laser power beaming -- transmitting electric power without wires via laser -- has been demonstrated for kilowatt power levels and kilometer distances to a variety of moving targets. This paper reviews the demonstrated and projected capabilities and limitations of laser power beaming, and analyzes the requirements for several application areas relevant to defense and security: unmanned aerial vehicles, communications relays, sensor networks, and field unit or forward operating base power.

8045-41, Session 9

Projecting the future of robotics from its past

J. D. English, Energid Technologies (United States); P. Muench, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

Fields of endeavor, particularly those as diverse and technology-driven as robotics, take trajectories that are difficult or impossible to predict. Unforseeable disruptive events, developments, and discoveries lead to unforeseeable disruptive change, and the best one can do for prediction is extrapolate from the past and reason about likely disruptions. In this article, we focus only on the former. Our goal is to extrapolate from the progress in commercial and military robotics over the last 30 years to form a baseline of expectation looking forward 30 years. We analyze the technologies underlying robotics as well as the direct applications of robotic systems and project advancement along the natural dynamics of each technology or application, be it static, linear, or exponential in nature. Addressed technologies include planning and control algorithms, software, computer processing, mechanical structures, actuation, and sensing. We connect the projections to predict robotics advancement through comparison with past changes in other military technologies, including those behind aircraft, tracking radar, and ballistic missiles. The conclusions give nominal expectations for robotic systems 30 years into the future, results that can serve both to estimate the impact of potential disruptive developments and to guide researchers in seeking them.

8045-42, Session 9

Quantitative investigation of the perception of the technology needs, trends, and future vision for unmanned systems

R. F. Storm, J. Paul, Ricardo Inc. (United States); C. Clothier, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); J. A. Kovac, AeroMech Engineering, Inc. (United States)

Forecasting the growth and direction of the unmanned systems market is a challenging endeavor. To date, despite the numerous opinion based articles and qualitative studies on the subject of unmanned systems; a comprehensive study on the state of the industry and future technology trends does not exist outside of the all encompassing "the future is bright" mantra. Much of the current data is heavily opinion based and not peer reviewed. Dependent on the source and application (ground, air, surface, or undersea) there are drastically varied answers on platforms, technology needs, growth, and direction. Using quantitative survey methods and academic research principles; it is the goal of this paper to offer a comprehensive, quantitative, and meaningful analysis of the market and anticipated future technology needs.

The paper consists of a literature review and a quantitative survey using online survey tools with populations gathered from industry related social networks such as Linked-In's AUVSI group with over 2000 members. The survey investigates the perceived needs of the market, trends, technology growth areas, and future vision for each of the unmanned technology disciplines (ground, air, surface, and undersea).

Upon completion of the survey, the data will be correlated and analyzed by industry experts from each discipline. The industry experts will evaluate the results and provide further discussion on the industry perception and technology trends. The results of the survey will then be compared against each unmanned sector to develop a common picture of the platforms, technology needs, growth, and direction of the marketplace.

8045-45, Session 9

Taking on the tall poles of autonomous robot navigation

M. H. Rosenblum, Lockheed Martin Corp. (United States)

The Holy Grail of autonomous ground robotics has been to make ground vehicles that behave like humans. Over the years, as a community, we have realized the difficulty of this task, and we have back pedaled from the initial Holy Grail and have constrained and narrowed the domains of operation in order to get robotic systems fielded. This has lead to phrases such as "operation in structured environments" and "open-and-rolling terrain" in the context of autonomous robot navigation. With these constraints, we have minimized the gap between the current state of robotic capability and operational requirements making it possible to field ground robotic systems now or soon, which is good for all of us working in the field of robotics. Unfortunately, constraining the problem in this way has only put off the inevitable, i.e., solving the myriad of difficult robotics problems that we identified as long ago as the 1980's on the Autonomous Land Vehicle Project and in most cases are still facing today. These "Tall Poles" have included but are not limited to navigation through complex terrain geometry, navigation through thick vegetation, the detection of geometry-less obstacles such as negative obstacles and thin obstacles, the ability to deal with diverse and dynamic environmental conditions, the ability to function in dynamic and cluttered environments alongside other humans, and any combination of the above. Lockheed Martin Autonomous Systems has focused on attacking these tall poles. Our lofty goal and mission statement is "Any A to Any B". On the path to achieving this goal, our efforts have included investigation into alternative sensing, robotic architecture design and improvements, and decision and control algorithms. This paper is an overview of the progress we have made at Autonomous Systems over the last three years in trying to knock down some of the tall poles remaining in the field of autonomous ground robotics.

Conference 8046: Unattended Ground, Sea, and Air Sensor Technologies and Applications XIII

Thursday-Friday 28-29 April 2011

Part of Proceedings of SPIE Vol. 8046 Unattended Ground, Sea, and Air Sensor Technologies and Applications XIII

8046-01, Session 1

Networked localization of sniper shots using acoustics

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The presence of snipers in modern conflicts leads to high insecurity for the soldiers. In order to improve the soldier's protection against this threat, the French German Research Institute of Saint-Louis (ISL) initiated studies in the domain of acoustic localization of shots. Mobile antennas mounted on the soldier's helmet were initially used for real-time detection, classification and localization of sniper shots. It showed good performances in land scenarios, but also in urban scenarios if the array was in the shot corridor, meaning that the microphones first detect the direct wave and then the reflections of the Mach and muzzle waves. As soon as the acoustic arrays were not near to the shot corridor (only reflections are detected) this solution lost its efficiency and erroneous estimated position were given.

In order to estimate the position of the shooter in every kind of urban scenario, ISL started studying time reversal techniques. Knowing the position of every reflective object in the environment (buildings, walls, ...) it should be possible to estimate the position of the shooter. First, a synthetic propagation algorithm has been developed and validated for real scale applications. It has then been validated for small scale models, allowing us to test our time reversal based algorithms in our laboratory. In this paper we discuss all the challenges that are induced by the application of sniper detection using time reversal techniques. We will discuss all the hard points that can be encountered and try to find some solutions in order to optimize the use of this technique.

8046-02, Session 1

Microphones' directivity for the localization of sound sources

M. Tajari, P. Rizzo, Univ. of Pittsburgh (United States)

In a recent paper the proof-of-concept of an approach for the localization of acoustic sources was presented. The method relies on the use of unidirectional microphones and amplitude-based signals' features to extract information about the direction of the incoming sound. By intersecting the directions identified by a pair of microphones, the position of the emitting source can be identified.

In this paper we expand the work presented previously by assessing the effectiveness of the approach for the localization of an acoustic source in an indoor setting. As the method relies on the accurate knowledge of the microphones directivity, analytical expression of the acoustic sensors polar pattern were derived by testing them in an anechoic chamber. Then an experiment was conducted in a classroom-type environment by using an array of three unidirectional microphones. The ability to locate the position of a commercial speaker placed at different positions in the room is discussed.

The objective of this study is to propose a valid alternative to the common application of spaced arrays and therefore to introduce a new generation of reduced size sound detectors and localizers.

8046-03, Session 1

Supersonic projectile models for asynchronous shooter localization

R. J. Kozick, Bucknell Univ. (United States); G. T. Whipps, U.S. Army Research Lab. (United States); J. N. Ash, The Ohio State Univ. (United States)

In this work we consider the localization of a gunshot using a distributed sensor network measuring time differences of arrival between a firearm's muzzle blast and the shockwave induced by a supersonic bullet. This so-called MB-SW approach is desirable because time synchronization is not required between the sensors, however it suffers from increased computational complexity and requires knowledge of the bullet's velocity at all points along its trajectory. While the actual velocity profile of a particular gunshot is unknown, one may use a parameterized model for the velocity profile and simultaneously fit the model and localize the shooter. In this paper we evaluate a number of velocity profile models from the literature against measured data and consider their efficacy in the localization problem. We study efficient solutions for the localization problem and develop models that trade off fidelity and computational complexity. In particular, we show that a profile from a constant deceleration admits a closed-form likelihood expression and reduces estimation bias over the constant velocity model, with a small increase in computational complexity.

8046-04, Session 1

Suppressor evaluation

D. Grasing, U.S. Army Research, Development and Engineering Command (United States)

No abstract available

8046-05, Session 1

Helicopter gunfire detection system: shockwave only solutions

S. V. Desai, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8046-06, Session 1

Helicopter gunfire detection system: livefire data collection results

B. Ellwood, U.S. Army Research, Development and Engineering Command (United States)

No abstract available

8046-07, Session 2

Power line detection and avoidance using an electric and magnetic-field sensing system optimized for small unmanned aerial vehicles (SUAVs)

B. G. Morris, U.S. Army Research Lab. (United States)

Unmanned aerial vehicles (UAV) have been traditionally used as Intelligence, Surveillance, and Reconnaissance (ISR) assets, and their capability is being boosted by advances in sensors and modern information and communications technologies. Missions being envisioned for UAVs are varied, but typically involve some form of patterned flight, tracking, detection and monitoring activity. Power lines are a major obstacle to flight in urban environments and are relatively undetectable by conventional microwave radar owing to their small size. Thermal imaging systems are also inadequate because wires are often at the same temperature as the background or below the resolution of these systems. The electric field (E-field) on power lines is directly related to the voltage on the lines; similarly, the magnetic field (B-field) is related to the electric current. One relatively inexpensive way to equip a UAV with the capability to detect power lines is to utilize E&B-field sensors specifically for this task. The Army Research Laboratory (ARL) has investigated E&B-field sensor technology for several years [1-2]. We recently integrated E&B-field sensors on a SUAV and measured power-line fields in-flight. The detection range is a complex function of the field strength which increases with increasing line voltage, decreases with increasing line-to-SUAV distance, and varies with the relative geometry of the power lines. We successfully demonstrated proof-of-concept for a sensitive directional E&B-field sensing system that can detect, track and avoid power lines. Other applications being envisioned include geo-locating electric power activities, energy harvesting, transmission/distribution grid monitoring and power-line navigation as an alternative to GPS.

8046-08, Session 2

A compact, fast-response synchronous measurement of temperature for UAV applications

A. Khan, M. A. Zondlo, Princeton Univ. (United States)

We report a compact, portable, low power tunable diode laser based sensor for a fast, non-intrusive measurement of temperature on airborne-based vehicles. The proposed sensor design avoids common problems in existing sensors such as adiabatic compression of the ambient airstream, thermal inertia of the sensing element, and impinging cloud particles. These effects are quite common in the conventional temperature sensors used in most aerial vehicles for ambient temperature measurements. The molecular oxygen (O2) transitions are measured using a 765 nm vertical cavity surface emitting laser (VCSEL) in the spectral region of two closely spaced oxygen transitions, centered at 13084 cm-1 and 13086 cm-1 respectively.

Another advantage of the proposed sensor design is that it can simultaneously detect another trace gas species along with in situ measurement of the temperature. For example, in this design we detect carbon dioxide (CO2) concentration using a 2008 nm VCSEL. The two laser beams are coupled into a single 20 cm multipass cell and the absorption signal (from both carbon dioxide and oxygen) was detected simultaneously on a 2 micron detector. Second harmonic (nf, n=2) detection, using wavelength modulation spectroscopy (WMS) was employed to enhance the sensitivity of measurements. The sensor was calibrated for drifts in a temperature-regulated bath with accuracy and stability of 0.05 K. The sensor can readily be miniaturized and consumes less than 2 W of power, ideal for the use of aerial vehicles and airborne measurements.

8046-09, Session 2

Unmanned air systems (UAS) autonomous collision avoidance system (ACAS)

R. T. Hintz, Naval Air Warfare Ctr. Weapons Div. (United States)

No abstract available

8046-10, Session 2

Miniature UUV concept for coastal surveillance

E. M. Carapezza, Defense Advanced Research Projects Agency (United States)

No abstract available

8046-12, Session 3

Biomimetic fusion that enhances sensor performance in bimodal surveillance system

L. Ziph-Schatzberg, The Boston Univ. Photonics Ctr. (United States); S. Kelsall, General Dynamics Electric Boat (United States); A. E. Hubbard, Boston Univ. (United States)

Algorithms for synergistically fusing acoustic and optical sensory inputs, thereby mimicking biological attentional processes are described. Many existing perimeter defense surveillance systems using more than one sensory modality combine different sensors' information to corroborate findings by other sensors and to add data from a second modality. In contrast to how conventional systems work, animals combine information from multiple sensory inputs in a way that improves each sensory system's performance. We demonstrated that performance is enhanced when information in one modality is used to focus processing in the other modality (a form of attention). This synergistic combination improves surveillance efficacy by focusing auditory and visual "attention" on a particular target or location.

Algorithms for combining auditory and visual information were developed. These combination algorithms perform "zoom-with-enhanced-acuity" in both the visual and auditory domains, triggered by detection in either domain. Sensory-input processing algorithms focus on specific locations, indicated by at least one of the modalities. This spatially focused processing emulates biological attention-driven focusing. We showed that given information about the target, the acoustic algorithms were able to achieve over 80% correct target detection at SNRs of -20 dB and above, as compared with similar performance at SNRs of -10 db and above without target information from another modality. Similarly, the visual algorithm achieved performance of over 80% detection with added noise variance of 0.001 without target indication, and maintained 100% detection at added noise variance of 0.1 when target information is taken into account.

8046-13, Session 3

MUGI: the covert surveillance system

I. Kasher, U. Adar, Seraphim Optronics Ltd. (Israel)

Mini Unattended Ground Imager (MUGI) was designed to meet two opposing requirements: covertness and best surveillance performance.

The main dilemma concerns the aperture. On the one hand it forms the optical limit of surveillance ranges and sectors, on the other hand it is the Achilles Heel of the covert system. The task of deploying and camouflaging the sensor is put at the focus of the design. The techno-operational decision making process is explained with the resulting non conventional realization of the MUGI system: a periscopic, sealed,

one piece sensor. It requires only a minimal size slit for aperture with no movement, no reflection and no noise that may give in its existence. MUGI's multitude features, surveillance performance and its ability to blend and disappear into the natural background are demonstrated.

8046-14, Session 3

SCORPION II persistent surveillance system features update

M. A. Coster, J. L. Chambers, G. A. Prisco, Northrop Grumman-Xetron (United States)

This paper highlights the most recent added features and benefits available in the latest generation of Northrop Grumman SCORPION II persistent surveillance and target recognition systems produced by the Xetron campus in Cincinnati, Ohio. Leveraging smaller, lighter and more power efficient SCORPION II sensor and universal gateway components with foliage penetrating ad-hoc network communications, persistent field programmable systems that are easier to conceal can be optimized for both image capture and data exfiltration. Since 1998 Northrop Grumman has integrated best in class sensors with its proven universal modular gateway to provide encrypted data exfiltration to Common Operational Picture (COP) systems while also providing the added benefits of remote sensor command and control. In addition to the SCORPION II suite of sensor components, a growing list of over sixty different sensor and camera types from a variety of manufacturers have been integrated with the SCORPION family of gateways. In addition to updating several different COP systems, SCORPION and SCORPION II data can be directly processed using a common sensor status graphical user interface (GUI) that allows for viewing and analysis of images and sensor data from hundreds of SCORPION system Gateways on single or multiple displays.

8046-15, Session 3

Critical asset protection modeling, simulation, analysis, and visualization

W. Malinowski, R. Cruz, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

A comprehensive Modeling and Simulation (M&S) capability is required to assess, improve and visualize newly fielded technologies for Critical Asset Protection (CAP).

Protection is addressed in the planning stages of any secure facility in order to provide adequate defense of critical personnel and assets. This paper will discuss a research and development effort to use Government off the Shelf Software (GOTS) to complete this task.

8046-16, Session 3

Integrated base defense (IBD) program

R. Giarratano, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8046-17, Session 4

Robust discrimination of human footsteps using seismic signals

A. Faghfouri, M. B. Frish, Physical Sciences Inc. (United States)

Unattended Ground Sensors (UGS) are used in the southern and northern borders of the U.S. to detect illegal personnel crossings. However, movements of wild and domesticated animals (e.g., jack rabbit, coyote, mule deer, cow, horse, deer, and moose) and vehicles in the same areas considerably diminish the human detection attempts. This paper describes a method based on statistical signal processing which discriminates the seismic signals generated by the human footsteps from the animals and vehicles. The method includes the steps of:

(1) Segmenting seismic signals into short windows, and extracting from them multiple features based on their power, pattern, spectral, and statistical properties;

(2) Using representative signal samples to train a supervised classifier;

(3) Providing classifier result sequences to a decision algorithm which enhances the probability of detection.

We report tests of this method using data comprising more than 200 files, each longer than 30 seconds, acquired from diverse activities including human walking and running, movements of horses, cows, coyotes, jack rabbits, vehicles, and background. 15% of the data were devoted to training, while the remaining 85% were utilized for testing the method. The described method achieved probabilities of detecting the human activity exceeding 98% with false alarms less than 1%. Similar algorithms can benefit military applications (e.g., surveillance, reconnaissance), and civil infrastructure protection (e.g., intrusion of pipeline or powerline rights-of-way).

8046-18, Session 4

Multimodal sensor fusion for personnel detection

S. V. Desai, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8046-19, Session 4

Active ultrasonic micro-Doppler for human classification

S. A. Quoraishee, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8046-20, Session 5

Fish schools and bird flocks as mobile sensor arrays

C. S. Bendall, Space and Naval Warfare Systems Ctr. Pacific (United States)

No abstract available

8046-21, Session 5

Escape and evade control policies for ensuring the physical security of nonholonomic, ground-based, unattended mobile sensor nodes

D. Mascarenas, C. Stull, C. R. Farrar, Los Alamos National Lab. (United States)

In order to realize the wide-scale deployment of high-endurance, unattended mobile sensing technologies, it is vital to ensure the self-preservation of the sensing assets. Deployed mobile sensor nodes face a

variety of physical security threats including theft, vandalism and physical damage. Unattended mobile sensor nodes must be able to respond to these threats with control policies that facilitate escape and evasion to a low-risk state. In this work the Precision Immobilization Technique (PIT) problem has been considered. The PIT maneuver is a technique that a pursuing, car-like vehicle can use to force a fleeing vehicle to abruptly turn ninety degrees to the direction of travel. The abrupt change in direction generally causes the fleeing driver to lose control and stop. The PIT maneuver was originally developed by law enforcement to end vehicular pursuits in a manner that minimizes damage to the persons and property involved. It is easy to imagine that unattended autonomous convoys could be targets of this type of action by adversarial agents. This effort focused on developing control policies unattended mobile sensor nodes could employ to escape, evade and recover from PIT-maneuver-like attacks. The development of these control policies involved both simulation as well as small-scale experimental testing. The goal of this work is to be a step toward ensuring the physical security of unattended sensor node assets.

8046-22, Session 5

A method for robust adaptation of the configuration of distributed sensor fields

T. A. Wettergren, Naval Undersea Warfare Ctr. (United States)

We illustrate an approach for adapting the configuration of surveillance-based distributed sensor fields. By using a robust method of centralized adaptation of the field configuration, the performance of distributed sensor fields can be greatly extended. This extension can be in terms of improved performance due to new local knowledge of the environment, improvement to compensate for individual sensor node failures, and improvement due to changes in the operational goal. In all of these situations, it is crucial to adapt only in a manner that is consistent with the performance intent of the original deployment strategy. In this paper, we use the concept of Pareto optimality (that is, the achievement of desired tradeoffs between competing objectives) as a mechanism for describing the intent of the original deployment. We then illustrate a computational approach to adaptation of the field configuration that can be performed to maintain this intent in the presence of a variety of sources of field degradation. Numerical examples are shown that illustrate this effect using a sparse sensor network that is designed for providing surveillance coverage of nonhomogeneous environments. We conclude with an analysis of the stability properties of this adaptation procedure, along with guidelines for its use in practical systems.

8046-23, Session 5

FIRESTORM: a collaborative network suite application for rapid sensor data processing and precise decisive

S. Kaniyantethu, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No abstract available

8046-24, Session 6

Detection of electromagnetic waves using MEMS antennas

P. G. C. Datskos, Oak Ridge National Lab. (United States)

No abstract available

8046-25, Session 6

An empirical method for dynamic camouflage assessment

J. G. Blitch, Colorado State Univ., DoD SMART Program (United States)

No abstract available

8046-26, Session 6

Relative intensity noise for uncooled silicon carbide mid-wave infrared detectors

G. Lim, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); A. Kar, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

A detector has been fabricated by laser doping an n-type 4H-SiC substrate with gallium for the MWIR wavelength 4.21 um. It operates at room temperature and produces optical signal, which is the change in the reflected power of a probe beam. The operating mechanism of this detector is that the incident photons induce the transition of electrons from the valence band to the dopant energy level and, consequently, modify the refractive index of the doped substrate. The Ga energy level is found to be in the wavelength range of 4 to 5 um based on optical absorption measurements. The laser doping technique enhances the solid solubility (6.251×10^20 cm^-3) of Ga in the substrate, exceeding the equilibrium limit (1.8×10^19 cm^-3 at 2500 K). The optical response of the detector, which was maintained at room temperature, was determined for incident photons of wavelength 4.21 um by measuring the reflectance of the detector using a He-Ne laser of wavelength 632.8 nm as the probe beam. The reflectance data were used to calculate the variation in the refractive index of the detector at the MWIR wavelength. The doped sample exhibits a distinct change in its refractive index compared to the undoped sample. These results indicate that the doped sample can be used as an MWIR detector. The spectral densities of relative intensity noise (RIN) are also examined for four components of the detector. The responsivity, noise equivalent temperature difference (NETD) and detectivity can be obtained by analyzing the sources of noise in these components. The detectivity of the optical photodetector of this study has higher value than the ideal electrical photodetector. The experimental value of NETD for a radiation source at 25°C, however, is found to be higher than the theoretical value obtained from the spectral densities of RIN.

8046-27, Session 6

Ultraviolet photodetectors directly integrated on CMOS using low-temperature ZnO nanowire techniques

R. Olah, A. Dutta, Banpil Photonics, Inc. (United States); D. Wang, Consultant (USA); T. Manzur,

Visible blind and solar blind ultraviolet (UV) photodetector arrays with spectrum range below visible light or solar blind avoiding interference from visible light and even solar radiation, possess potential applications in the fields of medical diagnostics, fire alarms, combustion monitoring and solar astronomy. Two solutions presently used for visible blind and solar blind detection are AlGaN and photomultiplier tubes (PMT). AlGaN photodector arrays have been developed but have several key problems of large dislocation densities, low doping efficiency and thermal mismatching with all these problems further complicated by the large aluminum composition necessary to achieve visible blind and solar blind photodetectors. PMT detectors have high sensitivity but are bulky, fragile glass tubes that require large voltage biases and cannot be used to

generate photodetector arrays.

A promising candidate for UV detectors is wurtzite ZnO with a high bandgap of (3.4 eV, 365 nm). Zinc oxide (ZnO) with combinations of Magnesium (Mg) or Cadmium (Cd) can be tuned to absorb ultraviolet light from 210 nanometers (2.8 eV) to 450 nanometers (5.9 eV). This enables zinc oxide to be tunable to visible blind or solar blind spectrums.

Banpil has been developing visible and solar blind photodetectors using ZnO nanowires grown at temperatures below 400C to facilitate direct ZnO growth on silicon read out integrated circuits. Nanowires provide maximum photon absorption increasing quantum efficiency. To increase the bandgap to achieve solar blindness, the bandgap can be increased to 5.5 eV for solar blind visibility. Potential candidates to combine with ZnO to increase the bandgap potential are magnesium oxide MgO and beryllium oxide BeO. Solution methods were developed to grow BeZnO nanowires and solution methods to overcome the ZnO wurtzite, MgO cubic and miscibility gap to grow MgZnO nanowires. Modeling, simulation, process steps to grow BeZnO and MgZnO using electrophoresis and final measurement results are shown for generating BeZnO and MgZnO nanowire solar and visible blind sensors.

8046-28, Session 6

Nanostructure-based EO/IR focal plane arrays for unattended ground sensor applications

A. K. Sood, Magnolia Optical Technologies, Inc. (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); A. F. M. Anwar, Univ. of Connecticut (United States); N. K. Dhar, D. L. Polla, DARPA (United States); P. S. Wijewarnasuriya, Army Research Lab. (United States)

Next Generation EO/IR focal plane arrays using nanostructure materials are being developed for a variety of Defense Applications including Unattended Ground Sensor Applications. Several different nanomaterials are being evaluated for these applications. These include ZnO nanowires that have demonstrated large signal to noise ratio as a wide band gap nanostructure material in the UV band. Similarly, the work is under way using Carbon Nanotubes (CNT) for a high speed detector and focal plane array as bolometer for IR bands of interest, which can be implemented for the unattended ground sensor applications.

In this paper, we will discuss the sensor design and model predicting performance of an EO/IR focal plane array that can cover the UV to IR bands of interest. The model can provide a robust means for comparing performance of the EO/IR FPA's and Sensors that can operate in the UV, Visible-NIR (0.4-1.8), SWIR (2.0-2.5), MWIR (3-5), and LWIR bands (8-14). This model can be used as a tool for predicting performance of nanostructure arrays under development. We will also discuss our results on growth and characterization of ZnO nanowires and CNT's for the next generation sensor applications.

8046-29, Session 6

Free-space optical communication links at 1.55 µm for remote operation

J. W. Zeller, Naval Undersea Warfare Ctr. (United States)

No abstract available

8046-30, Session 6

Nighttime camera options for unattended ground sensor (UGS) applications

D. C. Hartup, L-3 Communications Nova Engineering (United States); C. M. Hanson, L-3 Electro-Optical Systems (United States); R. A. Owen, L-3 Communications Nova Engineering (United States)

There are several existing and emerging options for nighttime cameras that can be used in Unattended Ground Sensor (UGS) applications. This paper will present new and emerging imaging options. The advantages and disadvantages of each technology as it relates to UGS applications will be discussed. Key parameters include resolution, size, power consumption, and image quality. The nighttime camera technologies that will be discussed include Long Wave Infrared (LWIR), Short Wave Infrared (SWIR), and Image Intensified (I2). A new amorphous silicon 1024 x 768 pixel LWIR imager with 17 um pixels that will soon be available from L-3 Infrared Products is described. The higher resolution of this imager, compared to currently available 640 x 480 pixel versions, will have several advantages for UGS applications. For example, some advantages are increased detection distance, reduced lens focal length, and higher resolution images of potential targets. This camera also features very low power consumption and a compact form factor. There is an increasing need for facial and license plate recognition in UGS systems. While EO cameras with high pixel densities can be used to meet this requirement during daylight, SWIR or I2 options are needed at night. I2, an inherently analog technology, can provide very high resolution images to meet the requirement. An InGaAs I2 camera for UGS applications is described. In addition, a new SWIR camera from L-3 EO Products with greater than 1 Mpixels will be analyzed for use in meeting the facial and license plate recognition requirement.

8046-31, Session 6

Heading errors in an alignment-based magnetometer

C. Hovde, Southwest Sciences, Inc. (United States); B. Patton, Univ. of California, Berkeley (United States); O. Versolato, Univ. of Groningen (Netherlands); E. Corsini, S. Rochester, D. Budker, Univ. of California, Berkeley (United States)

A prototype magnetometer for anti-submarine warfare applications is being developed based on nonlinear magneto-optical rotation (NMOR) in atomic vapors. NMOR is an atomic spectroscopy technique that exploits coherences among magnetic sublevels corresponding to alignment of the ground electronic state of a vapor of alkali atoms to measure magnetic fields with high precision. NMOR uses stroboscopic optical pumping via frequency or amplitude modulation of a linearly polarized laser beam to create the alignment. An anti-relaxation coating on the walls of the atomic vapor cell results in a long lifetime of up to 1 s for the coherence and enables precise measurement of the precession frequency. With proper feedback, the magnetometer can self-oscillate, resulting in accurate tracking and fast time response.

The spectra of the F=2 NMOR resonance of 87Rb have been measured as a function of heading in Earth's field. The nonlinear Zeeman effect splits the resonance into three components. The spectra show a high degree of symmetry, consisting of a central peak and two side peaks of nearly equal intensity. As the heading changes, the ratio of the central peak to the average of the two side peaks changes. The amplitudes of the side peaks remain nearly equal. The spectral results are compared to a detailed simulation based on a numerical solution of the density matrices that includes the optical and magnetic fields. An analysis of the spectra indicates that the heading error ultimately could be reduced to just 10 pT. A broader background shift is also observed in the spectra. While this background can be removed when fitting resonance spectra, understanding it will be important to achieving the small heading error in self-oscillating mode that is implied by the spectral measurements.

Conference 8047: Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR II

Tuesday-Thursday 26-28 April 2011

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8047-01, Session 1

Ground/air multisensor interoperability, integration, and networking for persistent ISR: what, why, who

M. A. Kolodny, U.S. Army Research Lab. (United States)

No abstract available

8047-02, Session 1

Promoting interoperability within the UGS community and effective acquisition of UGS solutions for the warfighter

R. Heathcock, U.S. Dept. of Defense (United States)

The Defense Intelligence Agency (DIA) is working to establish standards for interoperability of the Unattended Ground Sensors (UGS) the government deploys. Among its objectives, this initiative aims to provide interface standards to enable interoperability of disparate components from multiple vendors, flexible configuration, rapid insertion of new capabilities, and reduced life cycle costs. To this end, the Under Secretary of Defense for Technical Collection and Analysis created an UGS Standards Working Group. Its charter authorizes the working group to identify, define, and socialize standards for current and future UGS. This paper presents the group's objectives in detail, as well as the status of its mandate.

8047-03, Session 1

Terra Harvest: an open, integrated battlefield unattended ground sensors (UGS) architecture

R. Heathcock, U.S. Dept. of Defense (United States); C. Brasch, K. Linnebur, MITRE Corp. (United States)

The Defense Intelligence Agency (DIA) is developing Terra Harvest, an open, integrated battlefield Unattended Ground Sensors (UGS) architecture that will employ multiple, flexible sensors via standards-based integration. The Terra Harvest open architecture separates the UGS system into fundamental components and standardizes internal and external interfaces to optimize interoperability. Other acquisition programs can take advantage of this open architecture to meet challenging mission requirements.

8047-04, Session 1

Architectural developments for Terra Harvest and the UGS Standards Working Group

J. Houser, U.S. Army Research Lab. (United States)

No abstract available

8047-05, Session 1

After three phases of the Terra Harvest program, what are the lessons learned, and future impacts

D. Buster, D. Gerlock, Honeywell, Inc. (United States)

Since mid 2009, Honeywell has been supporting the Defense Intelligence Agency (DIA) on their Terra Harvest program. This paper addresses the lessons learned on Terra Harvest, and looks to the future impacts of the proposed UGS controller standard.

We start with a brief background on Terra Harvest. The overall intent of Terra Harvest is to germinate UGS controllers that are open to new sensors, communications, and data processing ('open' meaning low development cost). Honeywell started with a trade study, developed an UGS controller prototype, tested it at the Empire Challenge exercise, and at DIA's request, offered a portion of Honeywell's NEOS software as the starting point for an UGS controller standard. DIA funded several vendors to develop sensors and communications plug-ins according to the proposed standard.

We explore some of the political and technical lessons learned from Terra Harvest so far. We also look ahead to the impacts of an UGS controller standard - how does the Government intend to use the standard, and how might vendors participate.

8047-06, Session 1

Terra Harvest open source environment (THOSE): a universal unattended ground-sensor controller

K. Klawon, J. Gold, Univ. of Dayton Research Institute (United States); D. Landoll, P. M. Hirz, 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 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 implementation strategy for some of the key software components.

Preliminary integration/test results and the Team's approach for transitioning the THOSE design and source code to the Government are also presented.

8047-07, Session 2

Interoperability: a big picture perspective

M. A. Kolodny, U.S. Army Research Lab. (United States)

No abstract available

8047-08, Session 2

Integration of current force unattended ground sensors for the Empire Challenge

G. H. Stolovy, U.S. Army Research Lab. (United States)

This paper will describe the integration and participation of the Current Force UGS (Unattended Ground Sensors) systems into the US Joint Forces Command EMPIRE CHALLENGE 2010 Exercise.

8047-09, Session 2

A packaged native data format for interoperability of unattended ground sensors with a sensorML-enabled controller

J. L. Chambers, A. J. Brunck, Jr., Northrop Grumman-Xetron (United States)

Unattended Ground Sensors (UGS) from a wide range of manufacturers have difficulty interoperating with each other, and with common control and dissemination points. Typically, UGS data is transmitted via radio frequency (RF) or wired connections to a central location where the data can be fused together and transmitted to a Processing, Exploitation, and Dissemination (PED) system. These PED systems are charged with analyzing the data to create real-time, actionable intelligence for the war fighter. However, when several disparate sensors from different manufacturers are used, interoperability problems arise. An UGS controller that accepts data from a wide range of sensors, and transmits this data in a common format, is essential. This paper proposes a packaged native data format to transmit this data to PED sites. The data format would be used in conjunction with the Open Geospatial Consortium (OGC) Sensor Model Language (SensorML) sensor descriptions. SensorML 1.0 is an approved OGC standard, and one of the major components within the OGC Sensor Web Enablement (SWE) suite of standards. By incorporating SensorML, an UGS controller can accept data from various manufacturers' sensors, interpret that data using the SensorML descriptions, thereby allowing the controller to interoperate between sensors. Furthermore, once the data has been transmitted to the PED, SensorML can be used to translate the packaged native data sensor format . A SensorML-enabled UGS controller that transmits packaged native data format sensor information is a powerful tool that provides situational awareness by combining multiple sensors to form a single common operational picture (COP).

8047-10, Session 2

Model-driven SOA for sensor networks

C. Gibson, J. Ibbotson, D. Braines, T. Klapiscak, IBM United Kingdom Ltd. (United Kingdom); B. K. Szymanski, S. Geyik, Rensselaer Polytechnic Institute (United States)

Previous work has explored the application of enterprise middleware techniques out at the edge of the network -- specifically the message bus model commonly found in commercial IT infrastructures -- to address some of the challenges of delivering complex sensor network solutions over heterogeneous communications infrastructures. We develop this concept further into a semantically rich, model-based design and analysis approach that considers the sensor network and its contained services (including sensors and information processing algorithms) as a service-oriented architecture (SOA).

SOA in the enterprise is largely static, oriented towards application integration, and generally operates on highly reliable network and computing infrastructures. Sensor networks do not share these characteristics and in this paper we detail a practicable SOA for sensor networks, including a stream-based service composition approach that is appropriate to this environment. Underpinning this is a semantic model that can be used to describe sensor network services, and which enables a systematic approach to service composition, analysis, and deployment. This is illustrated with transformations of the model for static and dynamic analysis (using domain-specific techniques) in support of domains such as performance, quality of service, and security. Finally we show how the use of our semantic model enables cross intelligence domain integration -- i.e. integration of the ISR domain with other intelligence domains such as HUMINT -- to simplify intelligence gathering and allow users (analysts) to express queries in a structured form of natural language called Controlled English.

8047-11, Session 2

Decentralized operating procedures for orchestrating data and behavior across distributed military systems and assets

N. Peach, PB Partnership Ltd. (United Kingdom)

In this paper we present a method for a highly decentralized yet structured and flexible approach to achieve systems interoperability by orchestrating data and behavior across distributed military systems and assets with security considerations addressed from the beginning. We describe an architecture of a tool-based design of business processes called Decentralized Operating Procedures (DOP) and the deployment of DOPs onto run-time nodes, supporting the parallel execution of each DOP at multiple implementation nodes (fixed locations, vehicles, sensors, soldiers) throughout a battlespace to achieve flexible and reliable interoperability.

The described method allows the architecture to; a) provide fine grain control of the collection and delivery of data between systems; b) allow the definition of a DOP at a strategic (or doctrine) level by defining required system behavior through process syntax at an abstract level, agnostic of implementation details; c) deploy a DOP into heterogeneous environments by the nomination of actual system interfaces and roles at a tactical level; d) rapidly deploy new DOPs in support of new tactics and systems; e) support multiple instances of a DOP in support of multiple missions; f) dynamically add or remove run-time nodes from a specific DOP instance as missions requirements change; g) model the passage of, and business reasons for the transmission of each data message to a specific DOP instance to support accreditation; h) run on low powered computers with lightweight tactical messaging. The architecture leverages the UK MOD Generic Vehicle Architecture (GVA) programme and System Information Exploitation (SIE) study.

8047-12, Session 3

PILAR gunfire detection system enhancements (GDS)

A. Donzier, 01dB-Metravib (France); S. Gomez, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

Maintaining and establishing law and order, countering civil disturbances and responding to various levels of threats have been a recurring task for US forces involved in joint, multinational, and interagency operations.

This paper presents the most up-to-date enhancements of the PILAR M1 Fixed Site (FS) and M2 Vehicle Mounted (VM) Acoustic Gunfire Detection System (GDS). Information on the various tests conducted to assess the system's effectiveness under realistic operational conditions as part of the PILAR Foreign Comparative Testing (FCT) effort is also provided. The enhancements include hardware and software upgrades to the existing GDS configuration that provide the user with critical counter sniper capabilities including mapping, real time Global Positioning Satellite (GPS) location of sniper fire relative to the vehicle on the move, and optronic sensors for identification and designation of the threat. Such sensors range from multifunction sensors mounted on a motorized turret to sights that provide the user with actionable information to promptly retaliate against hostile gunfire. This paper provides a general overview of the PILAR GDS capabilities needed to provide military and civilian security forces with enhanced Situational Awareness (SA) to effectively locate the threat and amplify tactical performance. The benefits of the crucial upgrades to the essential mobile and ground systems will be discussed and analyzed.

8047-13, Session 3

The acoustic vector sensor: a versatile battlefield acoustics sensor

J. Wind, H. de Bree, Microflown Technologies (Netherlands)

The invention of the Microflown has made it possible to measure acoustic particle velocity directly. An acoustic vector sensor (AVS) measures the pressure and the particle velocity in all three directions, such that the source direction is measured directly. The sensor is a uniquely versatile battlefield sensor because its size is a few millimeters and it is sensitive to sound from 10Hz to 10kHz.

This article shows the results of various field tests of acoustic vector sensors to determine the direction of small caliber firearms, heavy artillery, fixed wing aircraft and helicopters. Furthermore, we consider on which platforms the sensors can be used. An operational test of a network of stand-alone ground sensors is discussed. Furthermore, we consider the ongoing work of mounting the sensor on the Fennek reconnaissance vehicle and on an unmanned areal vehicle (UAV).

8047-14, Session 3

Attenuation of individual seismic-wave types using various architectural enclosures for geophones

S. Schumer, U.S. Army RDECOM-ARDEC (United States)

A major difficulty in classifying seismic events in the near field is the existence of multiple wave types and their lack of time to separate from one another. As the seismic components travel through a medium the difference in their velocities results in a superimposed signal that will look drastically different, even small distances. If individual wave types can be attenuated, it can be possible to accurately measure information contained in a single wave type. The paper here proposes to determine if measuring seismic data from within enclosures of specific architectural design can be utilized to attenuate specific wave types while maintaining the energy of other wave types. The technique leads to drastically improved classification and localization capabilities of near field seismic events.

8047-15, Session 3

Embedded real-time classifier for profiling sensors and custom detector configuration

R. K. Reynolds, Jr., S. K. Chari, The Univ. of Memphis (United States); D. J. Russomanno, Indiana Univ.-Purdue Univ. Indianapolis (United States)

A profiling sensor has been realized using a vertical column of sparse detectors with the sensor's optical axis configured perpendicular to the plane of the vertical column. Detectors of the profiling sensor are traditionally placed in a sparse vertical column configuration. A subset of the detectors may be removed from the vertical column and placed at arbitrary locations along the anticipated path of the objects of interest forming a custom detector array. Objects passing through the profiling sensor's field of view have traditionally been classified via algorithms processed off-line. However, reconstruction of the object profile is impossible unless the detectors are placed at a known location relative to each other. Measuring these detector locations relative to each other can be particularly time consuming, making this process impractical for custom detector configuration in the field. This paper describes a method that can be used to determine a detector's relative location to other detectors by passing a known profile through the sensor's field of view as part of the configuration process, as well as real-time classification results produced by the embedded controller for a variety of objects of interest taken over multiple field collection events in a variety of environments.

8047-16, Session 3

An assessment of a 360-degree profiling sensor for object classification

J. B. Brown, S. K. Chari, E. Jacobs, The Univ. of Memphis (United States)

Profiling sensor systems have been shown to be effective for detecting and classifying humans against animals. A profiling sensor with a 360 horizontal field of view was used to generate profiles of humans and animals to be used for classification. The sensor system contains a long wave infrared camera focused on a smooth conical mirror to provide a 360 degree field of view. Human and animal targets were detected at 30 meters and an approximate height to width ratio was extracted for each target. Targets were tracked for multiple frames in order to segment targets from background. The average height to width ratio was used as a single feature for classification. The Mahalanobis distance was calculated for each target in the single feature space to provide classification results.

8047-17, Session 4

SmartPhone innovations for persistent surveillance

R. Williams, Air Force Research Lab. (United States)

The Discovery Lab develop technology for smartphones and iPads that brings persistent surveillance capabilities to the warfighter on the ground. Leveraging COTS technologies and might adapting novel architectures and communications prototocols, the team demonstrated the ability to control ground sensor networks plus ground robotic sensors via a network of smartphone apps. In addition, a novel application was developed for iPad that allowed a used to interact with wide area motion imagery products via a touch interface.

8047-18, Session 4

TwittINT

R. Williams, Air Force Research Lab. (United States)

Researchers are trying to use TWITTER to gain an understanding of the world's wants, needs, and thoughts. Most are concerned with the context of what the world is saying through their tweets. On the other hand, the TwittINT project is focused on understanding when and where people are tweeting as opposed to the content of the message. Through initial

exploratory data analysis, it was found that the area contained certain locations or hotspots where people seemed to be more inclined to tweet and a higher frequency of tweeting can be expected during certain days of the week. Regression analysis was performed to fit a model for the upper and lower bounds of the expected frequency of tweets for each day of the week. A "future" week of data was used to test this model and fit well within the control limits. Therefore the prospect of using tweet patterns to predict the quantity and locations of expected tweets in real time is probable.

8047-19, Session 4

Web-based open layered sensing testbed

R. Williams, Air Force Research Lab. (United States)

One of the biggest challenges to address in the sensing environment is how to provide the sheer volume of data to the user in a manageable way. The concept of Layered Sensing is to bring these multiple sensors together for situation awareness. At the Discovery Lab at Tec^Edge, a multidisciplinary team of researchers built AFRL's baseline Open Layered Sensing Testbed (OpenLST) that successfully integrates seven air, ground, and cyber sensor layers for advanced visualization, analysis, and exploitation. This prototype combines traditional GIS data, direct sensing data, and indirect sensing data such as cultural profiles and building descriptions into an integrated, geo-referenced visualization, effectively turning every pixel of interest into an encyclopedia of information about that location. It is being adapted to be web-based.

8047-20, Session 4

Virtual world technology for persistent surveillance command and control

R. Williams, Air Force Research Lab. (United States)

Virtual world technology is the idea of representing information in 3D for fast and precise comprehension. Virtual worlds can be used to set up small scale representations of large areas and accurately represent location signals such as GPS, in order to provide persistent surveillance on the area. The 3D representation of these signals makes it easier for the individual monitoring the area to quickly assess the state of their area of responsibility. Previous work at the Discovery Lab at Tec^Edge used a natural disaster scenario to successfully demonstrate an increased situational awareness. The research proved that if tracking signals were present on key vehicles and individuals, the closest emergency assets capable of handling the situation could be efficiently redirected to the scene. The command and control approach can greatly benefit from 3D representation of information.

8047-21, Session 4

Adapting persistent surveillance storage innovations for homeland security

R. Williams, Air Force Research Lab. (United States)

The Persistent Surveillance Storage Architecture (PSSA) is a framework for developing "plug and play" components to ingest, process, store and retrieve sensor data and metadata for intelligence, surveillance, and reconnaissance purposes. The flexible design and simple integration model provided by this framework allow it to be easily adapted to support a variety of defense and homeland security related problems. Over this past summer, a group of student interns utilized the PSSA framework to implement a system for detecting, tracking and responding to a simulated outbreak of bovine hoof and mouth disease among Ohio cattle farms. The project, called "COWPATH", utilized the PSSA framework to connect real-time image and text data feeds and disease data generated by a simulation program to a command and control center.

8047-22, Session 5

Semantically enriched data for effective sensor data fusion

G. R. de Mel, Univ. of Aberdeen (United Kingdom); T. Damarla, T. Pham, U.S. Army Research Lab. (United States)

Sensor data fusion plays a major role in assisting decision makers by providing them with an improved situational awareness so that informed decisions could be made about the events that occur in the field. This involves combing a multitude of sensor modalities, sources such that the resulting output is better (i.e., more accurate, complete, dependable etc.) than what it would have been if the sensor data / sources taken individually. However, these sensor data lack any context related information (e.g., detected event, event classification, relationships to other events, etc.). This hinders the fusion process and may result in creating an incorrect picture about the situation. Thus, results in false alarms, waste valuable time/resources.

In this paper, we propose an approach that enriches sensor data with semantic attributes so that these data have proper meaning. This will assist underlying applications to present analysts with correct data/sources for a particular event for fusion. Also, we believe annotated stored data will assists in easy retrieval of historical data that may be related to the current fusion. We use a subset of Web Ontology Language (OWL), OWL-DL to present a lightweight and efficient knowledge layer for sensor data annotation and use rules to capture crucial domain concepts. We discuss a solution architecture and provide a proof-of-concept tool to evaluate the proposed approach. We discuss the importance of such an approach with a set of user cases and show how a tool like the one proposed could assist analysts, planners to make better informed decisions.

8047-23, Session 5

A flexible data fusion architecture for persistent surveillance using ultra-low-power wireless sensor networks

J. A. Hanson, K. L. McLaughlin, T. J. Sereno, Jr., SAIC (United States)

We have developed a flexible, target-driven, multi-modal, physics-based fusion architecture that efficiently searches sensor detections for targets and rejects clutter while controlling the combinatoric problems that commonly arise in data-driven fusion systems. The informational constraints imposed by long lifetime requirements make systems vulnerable to false alarms. We demonstrate that our data fusion system significantly reduces false alarms while maintaining high sensitivity to threats. In addition, mission goals can vary substantially in terms of targets-of-interest, required characterization, acceptable latency, and false alarm rates. Our fusion architecture provides the flexibility to match these trade-offs with mission requirements unlike many conventional systems that require significant modifications for each new mission.

We illustrate our data fusion performance with case studies that span many of the potential mission scenarios including border surveillance, base security, and infrastructure protection. In these studies, we deployed multi-modal sensor nodes - including geophones, magnetometers, accelerometers and PIR sensors - with low-power processing algorithms and low-bandwidth wireless mesh networking to create networks capable of multi-year operation. The results show our data fusion architecture maintains high sensitivities while suppressing most false alarms for a variety of environments and targets.

8047-24, Session 5

Knowledge-aided multisensor data fusion for maritime surveillance

G. Battistello, M. Ulmke, W. Koch, Fraunhofer FKIE (Germany)

Multi sensor fusion techniques are widely employed in several surveillance applications (e.g., battlefield monitoring, air traffic control, camp protection, etc). The necessity of tracking the elements of a dynamic system usually requires combining information from heterogeneous data sources in order to overcome the limitations of each sensor. The gathered information might be related to the target kinematics (position, velocity), its physical features (shape, size, composition) or intentions (route plan, friend/foe, engaged sensor modes, etc). The combination of such heterogeneous sensor data proved to benefit from the exploitation of context information, i.e., static and dynamic features of the scenario, represented in a Knowledge Base (KB). A Geographic Information System (GIS) is a typical example for a KB that can be exploited for the enhancement of multi sensor data fusion.

The present paper describes potential strategies for "knowledge-based" data fusion in the area of Maritime Situational Awareness (MSA). MSA is founded on the data from heterogeneous sources, including radars, Navigation Aids, air- and space-based monitoring services, and recently-conceived passive sensors. Several strategies for optimally fusing two or more of these information data flows have been proposed for MSA applications. Relevant KB information comprises port locations, coastal lines, preferred routes, traffic rules, and potentially a maritime vessel database. We define mathematical models and techniques to integrate kinematic constraints, e.g., in terms of navigation fields, and different object behavior into a data fusion approach. For an exemplary sensor suite, we evaluate relevant performance measures in the framework of centralized and decentralized fusion architectures.

8047-25, Session 5

Sensor trustworthiness in uncertain time varying stochastic environment

A. Verma, R. Fernandes, K. Vadakkeveedu, Knowledge Based Systems, Inc. (United States)

In this paper we investigate the trustworthiness of a sensor measuring a time varying stochastic process. In many persistent surveillance applications, unattended multiple mobile and/or fixed sensors are deployed in remote regions to sense, track and report few or several key features of the environment. The information is usually communicated through wireless sensor network to a centralized base station. However, the accuracy or the trustworthiness of the information received through a remote and unattended sensor through a remotely deployed sensor network cannot be readily assumed as there is a large possibility that one or more sensors may get disabled, corrupted, or the sensor network may be compromised resulting in unreliable of falsified information transmission through the network. Often these features of interest are stochastic in nature that has time varying and uncertain probability distribution. This paper uses information theory concepts utilizing entropy based metrics to determine the trustworthiness of the information and/or detection of events through data analysis and corroboration in an uncertain and stochastic environment.

8047-27, Session 6

Implementation of a sensor-guided flight algorithm for target tracking by small UAVs

G. E. Collins, Toyon Research Corp. (United States); J. Liese, California Polytechnic State Univ., San Luis Obispo (United States)

Small fixed-wing UAVs (SUAVs) such as Raven and Unicorn have limited power, speed, and maneuverability. Their missions can be dramatically hindered by environmental conditions (wind, terrain), obstructions (buildings, trees) blocking clear line of sight to a target, and/or sensor hardware limitations (fixed stare, limited gimbal motion, lack of zoom). Toyon's Sensor Guided Flight (SGF) algorithm was designed to account for SUAV hardware shortcomings and enable long-term tracking of maneuvering targets by maintaining persistent eyes-on-target. SGF was successfully tested in simulation with high-fidelity UAV, sensor, and environment models, but real-world flight testing with 60" Unicorns revealed surprising "second order" challenges that were not highlighted by the simulations. This paper describes the SGF algorithm, our first round simulation results, our second order discoveries from flight testing, and subsequent improvements that were made to the algorithm.

8047-28, Session 6

Localization using ground- and air-based acoustic arrays

G. H. Goldman, C. G. Reiff, U.S. Army Research Lab. (United States)

In this effort, techniques were developed to localize acoustic signals using tetrahedral microphone arrays located on the ground and on an aerostat. The angle of arrival (AOA) was computed at each array, and then the position of the source was estimated using triangulation. The AOA calculations were performed in the frequency domain using least squares and digital beamforming techniques, and in the time domain using a generalized cross correlation method. A multipath model was incorporated into the digital beamforming algorithm to improve the elevation angle estimate. The position of the targets was calculated by minimizing the weighted squared error of different combinations of 2-D and 3-D AOA estimates. The height of the targets was also estimated by projecting the 2-D position obtained using all the sensors onto the 3-D bearing estimate obtained from the array on the aerostat.

The algorithms were tested offline using data collected by the U.S. Army Research Laboratory. The ground truth positions of the targets were recorded using a GPS system and compared to the results from the localization algorithms. The algorithms performed well, estimating the x and y coordinates of the targets, but had difficulty obtaining consistently good height or z coordinate estimates.

8047-29, Session 6

On the detection, classification, and tracking of unmanned air vehicles using low-cost acoustic arrays

B. Ellwood, S. Schumer, D. Grasing, U.S. Army Research, Development and Engineering Command (United States)

U.S. Army RDECOM-ARDEC's (ARDEC) recent involvement in a DoD sponsored Counter Unmanned Aircraft System (UAS) demonstration that took place May, 2010.

The purpose of the demonstration was to evaluate and document various technologies that can be employed to detect, track, identify and defeat a range of UAS threats. Various physical attributes of UAS and their associated flight patterns make detection and engagement difficult using traditional aircraft and missile defense technologies. This is especially true of small UAS, necessitating the use of other orthogonal sensing modalities to increase detection/tracking rates. ARDEC's participation in the experiment was to perform high fidelity data collection which would act as the basis for the development of acoustic based small UAS detection and localization algorithms. Exploiting recent advancements in acoustic algorithms and array configurations, ARDEC is examining the problem from a sensory augmentation view point. The paper will provide a high level understanding of the effort while detailing the variety of UAS flown during the test and some of the attributes that are being studied for detection against low signal-to-noise ratio (SNR) targets. The overall goal of the effort is to demonstrate the capability to conduct surveillance of

Return to Contents

low cost threat UASs. The identified approach that is being investigated is a multi modal system that will pass information along to existing C2 systems for cueing and if necessary engagement. There are also opportunities to fuse acoustic findings with other types of sensors to form a multi-modal system.

8047-30, Session 6

Integration of a vehicle tracker into the SPADE architecture

A. Kondrath, R. Van Hook, Air Force Research Lab. (United States)

Due to increased surveillance, information, and exploitation assets, and the wide variety of interfaces, protocols, etc that these systems use, the interactions between these systems is rapidly growing more complex. Likewise, integrating a new component into existing systems is no longer a trivial challenge. In order to make modification and integration of components into a larger system easier, the Air Force Research Labs have developed and deployed Sensor Processing Architecture for Data Exploitation (SPADE). The contribution of this paper is to discuss the successful integration of a vehicle tracker into the SPADE architecture, using Pursuer as the user interface.

8047-31, Session 7

Open-source layered sensing model

T. V. Rovito, M. Lenzo, M. McClure, R. D'Alto, J. Endicott, Air Force Research Lab. (United States); C. Cohenour, Ohio Univ. (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.

8047-32, Session 7

Operational information content capacity

T. F. La Porta, A. Yener, The Pennsylvania State Univ. (United States); R. Govindan, The Univ. of Southern California (United States); M. P. Johnson, The Pennsylvania State Univ. (United States); R. Ramanathan, BBN Technologies (United States)

Tactical networks should be optimized to deliver the maximum amount of useful information from which decisions may be derived. This requires that both the quality and amount of information be considered. The quality of information (QoI) may be judged by both intrinsic (e.g., the precision of an image in terms of bits/pixel) and contextual qualities (e.g., the field of view of an image when determining the number of people in an area). We define the operational information content capacity (OICC) as the measure of the amount of useful information a network can deliver. In this paper we discuss several ways to quantify OICC and determine the residual information content capacity in a network given a set of information requests.

We first define functions which relate metrics such as precision, correctness, and timeliness to the quality of a piece of information to be used for a certain purpose. From this we determine the amount of data bits (and rate) required to deliver the information to its recipient and the resultant "information bits" which can be derived. For example, an image used for facial recognition may produce one information bit (match or no match). In other cases the information may be stochastic (e.g., 85% chance of a match). This measure is transformed into a network requirement which can then be used along with information about network-wide information requests and information fusion gains to determine the OICC of a network.

8047-33, Session 7

Forecasting routes and self-adaptation in multi-hop wireless sensor networks (WSN)

T. Bourdenas, IBM Thomas J. Watson Research Ctr. (United States) and Imperial College London, (United Kingdom); F. Bergamaschi, IBM United Kingdom Ltd. (United Kingdom); D. Wood, P. Zerfos, IBM Thomas J. Watson Research Ctr. (United States); A. Swami, U.S. Army Research Lab. (United States); M. Sloman, Imperial College London (United Kingdom)

Sensor networks find application in many tactical ISR/ISTAR processes and applications. However, these processes and applications depend on reliable collection, distribution and delivery of information that, typically, travels over multiple interconnecting nodes to reach processing centers, and are susceptible to various disruptions such as the ones caused by message drops, packet loss and loss of connectivity due to high traffic volumes and noise on the wireless medium. In this paper we investigate and present approaches to both proactively and reactively adapt routing over such networks by forecasting potential faulty regions of the network and reorganizing their routing paths. We utilize information on node availability, link reliability, node traffic load and event correlation to select the most appropriate routes for sending messages on multi-hop overlay networks. Based on node uptime and traffic patterns, we forecast the availability of routes on the network and match those to the requests for data/information from sensors. In addition, policies enable the network administrator to control route selection by weighting metrics collected by the system and define, further, constraints based on node affiliation and authentication requirements.

We have implemented these approaches on the ITA Sensor Fabric, an evolving middleware infrastructure for sensor networks. The ITA Sensor Fabric addresses the challenges of sensor identification and discovery, sensor access and control, sensor classification and interoperability, data sharing, dissemination and policy-based interoperability and trust by providing unified access to, and management of, sensor networks. In this paper we discuss how we combined and integrated IBM Watfore technology, a time-series forecasting library, along with IBM WPML technology, a policy management framework, with the ITA Sensor Fabric, in order to improve the reliability of information delivery on high traffic mesh networks.

8047-34, Session 7

Broadcast scheduling with data bundles

F. Chen, M. P. Johnson, The Pennsylvania State Univ. (United States); D. Pizzocaro, A. Preece, Cardiff Univ. (United Kingdom); A. Bar-Noy, The Graduate Ctr. (United States); T. F. La Porta, The Pennsylvania State Univ. (United States)

Broadcast scheduling has been extensively studied in wireless environments, where a base station broadcasts data to multiple users. In a TDMA system, messages satisfying individual users' information needs are scheduled at different time slots. Due to the sole wireless channel's limited bandwidth, only a subset of the needs may be satisfiable, and so maximizing total (weighted) throughput is a popular objective.

In many realistic applications, however, data items are dependent or correlated in the sense that the joint utility of a group of items is not simply the sum of their individual utilities but rather depends on them in some more complicated way. On the one hand, substitute data (adopting terminology from economics) may provide overlapping information or the same information from different perspectives. For example, either turn-by-turn instructions or a map could lead one to a destination, so the utility of obtaining them both is less than the sum of their individual utilities. Conversely, complementary data are more valuable than the sum of their parts. For example, the four quadrants of a map may be most useful when presented together as a complete picture.

In this paper, we define a data bundle to be a group of data items with non-additive joint utility, and we study a resulting broadcast scheduling optimization problem whose objective is to maximize the utility provided by the delivered data. First, we formulate this problem as an Integer Program. Second, we adopt existing algorithms to the new problem setting and present new heuristics. We also examine a special case in which all users' needs have the common release time and deadline. Finally, we evaluate these algorithms through simulation.

8047-35, Session 7

Service-oriented reasoning architecture for resource-task assignment in sensor networks

G. R. de Mel, Univ. of Aberdeen (United Kingdom); F. Bergamaschi, IBM United Kingdom Ltd. (United Kingdom); T. Pham, U.S. Army Research Lab. (United States); W. Vasconcelos, Univ. of Aberdeen (United Kingdom)

The net-centric ISR/ISTAR networks are expected to play a crucial role in the success of critical tasks such as base perimeter protection, border patrol and so on. To accomplish these tasks in an effective and expedient manner, it is important that these networks have the embedded capabilities to discovery, delegation, and gather relevant information in a timely and robust manner.

In this paper, we present a systems architecture and implementation that combines a service based reasoning mechanism with the ITA Sensor Fabric middleware infrastructure so that tasks can be executed efficiently and effectively. A knowledge base, utilizing the Semantic Web technologies, provides the foundation for reasoning mechanism that assists users to discover, identify and allocate assets and resources made available through the Fabric middleware, that satisfy the needs of the tasks. Once assets and resources are allocated to any given task, they can be accessed, controlled, shared, and their data feeds consumed through the Fabric middleware. We use the semantic descriptions from the knowledge base to annotate the assets and resources (types, capabilities, etc.) in the Fabric so that they can be retrieved for reasoning during the discovery and identification phases. The reasoner is implemented as a HTTP web service, with the following characteristics:

1) Computational intensive operations are off-loaded to dedicated nodes, preserving the resources in the ISR/ISTAR networks.

2) HTTP services are accessible through a standard set of APIs irrespective of the reasoner technology used.

3) Support for seamless integration of different reasoners into the system.

8047-18, Session 8

Trident Spectre 2010: agile integration and demonstration of a multisensor airborne pod

G. Twaites, B. Rickenbach, General Dynamics Advanced Information Systems (United States)

TRIDENT SPECTRE is an annual battle lab experiment hosted jointly by members of the United States DoD and the Intelligence Community. The experiments involve technical collections, Geospatial Intelligence, Analysis, Human Intelligence, and communications. It offers a unique opportunity to test new ideas and concepts in a secure environment with users, operators, technicians, engineers, and industry partners collaboratively. Trident Spectre is intended to improve tactical intelligence capabilities for the warfighter, provide an operational assessment to validate successes, help to accelerate (not defeat) the acquisition process, and bring new technologies to the surface in a secure environment. The goal for the exercise is to examine and select technologies that are useful and mature enough to forward deploy in a timely manner. Selected technologies are evaluated in a controlled environment, simulating front line conditions. Successful experiments are selected for quick reaction capability, in theatre deployment. General Dynamics Advanced Information Systems participated in Trident Spectre 2010 during April through September of 2010 at the US Navy facilities at Ft. Story, Virginia. This paper provides a description of the Trident Spectre 2010 exercise, focusing on the agile process of developing a prototype airborne ISR pod that integrated technologies from multiple companies. The pod provides the capability to: identify targets of interest based on RF detections or accepted cueing information from off-platform sensors; geo-locate the detected network nodes; cross-cue WAMI sensors on another platform; cross-cue other airborne sensors (EO, IR, SAR, etc); and downlink motion imagery and metadata into the Governments RAPTOR-X ground station.

8047-19, Session 8

Discovering geospatial networks from ambiguous track data

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Wide area motion imagery (WAMI) sensors increasingly are being used for persistent surveillance of large urban areas. One of the potential uses for such surveillance is the discovery of geo-spatial networks, which are sets of locations linked by repeated traffic flow over an extended period of time. Detection of such networks may be of interest for example in uncovering networks of terrorist or criminal activity given initial seed locations, or in detailed analysis of traffic patterns for urban planning. WAMI sensors produce extremely large volumes of data, so automated exploitation is a critical need. While moving target tracking technology is an important element of the exploitation process, WAMI-derived tracks will always be imperfect because of occlusions and shadowing. Processes that derive information from track data must be robust to track discontinuities and linking errors.

In this work we present a simple method of deriving geo-spatial network links from ambiguous track segments or tracklets. The method avoids making explicit tracklet linking decisions and instead considers all locations reachable through kinematically feasible tracklet associations. Temporal aggregation filters out the false origin-destination location pairs arising from incorrect tracklet associations and enables discovery of the true network nodes. We also present a novel method of generating realistic track data for analysis and experimentation using street maps and routing information available through the Google Maps on-line API. Track discontinuities are introduced by applying occlusion maps to ideal track data. We present experimental network discovery results using simulated high density track data for a downtown urban setting.

8047-20, Session 8

Network exploitation using WAMI tracks

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Creating and exploiting network models from wide-area motion imagery (WAMI) is an important task for intelligence analysis. Tracks of entities observed moving in the WAMI sensor data are extracted, then large numbers of tracks are studied over long time intervals to determine specific locations that are visited (e.g., buildings in an urban environment), what locations are related to other locations, and the function of each location. This paper describes several parts of the network detection/exploitation problem, and summarizes a solution technique for each: (a) Detecting nodes is tackled via density-based clustering over a spatial hierarchy and also via a hierarchical Dirichlet Process Gaussian Mixture Model clustering algorithm; (b) Detecting links between known nodes is done via link transit frequency; (c) Node attributes to characterize a node are obtained via simple features; (d) Link attributes to characterize each link are tackled via Markov Logic Networks that discover conditional link transitions; (e) Link structure is inferred from node attributes and vice versa via Neighborhood Based Attribute Prediction; and (f) Decomposing a detected network into smaller networks is solved via spectral analysis partitioning. Experimental results are presented for each solution technique, and those are used to discuss issues for each problem part and its solution technique. Most of the experiments used GPS tracks (536 taxi cabs in San Francisco over 25 days) as a realistic stand-in for WAMI track data. The node detection experiments use that and also a small set of WAMI tracks. The Markov Logic Network experiment uses simulated data.

8047-36, Session 8

Bio-inspired UAV routing, source localization, and acoustic signature classification for persistent surveillance

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A team consisting of Teledyne Scientific Company, the University of California at Santa Barbara and the Army Research Lab is developing technologies in support of automated data exfiltration from heterogeneous battlefield sensor networks to enhance situational awareness. Uninhabited air 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 were used to reduce the system reaction time by generating autonomous collection routes that are data-driven. Bio-inspired techniques for search provide a novel strategy to detect, capture and fuse data. A fast and accurate method has been developed to localize an event by fusing data from a sparse number of UGSs. This technique uses a bio-inspired algorithm based on chemotaxis or the motion of bacteria seeking nutrients in their environment. A unique acoustic event classification algorithm was also developed based on using swarm optimization. Additional studies addressed the problem of routing multiple UAVs, optimally placing sensors in the field and locating the source of gunfire at helicopters. A field test was conducted in November of 2009 at Camp Roberts, CA. The field test results showed that the system can detect and locate the source of an acoustic event with very high accuracy. In nine independent test runs of a UAV, the system located the position of an explosion nine times with an average accuracy of 3 meters. The time required to perform source localization using the UAV was on the order of a few minutes.

8047-38, Session 8

A Bayesian formulation for auction-based task allocation in heterogeneous, multi-agent teams

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 algorithms scale well because agents generally only need to communicate bid information. In addition, the agents are able to perform their computations in parallel and can operate on local information. Furthermore, it is easy to integrate humans and other vehicle types and sensor combinations into an auction framework. However, standard auction mechanisms do not explicitly consider sensors with varying reliability. The agents' sensor qualities should be explicitly accounted. Consider a scenario with multiple agents, each carrying a single sensor. The tasks in this case are to simply visit a location and detect a target. The sensors are of varying quality, with some having a higher probability of target detection. The agents themselves may have different capabilities, as well. The agents use knowledge of their environment to submit cost-based bids for performing each task and an auction is used to perform the task allocation. This paper discusses techniques for including a Bayesian formulation of target detection likelihood into this auction based framework for performing task allocation across multi-agent heterogeneous teams. Analysis and results of experiments with multiple air and ground systems performing distributed target detection are also included.

8047-39, Session 8

Sensor and information fusion for enhanced detection, classification, and localization

M. V. Scanlon, W. D. Ludwig, U.S. Army Research Lab. (United States)

The U.S. Army Research Laboratory (ARL) has concluded research associated with the Sensor & Information Fusion for Improved Hostile Fire Situational Awareness Army Technology Objective, Research (ATO-R). The joint effort was led by ARL with the Armaments and the Communications & Electronics Research, Development, and Engineering Centers (CERDEC and ARDEC) partners. The ATO culminated with the Capstone Experiment demonstrating the attainment of its research goals to detect hostile fire (subsonic, supersonic, and suppressed small arms, mortars, rockets, RPGs, missiles, and IEDs) events and hostile human activities providing solutions before, during, and after the events; improved sensor networking technologies; and developing multi-modal time diverse data fusion/analysis and effective dissemination techniques of resultant actionable intelligence.

The Capstone Experiment successfully demonstrated a diverse modality of sensors, performance characteristics and sensor fusion benefits, while gathering useful data for future development of ad hoc networking, fusion, and enhanced human factures for dissemination actionable intelligence. These diverse sensor data sets include UV, IR, retro-reflection, visible, glint, LADAR, radar, acoustic, seismic, E-field, and narrow-band emission technologies using mult-modal platforms - small robot, UAV, UGS, manned ground vehicles, helicopter, and soldier-worn. Real time collection and fusion of this sensor data demonstrated distinctive image processing and networking techniques that reduced false positives and provided constant multi-modal surveillance of the battle space, improving both awareness and actionable intelligence. These results provided high confidence detections and accurate grid coordinates of threat location information that was disseminated to tactical commands and operational personnel, ultimately improving strike force efficiency and force protection effectiveness.

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8048-01, Session 1

Generalized fusion: a new framework for hyperspectral detection

P. Bajorski, Rochester Institute of Technology (United States)

The purpose of this paper is to introduce a general type of detection fusion that allows combining a set of basic detectors into one, more versatile, detector. The fusion can be performed based on the spectral information contained in a pixel, global characteristics of the background and target spaces, as well as spatial local information. The new approach shown in this paper is especially promising in the context of recent geometric and topological approaches that produce complex structures for the background and target spaces.

We show specific examples of generalized fusion and present some results on false alarm rates and probabilities of detection of fused detectors. We show that Alan Schaum's continuum fusion is a special case of generalized fusion. Our new framework allows better understanding of continuum fusion, as well as other useful types of fusion, such as discrete fusion proposed in this paper. We also explain the relationship between the generalized likelihood-ratio detectors and various fusion detectors.

8048-02, Session 1

Issues in algorithm fusion

A. P. Schaum, U.S. Naval Research Lab. (United States)

Binary discrimination problems that include epistemic uncertainties do not by their nature admit generally optimal solutions. We address the composite hypothesis (CH) testing problem, which is a mixed aleatory/epistemic question by virtue of its expression in terms of probability density functions that can depend on parameters with unknown values.

We require that any new theory of detection for CH problems meet several requirements: It should: (1) be invariant to an arbitrary transformation of coordinates; (2) produce optimal algorithms for problems admitting uniformly most powerful solutions; (3) be superior to prior methods in at least some cases.

The new theory of continuum fusion (CF), which was developed for hyperspectral detection applications, is examined in the light of these requirements. All CF methods are shown to satisfy (1). The published new CF flavors are shown to satisfy (2) for at least some important problems, while the most common prior test does not. And (3) is demonstrated for CF solutions to a subspace detection problem, using interval analysis

8048-03, Session 1

Log-linear Laplacian ratio (LLLR) algorithm for spectral detection using laboratory signatures

B. J. Daniel, A. P. Schaum, U.S. Naval Research Lab. (United States)

The potential of a new class of detection algorithms is demonstrated with the publically available RIT test data set. The continuum fusion (CF) methodology is applied to an affine target subspace model, which assumes that uncertainty in prediction of in-situ signature spectra from laboratory spectra is mostly confined to a one-dimensional region. The new algorithm results from imposing a CF methodology on a conventional GLRT-based algorithm. Performance is enhanced in two ways. First the Gaussian clutter model is replaced by a Laplacian distribution, which is not only more realistic in its tail behavior but, when used in a hypothesis test, also creates decision surfaces more selective than the hyperplanes associated with linear matched filters. Second, a log-Laplacian fusion flavor is devised that further increases the selectivity of decision surfaces to the point where outliers are also rejected.

8048-04, Session 1

Algorithm for detecting anomaly in hyperspectral imagery using factor analysis

E. Lo, Susquehanna Univ. (United States)

Hyperspectral imaging is particular useful in remote sensing to identify a small number of unknown man-made objects in a large natural background. An algorithm based on factor analysis for detecting such anomalies in a high-dimensional data set from hyperspectral imagery and its performance in comparison with conventional algorithms are presented in this talk. Under the factor model, each observable component of the background pixel is postulated to be a linear function of a few unobservable common factors with unknown factor loadings plus a single latent specific variate. The covariance of the pixel is assumed to be in factored form which is a product of the loading matrix and its transpose plus the diagonal covariance matrix of the specific variates. The anomaly detector is defined to be the Mahalanobis distance of the resulting residual between the pixel and its predicted value. Experimental results using Visible-Near-Infra-Red hyperspectral imagery are presented.

8048-05, Session 2

Extension and implementation of model-based hyperspectral change detection

J. Meola, Air Force Research Lab. (United States)

Within the hyperspectral community, change detection is a continued area of interest as it provides an avenue for detecting subtle CC&D targets in complex environments. Subtle targets which can be missed using other detection algorithms can often be detected using change detection due to increased suppression of background clutter. However, complicating the problem of change detection is the presence of shadow differences and parallax/misregistration error between the scenes which often produce the appearance of change. The change detection problem can be formulated using a physical model describing the illumination reaching the sensor on separate occasions. For sensors operating in the reflective region of the spectrum, an interesting change corresponds to a change in the reflectance term associated with the data model. The model incorporates shadow coefficients which explicitly account for shadow variations between scenes helping reduce false alarms associated with these differences. Here the model-based approach is extended to include spatial information present in the scene to help with the problems associated with misregistration/parallax and to help improve shadow estimates associated with the model. The extended model-based approach is applied to HYDICE data to assess performance and limitations.

8048-06, Session 2

Hierarchical image segmentation for context-dependent anomalous change detection

J. Theiler, L. Prasad, Los Alamos National Lab. (United States)

The challenge of finding small targets in big images lies in the characterization of the background clutter. The more homogeneous the background, the more distinguishable a typical target will be from its background. One way to homogenize the background is to segment the image into distinct regions, each of which is individually more homogeneous, and then to treat each region separately. In this paper we will report on experiments in which the target is an anomalous change, and the segmentation strategy is a hierarchical tree-based scheme.

This segmentation scheme starts with image edges as a prior and establishes proximity-based regional relationships between them via a Delaunay triangulation. The triangles are then grouped into polygons based on region-contour affinity criteria. The grouping criteria tend to assemble spectrally similar areas with relatively smooth boundaries. They are grouped further based on their individual and ensemble spatio-spectral characteristics, thus generating nested polygons at multiple scales.

We will investigate the detection of anomalous smaller polygons in the context of the larger polygons that they lie within.

8048-07, Session 2

Change detection using mean-shift and outlier-distance metrics

J. D. Zollweg, Rochester Institute of Technology (United States); D. B. Gillis, U.S. Naval Research Lab. (United States); A. Schlamm, D. W. Messinger, Rochester Institute of Technology (United States)

Change detection with application to wide-area search seeks to identify where interesting activity has occurred by comparing two images. Since there are many different classes of change, one metric may miss a particular class. Some metrics are better than others at detecting changes that are significant in the spectral domain, while others are better at mapping broad changes that cover a wide spatial extent. Therefore, it is potentially beneficial to select metrics with complementary properties. With this idea in mind, a new change detection scheme was created using mean-shift and outlier-distance metrics. These metrics require pixel distributions, so detection of change is at the sub-region level and not the pixel-level. Mean-shift measures the distance in spectral space that the mean of an image region shifts between images and assumes a larger shift indicates greater change. Outlier-distance measures the distance of the most outlying pixel to the mean of a region in spectral space and compares how that distance changes between corresponding regions of images. Using these metrics in combination should identify change more completely than either used in isolation. Additionally, using multiple change metrics opens up interesting visualization options. For instance, changes in land cover may be highlighted using one color and small, target-like changes in another. An algorithm using these metrics was developed and subsequently tested using registered sets of multi and hyperspectral imagery. The completeness of change detection using both metrics was generally better than when using either method alone, based on visual analysis of the image sets.

8048-08, Session 2

Graph theoretic metrics for spectral imagery with application to change detection

J. A. Albano, D. W. Messinger, A. Schlamm, W. F. Basener, Rochester Institute of Technology (United States)

Many popular spectral algorithms that are routinely applied to spectral imagery are based on the following models: statistical, linear mixture, and linear subspace. As a result, assumptions are made about the underlying distribution of the data such as multivariate normality or other geometric restrictions. Here we present a graph-based model for spectral data that avoids these restrictive assumptions and then apply graph theoretic metrics to quantify certain aspects of the resulting graph. The construction of the spectral graph begins by connecting each pixel to its m-nearest neighbors with an undirected weighted edge. The weight of each edge corresponds to the spectral Euclidean distance between the adjacent pixels. The number of nearest neighbors, m, is chosen such that the graph is connected i.e., there is a path from each pixel u to every other. This requirement ensures the existence of intra-cluster connections which will prove vital for our application to change detection. Once the graph is constructed, we calculate a metric called the Normalized Edge Volume (NEV) that essentially describes the internal structural volume based on the vertex connectivity and weighted edges of the graph. Finally, we demonstrate a graph-based change detection method that applies this metric. The algorithm begins by dividing an image into square tiles, constructing a spectral graph and then calculating the NEV for each tile. This algorithm serves as a method for cueing an image analyst to regions where important spectral changes have occurred. Results will be shown for both hyperspectral and multispectral imagery.

8048-10, Session 3

Characterization of turbulence in smokestack plumes via imaging Fourier-transform spectroscopy

J. L. Massman, K. C. Gross, Air Force Institute of Technology (United States)

An imaging Fourier transform spectrometer was used to collect hyperspectral imagery of a coal-burning smokestack in the midwave infrared (1.5-5.5 µm). The instrument was positioned approximately 350 meters from the stack exit, giving each pixel a field of view (FOV) of approximately 11.4 cm of the plume. The instrument collected hyperspectral images on a 128 x 128 pixel sub-window at a spectral resolution of 20/cm. Approximately 5000 data cubes were collected in 30 minutes. When acquiring interferograms of a turbulent source, however, rapid fluctuations in radiance due to sudden temperature changes in the plume introduce scene change artifacts and corrupt the spectra. A method of processing the interferograms prior to Fourier transformation which minimizes these scene change artifacts is presented. This method takes advantage of the DC component of the intensity and involves sorting the data into various quantiles at each optical path difference, resulting in quantile interferograms. Assuming the band-integrated plume radiance increases monotonically with temperature, each quantile interferogram maps to a spectrum defined by the corresponding quantile temperature. This method enables unbiased spectral retrievals of species concentrations and temperature without a priori knowledge of the underlying temperature distribution function. Moreover, interpretation of the various quantile spectra reveals information about the temperature distribution and its relationship to turbulence. This paper will examine the influence of turbulence on the spectra of the plume.

8048-11, Session 3

Anomaly detection of man-made objects using spectro-polarimetric imagery

B. D. Bartlett, A. Schlamm, C. Salvaggio, D. W. Messinger, Rochester Institute of Technology (United States)

In the task of automated anomaly detection, it is desirable to find regions within imagery that contain man-made structures or objects. The task of separating these signatures from the scene background and other naturally occurring anomalies can be challenging. This task is even more difficult when the spectral signatures of the man-made objects are designed to closely match the surrounding background. As new sensors emerge that can image both spectrally and polarimetrically, it is possible to utilize the polarimetric signature to discriminate between many types of man-made and natural anomalies. One kind of sensing technology that allows for spetro-polarimetric data to be collected is the incorporation of a liquid crystal tunable filter (LCTF) with a CCD camera thus creating a spectro-polarimetic imager (SPI). In this paper, an anomaly detection scheme is implemented which makes use of the spectral Stokes imagery collected of a real scene. The ability for the anomaly detector to find man-made objects is assessed as a function of the number of spectral bands available and it is shown that low false alarm rates can be achieved with relatively few spectral bands.

8048-12, Session 3

Selecting training and test images for optimized anomaly detection and material identification algorithms in hyperspectral imagery through robust parameter design

F. M. Mindrup, T. J. Bihl, K. W. Bauer, Air Force Institute of Technology (United States)

There are numerous anomaly detection and material identification algorithms proposed for hyperspectral imagery. Robust parameter design (RPD) techniques have been applied to some of these algorithms in an attempt to choose robust settings capable of operating consistently across a large variety of image scenes. Typically, training and test images used in RPD are considered categorical variables. This assumption can lead to varied results with incorrect RPD regression parameter estimates. Previous research developed a framework for optimizing anomaly detection in HSI by considering specific image characteristics as noise variables; these characteristics include the Fisher's score, percent of target pixels and number of clusters. Typically, the characteristics available in sets of images do not provide orthogonal noise designs assumed in RPD. This paper describes a method for selecting hyperspectral image training and test subsets yielding consistent RPD results. These subsets are not orthogonal, but still provide improvements over random training and test subset assignments by maximizing the volume and average distance between image characteristics. Several different mathematical models representing the value of a training and test set based on the D-optimal score, the norm of the distance from the training or test set cluster mean and the mean distance between training or test points are applied to toy problems.

8048-13, Session 3

Target detection using multiple hyperspectral imagers and physics-based models

E. Ientilucci, J. P. Kerekes, Rochester Institute of Technology (United States); A. Shaw, Gitam Technologies (United States)

The use of multiple hyperspectral imagers will be explored with applications to target detection.

8048-14, Session 3

An automated method for identification and ranking of hyperspectral target detections

W. F. Basener, Rochester Institute of Technology (United States)

The basic process of target detection is to apply a detection filter to a hyperspectral image to produce a detection plane for each target. We will present a new method for target detection that includes additional spatial processing, multiple detection and identification metrics such as F-Test, ACE, unmixing and sub-pixel spectral visualization to build a more complete understanding of the image. The result is a draft detection report of the objects in the image ranked according to the confidence of the identification of each object. This method can be used for faster ground processing as well as on board processing, and the detection reports are much smaller than the image files enabling fast communication to users.

8048-15, Session 3

Enhancement of flow-like structures in hyperspectral imagery using anisotropic diffusion

M. Marin-McGee, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Interrupted lines or flow-like structures as in images of cells, ship wakes, ship plumes, and fingerprints are relatively common. Analyzing flow-like patterns in images for image understanding is an active area of research in image understanding but there have been much less attention to the process of enhancement of those structures. The completion of interrupted lines or the enhancement of flow-like structures is known as Coherence-Enhancement (CE). In this work, we are studying nonlinear anisotropic diffusion filtering for coherence enhancement. Anisotropic diffusion is commonly used for edge enhancement by promoting diffusion in the direction of highest fluctuation of the contrast average within a neighborhood. For CE, the diffusion is promoted along the direction of lowest fluctuation in the neighborhood to take into account the coherence of the structures in the image. This paper presents the theoretical development for the coherence enhancement algorithms in vector images such as hyperspectral and multispectral based using a diffusion PDE. Examples using hyperspectral and multispectral imagery are presented.

8048-16, Session 4

Supporting relief efforts of the 2010 Haitian earthquake using an airborne multimodal remote sensing platform

J. W. Faulring, D. M. McKeown, J. W. van Aardt, Rochester Institute of Technology (United States)

The small island nation of Haiti was devastated in early 2010 following a massive 7.0 earthquake that brought about widespread destruction of infrastructure, many deaths and large-scale displacement of the population in the nation's major cities. The World Bank and ImageCat, Inc. tasked Rochester Institute of Technology's (RIT) Wildfire Airborne Sensor Platform (WASP) to gather a multi-spectral and multi-modal assessment of the disaster over a seven-day period to be used for relief and reconstruction efforts.

Traditionally, private sector aerial remote sensing platforms work on processing and product delivery timelines measured in days, a scenario that has the potential to reduce the value of the data in time-sensitive situations such as those found in responding to a disaster. This paper will describe the methodologies and practices used by RIT to deliver an open set of products typically within a twenty-four hour period from when they were initially collected.

Response to the Haiti disaster can be broken down into four major sections: 1) data collection and logistics, 2) transmission of raw data from a remote location to a central processing and dissemination location, 3) rapid image processing of a massive amount of raw data, and 4) dissemination of processed data to global organizations utilizing it to provide the maximum benefit. Each section required it's own major effort to ensure the success of the overall mission. A discussion of each section will be provided along with an analysis of methods that could be implemented in future exercises to increase efficiency and effectiveness.

8048-17, Session 4

Demonstration of delivery of ortho imagery in near-real-time for local emergency response

D. M. McKeown, J. W. Faulring, S. A. Cavilia, R. S. Krzaczek, J. W. van Aardt, Rochester Institute of Technology (United States)

The Information Products Laboratory for Emergency Response (IPLER) is a new initiative led by the Rochester Institute of Technology (RIT) to develop and put into use new information products and tools derived from remote sensing data. This effort involves technical development and outreach to the user community having the two-fold objective of providing new information tools to enhance public safety and fostering economic development.

Specifically, this paper addresses the demonstration of the collection and delivery of geo-referenced overhead imagery to local (county level) emergency managers in near realtime. The demonstration proved valuable to county personnel in showing what is possible and valuable to the researchers in highlighting the very real constraints of operatives in local government.

The demonstration consisted of four major elements; 1) a multiband imaging system incorporating four cameras operating simultaneously in the visible (color), shortwave infrared, midwave infrared and long wave infrared, 2) an on-board inertial navigation and data processing system that renders the imagery into geo-referenced coordinates, 3) a microwave digital downlink, and 4) a data dissemination service via FTP and WMS-based browser.

In this particular exercise, we successfully collected and downloaded over 700 images and delivered them to county servers located in their Emergency Operations Center as well as to a remote GIS van.

This work was sponsored by the US Department of Homeland Security under DHS grant 2009-ST-061-CI0001 and the National Science Foundation under grant IIP-0917839.

8048-18, Session 4

Deepwater horizon oil spill monitoring using airborne multispectral infrared imagery

S. S. Shen, The Aerospace Corp. (United States); P. E. Lewis, National Geospatial-Intelligence Agency (United States)

To be submitted later.

8048-19, Session 4

Spectral performance related to in-road victim operated improvised explosive devices campaign

A. D. Cropper, ITT Corp. Geospatial Systems (United States)

A recent sensor evaluation campaign was conducted to counter the threat of improvised explosive devices (IED). This campaign was designed to determine the extent to which existing airborne platforms are effective in detecting the emplacement disturbance and associated activities related to in-road Victim Operated Improvised Explosive Devices (VOIEDs). Many techniques are based on the detection of the physical device itself with varying detection performance, however this effort was associated with detecting other physical phenomenon associated with the emplacement of the devices, such as disturbed soil. Here we address the success to detect this threat using thermal technology employing a wavelet-based change detection algorithm. This presentation will focus on the successes of using thermal imagery from the air to identify disturbed soil associated with the emplacement of buried targets. Here we address methods to detect this threat using thermal technology employing a wavelet-based change detection algorithm. In addition, the presentation will provide examples of products from these methods and results from field testing.

8048-20, Session 4

Evaluation of potential emission spectra for the reliable classification of fluorescently coded materials

S. Brunner, C. M. Kargel, Univ. der Bundeswehr München (Germany)

The conservation and efficient use of natural and especially strategic resources like oil and water have become global issues, which increasingly initiate environmental and political activities for comprehensive recycling programs. To effectively reutilize oil-based materials necessary in many industrial fields (e.g. chemical and pharmaceutical industry, automotive, packaging), appropriate methods for a fast and highly reliable automated material identification are required. One non-contacting, color- and shape-independent new technique that eliminates the shortcomings of existing methods is to label materials with certain combinations of fluorescent markers ('optical codes, optical fingerprints') incorporated during manufacture. Since time-resolved measurements are complex (and expensive), fluorescent markers must be designed that possess unique spectral signatures. The number of identifiable materials increases with the number of fluorescent markers that can be reliably distinguished within the limited wavelength band available.

In the proposed paper we shall investigate the reliable detection and classification of fluorescent markers with specific fluorescence emission spectra. These simulated spectra are modeled based on realistic fluorescence spectra acquired from material samples using a modern VNIR spectral imaging system (ImSpectorV10E, Specim Inc.). In order to maximize the number of materials that can be reliably identified, we evaluate the performance of different classification algorithms with regard to various parameters (e.g. wavelengths, intensities and widths of main and side lobes, characteristics of optical sensor, signal-to-noise ratio, etc.). The results will help guide the design of appropriate fluorescent markers, optical sensors and the overall measurement system.

8048-21, Session 5

Image mapping spectrometry: a novel hyperspectral platform for rapid snapshot imaging

T. S. Tkaczyk, Rice Univ. (United States)

This paper presents the Image Mapping Spectrometry a new snapshot hyperspectral imaging platform for variety of applications. These applications span from basic science microscopy implementations through endoscopic diagnostics and reach to remote sensing and surveillance use. The IMS replaces the camera in a digital imaging system, allowing one to add parallel spectrum acquisition capability and to maximize the signal collection (> 80%). As such the IMS allows obtaining full spectral information in the image scene instantaneously at rates of 100 frames/second or higher. Currently implemented designs provide 350x350x48 and 285x285x60 datacube (x,y,) and spectral sampling of 2 to 6 nm in visible spectral range but is easily expandable to larger cube dimensions and other spectral ranges.

The operation of the IMS is based on redirecting image zones through the use of a custom-fabricated optical element known as an image mapper. The image mapper is a complex custom optical component comprised of high quality, thin mirror facets with unique 2D tilts. These mirror facets reorganize the original image onto a single large format CCD sensor to create optically "dark" regions between adjacent image lines. The full spectrum from each image line is subsequently dispersed into the void regions on the CCD camera. This mapping method provides a one-to-one correspondence between each voxel in the datacube and pixel on the CCD camera requiring only a simple and fast remapping algorithm.

This presentation provides fundamentals of IMS operations, describes examples of designs and demonstrates the platform flexibility for use in numerous applications (remote sensing, microscopy and medical diagnostic). It also draws perspective of future directions and potential for infrared imaging.

8048-22, Session 5

A Fabry-Perot interferometer with a spatially variable resonance gap employed as a Fourier transform spectrometer

P. G. Lucey, Univ. of Hawai'i (United States); J. Akagi, Spectrum Photonics, Inc. (United States)

We demonstrate a Fourier transform spectrometer (FTS) using a stationary Fabry-Perot interferometer with the gap between its partially reflecting layers varying orthogonal to the optical axis to produce a gradient in optical path different at a detector. The gradient produces a period fringe pattern that can be analyzed with standard FTS techniques. The device has some limitations in spectral resolution owing to the influence of incidence angle on the Fabry-Perot interferometer and these are quantified. Experiments in the visible and IR demonstrate the feasibility of this method for spectroscopy.

8048-23, Session 5

The enhanced MODIS airborne simulator hyperspectral imager

D. Guerin, T. Graham, J. Fisher, Brandywine Optics, Inc. (United States)

The NASA Enhanced MODIS Airborne Simulator (EMAS) is a suite of upgrades to solar reflected and thermal infrared channels of the MODIS Airborne Simulator (MAS). In the solar reflected bands, the MAS scanner functionality will be augmented with the addition of a separate push broom hyperspectral instrument, the EMAS-HSI. In addition to increasing the spectral resolution of MAS beyond 10nm, this spectrometer is designed to maintain radiometric stability that can be transferred to the existing MAS sensor. The design emphasizes environmental control and on-board radiometric stability monitoring. The stability monitor will include its own diagnostics to monitor drift from the laboratory calibration during data collection. The system is designed for high-altitude missions on the ER-2 and the Global Hawk platforms in support of Earth Venture missions. System performance trades optimize performance in MODIS spectral bands that support land, cloud, aerosol, and atmospheric water studies.

The sensor is a push-broom system that uses two Offner spectrometers to cover the 380-2400 nm spectral range. The sensor features an all-reflective telescope with at 50° full field-of-view. A dichroic cold mirror will split the image from the telescope just after a shared slit, with radiation longer than 990 nm reflected to the SWIR spectrometer. The VNIR spectrometer uses a TEC-cooled silicon CCD detector that samples the spectrum at 2.5 nm intervals, while the SWIR spectrometer uses a Stirling-cooled hybrid HgCdTe detector to sample the spectrum at 10 nm per band. Both spectrometers will feature 1.05 mRad instantaneous fields-of-view registered to the MAS scanner IFOVs.

8048-24, Session 5

An interference microfilter array with tunable spectral response for each pixel

F. E. Strömqvist Vetelino, A. A. Abtahi, Aerospace Missions Corp. (United States); P. B. Griffin, Stanford Univ. (United States); R. J. Morgan, U. Raghuram, Aerospace Missions Corp. (United States); F. Tejada, Sensing Machines (United States)

A MEMS standing wave spectrometer is turned into a wavelength tunable band-pass filter by the addition of a reflective coating. It results in the standing wave filter (SWF), a miniaturized Fabry-Perot band-pass filter with a semi-transparent detector that can be incorporated into a pixel-tunable focal plane array, suitable for multispectral, hyperspectral and ultraspectral imaging applications. The asymmetric Fabry-Perot cavity is formed between the reflective coating and a tunable mirror, originally part of the spectrometer. The performance of the SWF is optimized with modeling based on the matrix formalism used in thin film optics and with FDTD simulations. The SWF concept is taken from an ideal device to a design that can be fabricated using semi-conductor processing technology. The limiting factors of the SWF are discussed and a comparison between the design and fabricated components with 40 micron pixels is included.

8048-25, Session 5

Toward integration of AOTF-based hyperspectral imager in visual surveillance applications

S. Fefilatyev, Univ. of South Florida (United States); R. G. Rosemeier, Brimrose Corp. of America (United States)

Such characteristics as small form-factor, portability, and low-cost have made AOTF-based hyperspectral imagers attractive for use in many civilian applications such as pharmacy, quality control, and agriculture. AOTF-based hyperspectral imagers also hold big potential in military and security applications, where spectral signatures provide enormous information about observed objects. This paper explores several aspects of the use of AOTF-based hyperspectral imagers in the context of visual surveillance. First, we present the implementation of the low-cost miniaturized hyperspectral imaging device based on AOTF-filter coupled with InGaAs high-resolution, high-sensitivity NIR camera. Techniques of calibration, image acquisition, and hyperspectral data processing for such device are shown. Second, we report on the results of experiments to discriminate materials in hyperspectral images of static outdoor scenes. These results are demonstrated on a dataset of hyperspectral images containing cloth-materials that are visually similar but are different chemically and are observed in an environment with uncontrolled illumination. Finally, we discuss the extension of the application to certain dynamic scenes by integrating it with conventional surveillance cameras. The particular issue of low frame-rate provided by the hyperspectral imager is addressed by using "windowing" effect available in the underlying NIR imaging sensor. The frame rate can be significantly increased if only a portion of the focal plane array is used for hyperspectral image acquisition. Thus, spatial visual information available from conventional surveillance cameras is augmented with spectral information from the hyperspectral imager on a limited region of interest.

8048-26, Session 5

Broadband source for multispectral imager characterization

M. A. Medina, J. A. Mazzetta, S. D. Scoptaz, Electro Optical Industries, Inc. (United States)

Current development of optical sensors has led to their increased utility and potential in multispectral combinations. Applications for these imagers encompass not just single regions of the electromagnetic spectrum but indeed several bands of the thermal radiation spectrum (UV through LWIR) - indicative for instance of Earth's atmosphere. Accordingly, these multispectral imagers mandate the development of new test methods and test hardware to test, measure, and calibrate the benchmarks of their performance; benchmarks such as SNR, uniformity, sensitivity, linearity, and dynamic range. The design of the test hardware is thus driven to provide high-resolution, uniform, and stable broadband output. The goal is to minimize the amount and cost of measurement equipment required to demonstrate imager full functionality in the shortest amount of time. UV-VIS-SWIR multispectral imagers necessitate that test hardware be capable of producing an output that tracks from high daylight down through low light/starlight irradiance levels. This paper will explore the challenges, characterization, advantages and drawbacks of several types of multispectral sources spanning UV through SWIR over a high dynamic range of output. This paper will further present sample comparisons of different multispectral imagers with various source and standardized test methods and result calculations for typical specifications such as SNR and Resolution.

8048-27, Session 6

Hyperspectral processing in graphical processing units

M. E. Winter, E. Winter, Technical Research Associates, Inc. (United States)

With the advent of the commercial 3D video card in the mid 1990s, we have seen an order of magnitude performance increase with each generation of new video cards. While these cards were designed primarily for visualization and video games, it became apparent after a short while that they could be used for scientific purposes. These Graphical Processing Units (GPUs) are rapidly being incorporated into data processing tasks usually reserved for general purpose computers. It has been found that many image processing problems scale well to modern GPU systems. We have implemented four popular hyperspectral processing algorithms (N-FINDR, linear unmixing, Principal Components, and the RX anomaly detection algorithm). These algorithms show an across the board speedup of at least a factor of 10, with some special cases showing extreme speedups of a hundred times or more.

It has been found that Hyperspectral Image processing problems scale well to modern GPU systems. Setoain et al have implemented an end-member extraction algorithm and found a factor of ten improvement in runtime on a 512 megabyte image. Likewise, González et al and Tarabalka et al found a similar factor of ten speedup in completely different approaches. This sort of speedup allows data processing techniques that used to take minutes to be interactive, lowering the costs associated with hyperspectral image processing.

While previous generations of video cards were designed to operate on integer pixel data, the new range from both nVidia and ATI (amongst others) allow full IEEE compliant floating point computations. This opens the door to the offloading traditional hyperspectral processing to a mass market video card.

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8048-28, Session 6

Evaluation of the GPU architecture for the implementation of target detection algorithms for hyperspectral imagery

B. Trigueros-Espinosa, M. Velez-Reyes, N. G. Santiago-Santiago, Univ. de Puerto Rico Mayagüez (United States)

Hyperspectral sensors can collect hundreds of images taken at different narrow and contiguously spaced spectral bands. This high-resolution spectral information can be used to identify materials and objects within the field of view of the sensor by their spectral signature; however, the detection of individual spectral materials in a specific scene can be limited by different factors, such as, the spectral and spatial resolution of the sensor, or the spectral mixing of different materials within a pixel. Target detection in hyperspectral imagery also involves processing of large volumes of data, which require hardware platforms with high computational power. Additionally, in many applications, such as threats detection in surveillance systems, it is necessary to detect small targets under heavy clutter in real time, making this problem even more challenging.

In this work, we are studying the use of Graphics Processing Units (GPUs) as a computing platform for the implementation of target detection algorithms based on different models of background spectral variability. The GPU implementation was done using the Compute Unified Device Architecture (CUDA) of the NVIDIA® GPUs. In addition, a multi-core CPU-based implementation was developed to be used as a baseline for the speedups estimation. The detection accuracy of the implemented algorithms was evaluated using a set of phantom images simulating traces of different materials on clothing as models for detection of traces of explosives.

The final objective of this work is to study what elements in the structure of the detection algorithms make them suitable for GPU implementation and the development of library of detection algorithms to facilitate future use for researchers.

8048-29, Session 6

Parallel implementation of nonlinear dimensionality reduction methods using CUDA in GPU architecture

R. Campana, V. B. Manian, Univ. de Puerto Rico Mayagüez (United States)

Manifold learning are important techniques to preserve a nonlinear structure and the objects geometry of nonlinear high-dimensional data in the lower dimension.Manifold learning algorithms are very slow (high computational algorithms) and time consuming in estimating the solution. The goal of this work is to parallelize the three most important manifold learning algorithms to reduce the dimensionality of the hyperspectral images for subsequent application in object segmentation. These three methods are ISOMAP, Local Linear Embedding and Laplacian Eigenmap. The parallelization consists of implementing the bottleneck parts like k-nearest neighbor, shortest path for geodesic distance, Graph Laplacian and other features in the Compute Unified Device Architecture (CUDA) in GPU developed by NVIDIA.

The manifold algorithms are implemented on a 64-bit workstation equipped with a quad-core Intel® Xeon with 12 GB RAM and two NVIDIA® Tesla C1060 GPU cards.

Preliminary results for ISOMAP, Local Linear Embedding and Laplacian Eigenmap show good speed up using GPU compared to CPU implementation using C++. The best speed up obtained for these algorithms are 69.2x, 13.45x and 22.19x respectively. More results of speed up and application to hyperspectral image segmentation will be presented in the paper.

8048-30, Session 6

Comparison of subpixel phase correlation methods for image registration

R. A. Reed, Arnold Engineering Development Ctr. (United States)

The popular phase correlation method (PCM) for image registration has been extended to subpixel accuracy by several algorithms, each claiming accuracies on the order of 0.03 pixels for 256 x 256 images. However, the performance reported in the literature is based upon idealized images or upon just a few selected images. This leaves users in doubt as to which algorithm is truly superior. This work compares three subpixel PCM algorithms using a common set of realistic images derived from satellite imagery. The algorithm by Guizar et al. (conceptually the simplest) consistently performed best.

8048-31, Session 6

Real-time georeferencing for an airborne hyperspectral imaging system

T. O. Opsahl, T. V. Haavardsholm, A. Skaugen, I. Winjum, Norwegian Defence Research Establishment (Norway)

We describe the georeferencing part of FFIs real-time hyperspectral demonstrator system (Proc. SPIE 7695 76950A-1). In the demonstrator we use a custom synchronization unit to time stamp individual image frames as well as navigation data from a GPS and an IMU. The navigation data is Kalman filtered, giving an estimate of the camera's position and attitude for each frame. Together with a geometrical model of the camera, this allows us to find rays representing each pixel. In order to georeference a pixel, we need to find the intersection between its ray and a digital elevation model (DEM). Our method is based on raytracing from computer graphics and a highly efficient representation of the DEM. By adapting the calculations to match the ground resolution of our DEM, the cameras field of view and typical flight altitude, the computational load is reduced to such extent that we can do real time georeferencing in MATLAB with ease. Even the MATLAB implementation, with no parallel processing, can calculate ca 200 000 ray-DEM intersections per second using a DTED2 terrain model with roughly 30 meter resolution. Implemented on a graphics processor unit (GPU) using CUDA, the algorithm is capable of calculating more than 100 times as many ray-DEM intersections per second. Initial tests have demonstrated real-time performance for 60Hz HD video on a DEM with 5m resolution. Thus GPU-based georeferencing provides real-time performance even in the case of very complex terrain models and high image resolution.

8048-71, Session 6

GPGPU-based real-time conditional dilation for robust target detection in multispectral and hyperspectral imagery

J. P. Morgenstern, Vision4ce LLC (United States)

A significant topic in many image processing systems is the derivation of a threshold to enable the detection of targets, the detection of classes of objects which are different than the background clutter or the automated analysis of the output of spectral filters and/or anomaly filters. In many cases the background signals are uni-modal and the estimation of a robust threshold is a straightforward problem with known solution. There are some cases where the signals of interest have local contrast against their immediate surroundings but the application of a global threshold over the entire image produces poor results. In such cases an adaptive or local threshold operator offers a more robust solution.

One particular local threshold function is the conditional dilation [originally due to Serra] which produces a second image by a series of dilations but conditioned on not exceeding the signal levels in the original. In the limit this second image becomes a threshold surface where only locally contrasty areas or objects remain after application of the threshold. Algorithms have been introduced which enable use of conditional dilation in realtime systems by reducing the unbounded series of dilations to a small, fixed number of operations. In the present work we present an adaptation of this algorithm to a GPGPU device which enables highly parallel version of the algorithm subject to the unique architecture constraints of the GPGPU.

8048-32, Session 7

Identification and mapping of night lights signatures using hyperspectral data

F. A. Kruse, Naval Postgraduate School (United States); C. D. Elvidge, National Oceanic and Atmospheric Administration (United States)

This research demonstrates the use of imaging spectrometer (hyperspectral) data to identify, characterize, and map urban lighting based on spectral emission lines unique to specific lighting types. Spectral features were extracted from 1.2m spatial resolution ProSpecTIR hyperspectral data of Las Vegas, Nevada and compared to field and laboratory measurements made with an Analytical Spectral Devices (ASD) spectroradiometer. Specific types identified included blue and red neon, high pressure sodium, and metal halide lights. There were some indications of possible spectral mixing or variants of these light types, as evidenced by extra spectral lines in some of the extracted spectra. A binary encoding method was used to map the spatial distribution of lighting types based on simplified spectral signatures. A refined image map was produced using a spectral feature extraction approach. Results were overlain on a Quickbird panchromatic 0.4m spatial resolution image. In both cases, the ProSpecTIR data successfully identified and mapped night light types and distributions. The observed locations of specific light types were compared to a 3-D Las Vegas building model and signatures validated against ASD spectral library measurements. The hyperspectral mapping allowed determination of the nature and distribution of lights, which can potentially be used as a surrogate for measurement and characterization of urban development.

8048-33, Session 7

Ship detection in MODIS imagery

L. P. Dorado-Muñoz, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Understanding the capabilities of satellite sensors with spatial and spectral characteristics similar to those of MODIS for Maritime Domain Awareness is of importance because of the upcoming NPOES which includes the VIRS sensor that is a multispectral MODIS like sensor that will provide 100 minutes revisit times and 400/800m spatial resolution . In this paper, we study ship detection in MODIS imagery. Spectral and spatial signatures from ships in MODIS imagery are characterized. In particular, we study ship plumes and the spectral contrast between ship and the sea background. Different types of detection algorithms at full pixel and subpixel level are investigated. Results show the potential for such approach for Maritime Domain Awareness and point to some of the challenges for developing an operational system.

8048-34, Session 7

High-spatial resolution bidirectional reflectance retrieval using satellite data

R. C. Olsen, C. L. McConnon, A. M. Kim, Naval Postgraduate School (United States)

Worldview-2 spectral imagery acquired over Duck, NC and Camp Pendleton, CA were analyzed to extract Bidirectional Reflectance Distribution Functions (BRDF) for 8 spectral bands. Spectral data in the visible and near-infrared bands were acquired for 15 azimuth/elevation values during the Duck NC orbit pass; data were collected at ten-second intervals. Ten images were acquired over Camp Pendleton. Orthoready images were coregistered using first-order polynomials for the two image sequences. BRDF profiles have been created for scene elements: vegetation, asphalt, sand, and water.

Return to Contents

8048-35, Session 7

Multiresolution and directional filtering techniques for detecting dust storm direction in satellite imagery

M. Q. Alkhatib, S. D. Cabrera, The Univ. of Texas at El Paso (United States)

This paper presents a new method for finding the direction of a dust storm in satellite images including the 5-band NOAA-AVHRR imagery that were use in our previous work. The previous methods for obtaining the prominent direction of the dust storms involved the combination of edge detectors and local spectral-domain classification techniques applied to subimages/blocks. These approaches produced promising results but have the limitation of not providing consistent results among the subimages that overlap the dust storm region. In this paper, other algorithms like wavelets and state-of-the-art directional filters based on the contourlet transform are used to help us determine the direction with more precision and consistency among the relevant subimages.

Before applying the directional filtering to the candidate region of the multispectral image, a preprocessing step involves passing the image through a multi-resolution filter, this preprocessing step is required in order to enhance the image and improve its directional streaks, in turn, this will help improving the performance of the directional filter, and getting better and more consistent results. For AVHRR images, our methodology involves applying directional filtering on bands 4 and 5 since these wavelengths highlight the absorption and subsequent emission of thermal radiation by the silicate particles in the dust storms. Directional filtering is applied on these image bands at different angles where energy measurements are computed to find the prominent direction of the dust storm. The presence of a prominent direction in the texture of the candidate region of the dust storm can be used as a verification of its presence in an automated detection system.

8048-67, Poster Session

Hyperspectral band selection using statistical models

J. M. Maerker, A. Ebert, W. Middelmann, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Hyperspectral sensors are delivering a data cube consisting of hundreds of images gathered in adjacent frequency bands. Processing such data requires solutions to handle the computational complexity and the information redundancy. Principally, there are two different approaches deployable. Data compression merges this imagery to some few images. Hereby only the essential information is preserved. Small variations are treated as disturbances and hence removed. Band selection eliminates superfluous bands, leaving all other ones unmodified. Thus even minor deviations are preserved.

In our paper we are presenting a novel band selection method especially developed for surveillance purposes. Hereby, the capability to detect even small variations poses an essential requirement, only fulfilled by the second approach. Hereby, the computational complexity and the performance of such an algorithm depend on the available information. If complete knowledge about the targets and the background is available, contrast maximization establishes a perfect band selection. Without any knowledge the selection has to be performed by exploiting the band attributes often resulting in a poor choice. In order to avoid this, the developed algorithm incorporates the accessible information from the monitoring scene. In particular, in each band features (e.g. anomalies) based on proximity relations are extracted. Subsequently an assessment of their suitability is accomplished by means of the value margins and the associated distributions. The final selection is then based on the inspection of the variations caused by the illumination and other external effects. We demonstrate and evaluate the appropriateness of this new method with a practical example.

8048-68, Poster Session

Noise reduction of hyperspectral images by using joint bilateral filter

A. Heo, J. Lee, E. Choi, W. Choi, S. H. Kim, D. Park, KAIST (Korea, Republic of)

In this paper, we propose a new noise reduction method for hyperspectral images by using the joint bilateral filter. The Gaussian range kernel of the joint bilateral filter is applied to a sharp-edged image. In this proposed method, the sharp-edged image is constructed by the weighted summation of all bands of a hyperspectral image cube. In the process of the weighted summation, a stretched version of the color matching functions is used. Since the obtained sharp-edged image has high-frequency details, the joint bilateral filter plays a role not only to reduce noise but also to preserve the edge of hyperspectral images. We have evaluated the performance of the proposed denoising method on the hyperspectral imaging systems which we have developed for visible and near-infrared spectral regions. Simulation results show that the proposed method outperforms the conventional approaches such as mean filter, median filter and other kernel regression filters.

8048-69, Poster Session

High-fidelity spectrum reconstruction for filter-based spectrum sensor using sparse representation

C. Chang, N. Lin, National Taipei Univ. of Technology (Taiwan); U. Kurokawa, B. I. Choi, nanoLambda (United States)

In recent years, miniature spectrometers have been found useful in many applications to resolve the spectrum signature of objects. Sophisticated grating based spectrometers are difficult to make in chip-scales size, and has high manufacturing costs. Alternatively, low cost filter-based spectrum sensors have been being developed to fill these needs, thanks to recent advance in semiconductor imager techniques. However, filter-based spectrum sensors suffer from two major drawbacks. Firstly, the number of filters is limited, and secondly the filtering properties of the spectral sensors could be non-ideal. In this work, methods for conquering these two drawbacks are presented.

In general, an array filter-based spectrum sensor is often modeled as a system of equations. Techniques for spectrum reconstruction are often based on the method of solving an over-determined problem from least square criterion or using pseudo inverse. In this approach, spectral resolution is limited since the number of unknowns has to be less than the number of equations.

In this work, we model the spectrum reconstruction process as an under-determined problem, and bring up the concept of super-resolution. This technique is also known as sparse representation or compressive sensing. L1-minimization and nonnegative least squares (NNLS) optimization are used to achieve this idea of super-resolution. Notably, L1-minimization algorithms use linear programming to solve the norm-1 problem, whereas NNLS algorithms solve the problem in norm-2. While both methods possess different characteristics, our experimental results show that superior quality of spectrum reconstruction can be robustly delivered from both methods, with resolution higher than 1nm.

8048-70, Poster Session

Subpixel target detection and enhancement in hyperspectral images

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Hyperspectral data due to its higher information content afforded by higher spectral resolution is increasingly being used for various remote sensing applications including information extraction at subpixel level.

There is however usually a lack of matching fine spatial resolution data particularly for target detection applications. Thus, there always exists a tradeoff between the spectral and spatial resolutions due to considerations of type of application, its cost and other associated analytical and computational complexities. Typically whenever an object, either manmade, natural or any ground cover class (called target, endmembers, components or class) gets spectrally resolved but not spatially, mixed pixels in the image result. Thus, numerous manmade and/or natural disparate substances may occur inside such mixed pixels giving rise to mixed pixel classification or subpixel target detection problems. Various spectral unmixing models such as Linear Mixture Modeling (LMM) are in vogue to recover components of a mixed pixel. Spectral unmixing outputs both the endmember spectrum and their corresponding abundance fractions inside the pixel. It, however, does not provide spatial distribution of these abundance fractions within a pixel. This limits the applicability of hyperspectral data for subpixel target detection. In this paper, a new inverse Euclidean distance based super-resolution mapping method has been presented that achieves subpixel target detection in hyperspectral images by adjusting spatial distribution of abundance fraction within a pixel. Results obtained at different resolutions indicate that super-resolution mapping may effectively aid subpixel target detection.

8048-37, Session 8

Object classification using discriminating features derived from higher-order spectra of multi- and hyperspectral imagery

K. N. Zachery, J. Zhou, Y. Liao, Teledyne Scientific & Imaging, LLC (United States)

Many existing hyperspectrum analysis techniques are based on assumptions of linear mixture models. Recent research has suggested that there exists significant nonlinearity in hyperspectral imagery. Sources of nonlinearity include nonlinear reflectance due to variations in sensor-scene geometry, multi-path scatter, and variability of the water molecules in the media. Such nonlinearity violates the traditional linear mixing assumption. Nonlinear analysis techniques therefore are needed to better characterize the spectrum properties of the signals for improved classification and target detection. This paper describes a novel approach for the detection and classification of man-made objects using discriminating features derived from higher-order spectra (HOS), defined in terms of higher-order moments or cumulants of multi- and hyperspectral- signals. HOS spectral can characterize subtle complex nonlinear dependencies in spectral phenomenology of objects in hyperspectrum data and are insensitive to Gaussian noise. By exploiting these HOS properties, we have devised a robust method for classifying man-made objects from hyerspectrual signatures embedded in strong background noise and in the presence of confusers with spectrally similar signatures and in the presence of variable signal-to-noise ratios. Classification performance was tested with multi- and hyperspectral imagery collected from several different sensor platforms and is compared with the performance of conventional classifiers based on linear models. The experimental results based on measured data show that the classification predictions obtained from our HOS algorithm produced significant reduction in false alarms. Furthermore, when HOS-based features were combined with standard features derived from spectral properties, the overall classification accuracy was substantially improved.

8048-38, Session 8

Trilateral filter on multispectral imagery for classification and segmentation

W. Sun, D. W. Messinger, Rochester Institute of Technology (United States)

In this paper, we present a new approach to filtering high spatial resolution multispectral (MSI) or hyperspectral imagery (HSI) for the purpose of classification and segmentation. Our approach is inspired by the bilateral filtering method (Tomasi 1998) that smooths images while preserving important edges for gray-scale and color images. To achieve a similar goal for MSI/HSI, we build a nonlinear tri-lateral filter that takes into account both spatial and spectral similarities. Our approach works on a pixel by pixel basis; the spectrum of each pixel in the filtered image is the combination of the spectra of its adjacent pixels in the original image weighted by the three factors: geometric closeness, spectral Euclidean distance and spectral angle separation. Our approach reduces small clutter across the image while keeping edges with strong contrast. The improvement of our method is that we use both spectral intensity differences together with spectral angle separation as the closeness metric, thus preserving edges caused both by material as well as by similar materials with intensity differences. A k-means classifier is applied to the filtered image and its results show our approach can produce a much less cluttered class map. Results will be shown using imagery from the Digital Globe Worldview-2 multispectral sensor and the HYDICE hyperspectral imagery. This approach could also be expanded to facilitate feature extraction from MSI/HSI.

8048-39, Session 8

Automatic clustering of multispectral imagery by maximization of the graph modularity

R. A. Mercovich, A. A. Harkin, D. W. Messinger, Rochester Institute of Technology (United States)

Automatic clustering of spectral image data is a common problem with various desired and potential solutions. While typical spectral image clustering techniques use first order statistics and Gaussian models, our approach utilizes the spectral data structure to generate a graph representation of the image and then clusters the data by applying the method of optimal modularity for partitioning the graph. After defining and identifying pixel adjacencies to represent an image as an adjacency matrix, a recursive splitting to group spectrally similar pixels is performed using the method of optimal modularity maximization. The selection of pixel adjacencies greatly impacts the success of this spectral clustering technique. The graph is split using non-linear decision surfaces by maximizing its modularity, which is a scalar quantity that measures the difference between the number of edges in the group and the expected number of edges in a random graph. Using information from each recursion, this method produces a divisive hierarchical description, or tree, of the community structure within the graph and a variable level of detail cluster map that is visually useful. Additionally, this method out performs many typical automatic clustering methods, such as k-means, especially in highly cluttered urban scenes. Because the method is fully unsupervised, specification in advance of the number or size of clusters is not required. By ignoring reliance on the assumed shape of the spectral data, this method excels in regions where typical clustering methods fail and produces results that more reliably characterize the number of clusters in the data.

8048-40, Session 8

A scalable hierarchical image classification approach

F. P. Padula, H. N. Gross, D. R. Pogorzala, Integrity Applications, Inc. (United States)

The current extent of publicly available space-based image data and data products is unprecedented. Data from research missions and operational environmental programs provide a wealth of information to global users, and in many cases, the data are accessible in pseudo real-time. The availability of such data provides a unique opportunity to investigate how information can be cascaded through multiple spatial, spectral, radiometric, and temporal scales. A hierarchical image classification approach is developed using multispectral data sources to rapidly produce large area landuse identification and change detection

products. The approach derives training pixels from a coarser resolution classification product to autonomously develop a classification map at improved resolution. The methodology also accommodates parallel processing to facilitate analysis of large amounts of data.

Previous work successfully demonstrated this approach using a global MODIS 500 m landuse product to construct a 30 m Landsat-based classification map. This effort extends the previous approach to high resolution U.S. commercial satellite imagery. An initial validation study is performed to document the algorithm's performance and identify limitations in the process. Results indicate this approach is scalable and has broad applications to target and anomaly detection applications. In addition, discussion is focused on how information is preserved throughout the processing chain, as well as situations where the data integrity could break down. This work is part of a larger effort to deduce practical, innovative, and alternative ways to leverage and exploit the extensive low-resolution global data archives to address relevant civil, environmental, and defense objectives.

8048-41, Session 8

Multiclass sub-pixel target detection using functions of multiple instances

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The Functions of Multiple Instances (FUMI) method learns target prototypes from data points that are functions of both target and non-target prototypes. In this paper, a multi-class case of FUMI is considered where, given data points which are convex combinations of a target prototype and several non-target prototypes, the Multi-class Convex-FUMI (C-FUMI) method learns the target and non-target signatures, the number of non-target signatures, and determines the proportions of the all prototypes for each data point. For this method, training data need only binary labels indicating whether the data contains or does not contain some proportion of a target; the specific target proportions for the training data are not needed. After learning the targets' spectral signatures using the binary labeled training data, target detection is performed on test data. In the case of hyperspectral image analysis, this provides a method for multi-class sub-pixel target detection when the spectral signatures of the target classes are unknown. Results on simulated and real hyperspectral data are presented.

8048-42, Session 9

The operational land imager (OLI) and the thermal infrared sensor (TIRS) on the Landsat Data Continuity Mission (LDCM)

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The Landsat Data Continuity Mission (LDCM), a joint NASA and United States Geological Survey (USGS) mission, is scheduled for launch in December, 2012. The LDCM instrument payload will consist of the Operational Land Imager (OLI), provided by Ball Aerospace and Technology Corporation (BATC) under contract to NASA and the Thermal Infrared Sensor (TIRS), provided by NASA's Goddard Space Flight Center (GSFC). This paper will describe the design, capabilities and status of the OLI and TIRS instruments.

The OLI will provide 8 channel multispectral images at a spatial resolution of 30 meters and panchromatic images at 15 meter spatial resolution. The TIRS is a 100 meter spatial resolution push-broom imager whose two spectral channels, centered at 10.8 and 12 microns, split the ETM+ thermal bands. The two channels allow the use of the "split-window" technique to aid in atmospheric correction. The TIRS focal plane consists of three Quantum Well Infrared Photodetector (QWIP) arrays to span the 185 km swath width.

The OLI and TIRS instruments will be operated independently but in concert with each other. Data from both instruments will be merged into a single data stream at the (USGS)/Earth Resources Observation and Science (EROS) facility. The ground system, being developed by USGS, includes an Image Assessment System (IAS), similar to Landsat-7's, to operationally monitor, characterize and update the calibrations of the two sensors.

8048-43, Session 9

Calibration plan for the thermal infrared sensor on the Landsat Data Continuity Mission

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The Landsat Data Continuity Mission consists of a two-sensor platform with the Operational Land Imager and Thermal Infrared Sensor (TIRS). Much of the success of the Landsat program is the emphasis placed on knowledge of the calibration of the sensors relying on a combination of laboratory, onboard, and vicarious calibration methods. Rigorous attention to NIST-traceability of the radiometric calibration, knowledge of out-of-band spectral response, and characterizing and minimizing stray light should provide sensors that meet the quality of Landsat heritage. Described here are the methods and facilities planned for the calibration of TIRS which is a pushbroom sensor with two spectral bands (10.8 and 12 micrometer) and the spatial resolution 100 m with 185-km swath width. Testing takes place in a vacuum test chamber at NASA GSFC using a recently-developed calibration system based on a 16-aperture black body source to simulate spatial and radiometric sources. A two-axis steering mirror moves the source across the TIRS field while filling the aperture. A flood source fills the full field without requiring movement of beam providing a means to evaluate detector-to-detector response effects. Spectral response of the sensor will be determined using a monochromator source coupled to the calibration system. Knowledge of the source output will be through NIST-traceable thermometers integrated to the blackbody. The description of the calibration system, calibration methodology, and the error budget for the calibration system shows that the required 2% radiometric accuracy for scene temperatures between 260 and 330 K is well within the capabilities of the system.

8048-44, Session 9

Modeling space-based multispectral imaging systems with DIRSIG

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The Landsat Data Continuity Mission (LDCM) focuses on a next generation global coverage, imaging system to replace the aging Landsat 5 and Landsat 7 systems. The major difference in the new system is the migration from the multi-spectral whiskbroom design employed by the previous generation of sensors to modular focal plane, multi-spectral pushbroom architecture. Further complicating the design is that the reflective and thermal acquisition capability is split across two instruments spatially separated on a common satellite bus. One of the focuses of the science and engineering teams prior to launch is the ability to provide seamless data continuity with the historic Landsat data

archive. Specifically, the challenges of registering and calibrating data from the new system so that long-term science studies are minimally impacted by the change in the system design. In order to provide the science and engineering teams with simulated pre-launch data, an effort was undertaken to create a robust end-to-end model of the LDCM system. The modeling environment was intended to be flexible and incorporate measured data from the actual system components as they were completed and integrated. The output of the modeling environment needed to include not only radiometrically robust imagery, but also the meta-data necessary to exercise the processing pipeline. This paper describes how the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model has been improved to model space-based, multi-spectral imaging (MSI) systems in support of systems engineering trade studies. A mechanism to incorporate measured focal plane projections through the forward optics will be described. A hierarchal description of the satellite system will be presented including the details of how a multiple instrument platform is described and modeled, including the hierarchical management of temporally correlated jitter that allows engineers to explore impacts of different jitter sources on instrument-to-instrument and band-to-band registration. The capabilities of a new, non-imaging instrument to simulate the measurement of platform ephemeris will also be introduced. Finally, the geometric and radiometric foundations for modeling clouds in the DIRSIG model will be described and demonstrated as one of the more significant challenges in registering multi-spectral pushbroom sensor data products.

8048-45, Session 9

Data-driven simulations of the Landsat Data Continuity Mission (LDCM) platform

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The Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) are two new sensors being developed by the Landsat Data Continuity Mission (LDCM) that will extend over 35 years of Landsat archived data. In a departure from the whiskbroom design employed by all previous generations of Landsat, the LDCM system will employ a modular array, pushbroom design. Although this newly adopted pushbroom architecture has several advantages over the previous whiskbroom design, registration of the multi-spectral data products is a concern. In this paper, the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model was used to simulate an LDCM collection, which gives the Landsat Science Team access to data that would not otherwise be available prior to launch. The DIRSIG model was used to simulate the two-instrument LDCM payload in order to study the geometric impacts of the sensor design on the proposed processing chain.

The Lake Tahoe area located in eastern California was chosen for this work due to its dramatic change in elevation, which is ideal for studying the geometric effects of the new Landsat sensor design. Multi-modal datasets were used to create the Lake Tahoe site model for use in DIRSIG. National Elevation Dataset (NED) data were used to create the digital elevation map (DEM) required by DIRSIG, QuickBird data were used to identify different material classes in the scene, and Hyperion spectral data were used to assign radiometric properties to those classes. In order to model a realistic Landsat orbit in these simulations, orbital parameters were obtained from a Landsat 7 two-line element set. Line-of-sight vectors defining how the individual detector elements of OLI and TIRS instruments project through the optics were measured and provided by NASA. Additionally, the relative sensor response functions for the 9 bands of OLI and the 2 bands of TIRS were measured and provided by NASA. The instruments were offset on the virtual satellite and data recorders used to generate ephemeris data for downstream processing. Finally, potential platform jitter spectra were measured and provided by NASA and incorporated into the simulations. Simulated imagery generated by the model was incrementally provided to rest of the LDCM team in a spiral development cycle to constantly refine the simulations and complexity of the processing pipeline being tested for operation system.

8048-46, Session 9

Spectral requirements analysis of the primary flight focal plane arrays for the thermal infrared sensor

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The Thermal Infrared Sensor (TIRS) on board the Landsat Data Continuity Mission (LDCM) is a two-channel, push-broom imager that will continue Landsat thermal band measurements of the Earth. The core of the instrument consists of three Quantum Well Infrared Photodetector (QWIP) arrays whose data are combined to effectively produce a linear array of 1850 pixels for each band with a spatial resolution of approximately 100 meters and a swath width of 185 kilometers. In this push-broom configuration, each pixel may have a slightly different band shape. An on-board blackbody calibrator is used to correct each pixel. However, depending on the scene being observed, striping and other artifacts may still be present in the final data product. The science-focused mission of LDCM requires that these residual effects be understood.

The analysis presented here assisted in the selection of the three flight QWIP arrays. Each pixel was scrutinized in terms of its compliance with TIRS spectral requirements. This investigation utilized laboratory spectral measurements of the arrays and filters along with radiometric modeling of the TIRS instrument and environment. These models included standard radiometry equations along with complex physics-based models such as the MODerate spectral resolution TRANsmittance (MODTRAN) and Digital Imaging and Remote Sensing Image Generation (DIRSIG) tools. The laboratory measurements and physics models were used to determine the extent of striping and other spectral artifacts that might be present in the final TIRS data product. The results demonstrate that artifacts caused by the residual pixel-to-pixel spectral non-uniformity are small enough that the data can be expected to meet the TIRS radiometric and image quality requirements.

8048-47, Session 10

Joint segmentation and reconstruction of hyperspectral images from a single snapshot

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This work describes numerical methods for the joint reconstruction and segmentation of spectral images taken by compressive sensing coded aperture snapshot spectral imagers (CASSI).

In a snapshot, a CASSI captures a two-dimensional (2D) array of measurements that is an encoded representation of both spectral information and 2D spatial information of a scene, resulting in significant savings in acquisition time and data storage.

The double disperser coded aperture snapshot imager (DD-CASSI) is able to capture a hyperspectral image from which a highly underdetermined inverse problem is solved for the original hyperspectral cube with regularization terms such as total variation minimization. The reconstruction process decodes the 2D measurements to render a three-dimensional spatio-spectral estimate of the scene, and is therefore an indispensable component of the spectral imager. In this study, we seek a particular form of the compressed sensing solution that assumes spectrally homogeneous segments in the two spatial dimensions, and greatly reduces the number of unknowns, often turning the underdetermined system into one that is overdetermined. The proposed method generalizes popular active contour segmentation algorithms such as the Chan-Vese model and also enables one to jointly estimate both the segmentation membership functions and the spectral signatures of each segment. The results are illustrated on a simulated Hubble Space Satellite hyperspectral dataset, a real Urban HYDICE hyperspectral dataset, and a real DD-CASSI image in microscopy.

8048-48, Session 10

Estimation of low-resolution visible spectra from RGB imagery II: simulation results

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In a previous paper [Schau, H.C.,"Estimation of Low Resolution Visible Spectra from RGB Imagery", Proc. Algorithms and Technology for Multispectral, Hyperspectral, and Ultraspectral Imagers X ,SPIE,Orlando (2009)] , it was demonstrated that an estimate of a low resolution visible spectra of a naturally illuminated outdoor scene can be estimated from RGB values measured by a conventional color imager. In this paper we present a refined algorithm and document results in a study to estimate visible source spectra from solar illumination scenes using reflectance spectra generated from the USGS data base.

While the algorithm was initially tested with 9 typical materials, a more detailed test was desired. A collection of 492 typical reflectance spectra form the USGS data base were employed to generate source spectra of typical reflected materials. A measured solar spectra and another atypical solar spectra were employed together with the reflectance spectra to generate source spectra for the 492 material under typical and atypical solar conditions. RGB values were developed which were used as input to estimate the low resolution spectra; results were compared to the actual source spectra. Total error (absolute) over the visible spectral band was calculated and tabulated.

It is anticipated that this technique could be used in any application where an estimate of visible spectra is desired, and would be particularly useful in a hands-on approach to teaching remote sensing where students could use cell phones to develop visible spectra of common everyday objects for further analysis.

8048-49, Session 10

A multiband statistical restoration of the Aqua MODIS 1.6 micron band

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Damaged detectors, transmission errors, and electrical failure are all vexing but seemingly unavoidable problems leading to line drop and data loss. Standard interpolation can often provide an acceptable solution if the loss is sparse. Interpolation, however, introduces a-priori assumptions about the smoothness of the data. When the loss is significant, as it is on MODIS/Aqua, interpolation creates statistically or physically implausible image values and visible artifacts. Another approach is to use a related band, band 7, to estimate the missing band 6 data via a lookup table. This assumes that there is a functional relationship between band 7 and band 6. The specific spectral reflective, absorptive, and scattering properties of individual atmospheric and surface constituents vary in a complex manner precluding any functional relationship between bands 6 and 7. We will show that by exploiting the information from multiple bands, we can obtain an accurate estimate of the missing band 6 information. We will also demonstrate that the increased accuracy from a multi-band statistical estimate has significant consequences at the product level. The original NASA snow mask algorithm relies prominently on the band 6 measurement in determining the likelihood of snow cover on the ground at the location of each pixel in the image. The current NASA-utilized solution to this problem is to use band 7 measurements from MODIS on Aqua with an appropriately-adjusted algorithm. We will present the evaluations based on several standard performance metrics that demonstrate that the use of the original NASA algorithm with the restored band 6 data generates a more reliable snow mask than the modified algorithm with band 7 data.

8048-50, Session 10

Estimating true color imagery for GOES-R

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The ABI on GOES-R will provide imagery in two narrow visible bands (red, cyan), which is not sufficient to directly produce true color images. Color images are determined by three bands (RGB). In addition, accurate color images as perceived by the human visual system or measured using traditional color photographs, are the result of broad spectral responses. These responses have been standardized in terms of the International Commission on Illumination (CIE) 1931 XYZ color-space. In this paper we present a method to estimate an XYZ true color image from an ABI multi-spectral image simulated though spectral integration of a hyper-spectral image. This is provided by a high spectral resolution hyper-spectral image, such as from the Hyperion imager.

Spectral integration of the CIE standard X,Y, and Z responses produces an XYZ color image. Similarly we can synthesize the visible and near visible ABI bands using ABI specified spectral responses. This provides a training set from which we can estimate parameters of a piecewise multi-linear predictor.

We then use separate testing data to evaluate our ABI derived estimates of an XYZ colorspace image. The accurate true color we estimate from the simulated ABI is then suitable as a visualization how the image would appear from space to a human observer. It is also critical for applications that compare or fuse ABI imagery with conventional RGB color aerial or ground photography.

8048-51, Session 10

A new deblurring morphological filter for hyperspectral images

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In hyperspectral imaging, a spectrometer should be used to produce the spectral cube in the imagery device to split the electromagnetic energy at different wavelengths before its projection on the imaging array. This spectrometer may be a dispersive element, such as prism and grating, or an electronically tuneable filter. Some of dispersive spectrometers, such as Fourier transform interferometer (FTIR) and image multi-spectral imaging (IMSS), are based on sliding the lenses, or mirrors, along the optical axis which may result in a slightly out-of-focus blurring. Blind deconvolution techniques have been successfully used to decrease this blurring.

In this paper, we introduce a new method to deblurr the hyperspectral images keeping edges as sharp as possible. Motivated by the success of threshold decomposition, gradient-based operators are used to detect the locations of edges followed by an adaptive morphological filter to sharpen these detected edges. Experimental results demonstrated that the performance of the proposed deblurring filter is promising for hyperspectral images in target detection applications.

8048-52, Session 11

Hyperspectral anomaly detection using sparse kernel-based ensemble learning

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Ensemble learning has been widely used in pattern classification and recognition because an ensemble decision can generally provide more robust generalization performance compared to the regular decision by a single classifier. The authors have recently developed a novel ensemble learning technique called Sparse Kernel-based Ensemble Learning (SKEL) for hyperspectral classification problems that uses Support Vector machines (SVM) as sub-classifiers. In SKEL, sub-decisions were first made within randomly selected feature subspaces and an optimal sparse combination of the sub-decisions was subsequently obtained through the L-1 norm constrained optimization of the kernel weights. Significant improvement in detection performance was reported by using SKEL for hyperspectral as well as multivariate data.

In this paper, the principle of SKEL is extended to hyperspectral anomaly detection. In the proposed technique called Sparse Kernel-based Anomaly Detection (SKAD), a one class classifier based on support vector data description (SVDD) is used as a sub-classifier. Unlike supervised classification where SKEL maximizes the margin of a separating hyperplane of the sparsely combined kernel, SKAD finds an optimal sparse combination of the SVDD-based sub-classifiers to minimize the radius of the enclosing hypersphere of the local normalcy data. In SKAD, each sub-classifier first finds the most compact enclosing ball of the local background spectra within the corresponding randomly selected spectral subspace. Optimal sparse weighting of the kernels that minimizes the volum of the enclosing ball of the combined kernel is then obtained by using the gradient descent optimization of the kernel weights with L-1 constraint applied on them. The optimal hypersphere defines the support of the local normalcy data and spectral signatures outside the hypersphere are considered outliers.

In SKAD, for each pixel of a hyperspectral image, a local dual rectangular window is used where the spectra from the outer window represent normalcy data. Any spectral signature from the center of the inner window that falls outside the enclosing sphere supporting the normalcy data is considered an anomaly. SKAD will be applied to some hyperspectral images as well as multivariate data and a performance comparison to the regular SVDD will be reported.

8048-53, Session 11

Effect of random measurements on the performance of classical hyperspectral target detection algorithms

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In this paper, we study the effect of random measurements of spectral pixels on the performance of hyperspectral imagery (HSI) target detection. The classical HSI target detection algorithms, such as spectral matched filters (SMF), matched subspace detectors (MSD), adaptive subspace detectors (ASD), and the Reed-Xiaoli (RX) anomaly detection algorithm, are based on statistical hypothesis testing models. These algorithms exploit every band of the spectral pixels (which usually contain tens to hundreds of bands), thus operate in a high-dimensional space. The Johnson-Lindenstrauss lemma states that the distance between two vectors are preserved with a high probability by their random measurements using some proper projections. Therefore, it is possible for the target detection algorithms to directly operate in a much lower dimensional measurement space without reconstructing the original spectral pixels. This would greatly reduce the complexity of the imaging system, as well as improve the computational efficiency of the detection algorithms. In this paper, we explore the feasibility of taking the random measurements of pixels as input to the classical target detection algorithms. Specifically, the N-dimensional spectral pixels (both training and test samples) are projected onto an M-dimensional measurement space, where M is much smaller than N, using some measurement matrix. Popular choices of such measurement matrices include matrices whose entries are i.i.d. Gaussian or Bernoulli random variables. The detectors SMF, MSD, ASD, and RX are then applied to the M-dimensional measurement vectors to detect the targets of interests. The detection performances are compared both visually and quantitatively by the receiver operating characteristics curves. Through extensive experiments on several real HSI, we demonstrate the minimal compression ratio M/N under various types of random projections that are necessary to achieve detection performance comparable to that obtained by exploiting the original N-dimensional pixels.

8048-54, Session 11

Implications of model mismatch and covariance contamination on chemical detection algorithms

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Standoff detection of chemical warfare agents is necessary when physical separation is required to put people and assets outside the zone of severe damage. An important class of standoff sensors for chemical plumes is based on the principles of passive infrared (IR) spectroscopy. Typical standoff sensors utilize passive imaging spectroscopy in the long wave infrared (LWIR) atmospheric window (8-13µm). The LWIR region is well suited for gas-sensing applications because of the relative transparency of the atmosphere at these wavelengths and the presence of uniquely identifying features for a wide range of chemicals.

Optimum detection algorithms make decisions by comparing the likelihood ratio of “plume-present” and “plume-absent” hypotheses to a fixed threshold. Therefore, the application of these detectors requires radiance measurements from both pixels with plume and plume-free pixels. The plume-free pixels are used to estimate the mean and covariance of the background clutter. There are three prerequisites for good background estimation: (a) availability of a sufficient number of plume-free pixels (b) statistical similarity of plume-free background pixels to those of the background behind the plume (no background mismatch), and (c) absence of on-plume pixels in the estimation of the background (no background corruption). The likelihood of the “plume-present” hypothesis depends on the chemical signature of the plume of interest, which is obtained from a spectral library. However, the “signature” measured by the sensor is related to the library signature by the nonlinear Beer’s law. As a result there is a mismatch between the actual and used signature. Additional causes of mismatch are calibration errors, sensor noise, and covariance estimation errors.

In this paper we investigate the impact of these factors on the performance of chemical plume detection algorithms. The analytical investigations are limited to the classical matched filter detector. However, using a plume-embedding procedure to embed plumes into real backgrounds, we can study the performance of the matched filter and various other detectors (for example, the widely used adaptive cosine estimator) by estimating their receiver operating characteristic (ROC) curves. Preliminary theoretical and experimental results show that a limited amount of background data, spectral heterogeneity, and background corruption by plume may lead to significant performance degradation. Therefore, understanding the impact of these issues and developing robust practical algorithms for their minimization or avoidance is critical to the successful deployment of systems that protect the warfighter.

8048-55, Session 11

Performance limits of LWIR gaseous plume quantification

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The remote sensing of chemical vapor plumes via hyperspectral sensors in the long-wave infrared region has a wide variety of applications-for example, warning of hazardous airborne chemical agents due to deliberate or inadvertent release, regulation of industrial pollutants, or weapons production monitoring. In this paper, we derive the fundamental performance limits of plume quantification, and compare the relative importance of the various determining factors.

The central parameter in plume quantification is the mean concentration-path length (CL) product, which can lead to estimates of the absolute gas quantity present. The goal of this paper is to derive Cramer-Rao lower bounds on the variance of an unbiased estimator of CL in concert with other parameters of a general non-linear radiance model. These bounds offer a guide to feasibility of CL estimation, given a set of sensor system parameters, that is not dependent on any given algorithm. In addition,

the derivation of the bounds yields great insight into the physical and phenomenological mechanisms that control plume quantification. The performance limits are driven by interactions between the characteristics of the sensor, gases to be detected, and background radiance. The complexity of this interaction means that the quality of an estimate of CL may vary greatly as a function of the radiance parameters, even within a single image. Specific CL estimation algorithms may take advantage of only one, or more than one, of these mechanisms, depending on the intended application. Existing algorithms will be reviewed in the context of these results.

8048-56, Session 12

Multi- and hyperspectral scene modeling

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Often it is prohibitive or even impossible to obtain hyper-spectral data over real targets with existing sensors and under a number of conditions. In this paper we describe how a public domain raytracer with its own scene description language (POVRAY) can be used to model multi- and hyper-spectral scenes in the visible and also thermal. POVRAY is a very sophisticated geometric modeling language and renderer with many features making it valuable for complex scene generation. Macros exist for example to create whole cityscapes with hundreds of buildings, roads and cars with a few lines of code. Trees, cloudy skies, grass covered surfaces, water, plumes, textures also can be modeled and animated using a procedural method requiring little storage. The geometry of the scenes and position of objects is first modeled using free and shareware 3D editors such as Sketchup, Moray, Forester, Blender, Wings3d and Art of Illusion. Next a spectral database is used to assign reflectance spectra to each material in the scene which is then convolved for specific multi- and hyper-spectral sensors bands. A control program written in high level language IDL is then used to step through all bands of using reflectance values for three bands for each material. Each scene is then rendered either in sequence on a single computer or distributed to a cluster of computers each rendering a three-band scene at a time until all bands have been rendered. In addition to the three bands additional layers can be computed, e.g. surface normal, shadow, depth and object maps which can be used to generate all kinds of useful statistics such as the probability of observing a surface lit or in shade. The control program then gathers all rendered images into a hyper-spectral data cube for further analysis and performs user defined statistical studies. The advantage of using POVRAY is that the scene can be rendered using various rendering options from simple Gouraud type shading, single bounce raytracing, multiple bounce raytracing, radiosity and photon-mapping.

8048-57, Session 12

The target implant method for predicting target difficulty and detector performance in hyperspectral imagery

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The utility of a hyperspectral image for target detection can be measured by synthetically implanting target spectra in the image and applying detection algorithms. In this paper we apply this method, called the target implant method, for the purpose of determining the top performing algorithms for a given image and target, and the relative difficulty for detection of targets in a given image with a given detector. Our tests include variations on the matched filter, adaptive coherence/cosine estimator and constrained energy minimization detection algorithms. This enables one to predict the fill fraction at which a given target can be detected and the best detection algorithm in a given image under ideal circumstances.

HyMap images of Cooke City, MT and HYDICE images from the Forest Radiance collection were used. The HyMap imagery had 126 bands ranging from 454 to 2496 nm at a ground sample distance of approximately 3 meters. Seven flightlines were collected, six of which contain 4 fabric target panels and 3 vehicles with known spectra. The Forest Radiance imagery had 210 spectral bands (145 good bands) ranging from 397 to 2496 nm with a ground sample distance of approximately 1 meter.

Comparisons of predictions from this method to detection performance on real target pixels showed that the target implant method does provide accurate relative predictions in terms of both target difficulty and detector performance, but that reliably predicting the actual number of false alarms for a given target at a given fill fraction is difficult or impossible.

8048-58, Session 12

Dynamic dimensionality reduction for hyperspectral imagery

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Data dimensionality (DR) is generally performed by first fixing size of DR at a constant number, say p and then finding a technique to reduce an original data space to a low dimensional data space with dimensionality specified by p. This paper introduces a new concept of dynamic dimensionality reduction (DDR) which considers the dimensionality to be retained, p as a parameter instead of a constant so that it can adapt its value to meet various applications. It is quite different from the commonly used DR, referred to as static dimensionality reduction (SDR) with the parameter p fixed at a constant value regardless of applications. In order to materialize the DDR another new concept, referred to as progressive DR (PDR) is also developed so that the DR can be performed progressively with dimensionality varying the value of p. The advantages of the DDR over SDR are demonstrated by experiments conducted in endmember extraction, hyperspectral image classification, and linear spectral unmixing.

8048-59, Session 12

An empirical estimate of the multivariate normality of spectral image data

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Historically, much of spectral image analysis revolves around assumptions of multivariate normality. If the background spectral distribution can be assumed to be multivariate normal, then algorithms for anomaly detection, target detection, and classification can be developed around that assumption. However, as the current generation of sensors typically have higher spatial and/or spectral resolution, the spectral distribution complexity of the data collected is increasing and these assumptions are no longer adequate, particularly image-wide. However, large portions of the imagery may be accurately described by a multivariate normal distribution. A new empirical method for accessing the multivariate normality of a hyperspectral distribution is presented here. This method accesses the normality of spectral image tiles. This information can be used to indicate the degree of multivariate normality (or complexity) of the data and to determine the appropriate algorithm to use on the local image area for spatially adaptive processing.

8048-60, Session 12

Interactive visualization of hyperspectral images on a hyperbolic disk

A. A. Goodenough, A. Schlamm, Rochester Institute of Technology (United States)

Visualization of the high-dimensional data set that makes up hyperspectral images necessitates a dimensionality reduction approach to make that data useful to a human analyst. The expression of spectral data as color images, individual pixel spectra plots, principal component images, and 2D/3D scatter plots of a subset of the data are a few examples of common techniques. However, these approaches leave the user with little ability to intuit knowledge of the full N-dimensional spectral data space or to directly or easily interact with that data. In this work, we look at developing an interactive, intuitive visualization and analysis tool based on using a Poincare disk as a window into that high dimensional space. The Poincare disk represents an infinite, two-dimensional hyperbolic space such that distances and areas increase exponentially as you move farther from the center of the disk. By projecting N-dimensional data into this space using a non-linear, yet relative distance metric preserving projection (such as the Sammon projection), we can simultaneously view the entire data set while maintaining natural clustering and spacing. The disk also provides a means to interact with the data; the user is presented with a “fish-eye” view of the space which can be navigated and manipulated with a mouse to “zoom” into clusters of data and to select spectral data points. By coupling this interaction with a synchronous view of the data as a spatial RGB image and the ability to examine individual pixel spectra, the user has full control over the data set for classification, analysis, and instructive use.

8048-61, Session 12

Realism, utility, and the evolution of simulated remotely sensed imagery

E. Ontiveros, M. G. Gartely, Rochester Institute of Technology (United States)

Simulated imagery has been and will continue to be a great resource to the remote sensing community. It not only fills in the gaps when real imagery is not available but allows the user to know and control every aspect of the scene. Over the last 20 years we have seen its value in algorithm development, systems level design trade studies and phenomenology investigation. The realism of this data is often linked to its radiometric accuracy. Its visual appeal is further improved by the addition of spatial and spectral texture. The Rochester Institute of Technology’s Digital Imaging and Remote Sensing (DIRS) Laboratory has done extensive work on making simulations work more realistic while developing our in house image generator, DIRSIG. In the past we have invested hundreds of man hours to painstakingly build large scale scenes of real locations with manual methods. Recently, new procedural tools and open source geometry repositories have allowed the creation of similar scenes with improved scene clutter in significantly less time. It is now possible to assemble and build large city-scale scene geometries with a more automated work-flow over the course of a few hours. hours. Even with these advances, an observer viewing these high resolution, complex, spectrally and spatially textured simulated images is still visually aware that they are nothing but simulations, albeit radiometrically and spectrally accurate. This paper will investigate the above concerns regarding simulated imagery by looking at the utility, evolution and future of image simulations.

8048-62, Session 13

Simultaneous sparse recovery for unsupervised hyperspectral unmixing

D. T. Nguyen, Y. Chen, T. S. Han, T. D. Tran, The Johns Hopkins Univ. (United States)

Spectral pixels in a hyperspectral image (HSI) are known to lie in a low-dimensional subspace. The Linear Mixture Model (LMM) states that every spectral vector is closely represented by a linear combination of some signatures. When no prior knowledge of the representing signatures are available, they must be extracted from the image data, then the abundances of each vector can be determined. The whole process is often referred to as unsupervised endmember extraction (UEE) and unmixing.

As proposed in one of our recent papers, the LMM can be extended to Sparse Mixture Model R=MS + N, where not only single pixels but the whole HSI has a sparse representation using a dictionary M made of the data itself, and the abundance vectors (columns of S) are sparse at the same locations. The UEE and unmixing then can be done concurrently by solving for a row-sparse abundance matrix S.

In this paper, we attack this problem by posing a convex optimization problem, then using simultaneous sparse recovery techniques to find S. This approach promise a global optimum solution for the process, rather than suboptimal solutions of iterative methods which extract endmembers one at a time. We develop an algorithm for simultaneous sparse recovery which uses the l1-l2 norm of S is used to promote row-sparsity, and imposes non-negativity and sum-to-one constraints on the columns of S. Preliminary results show competitive results compared to other UEE methods. We also discuss aspects of efficiency and large scale data, as well as investigate the possibility of using this in conjunction with other unsupervised techniques in unsupervised classification tasks.

8048-63, Session 13

Joint sparsity for 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)

In this paper, we propose a joint sparsity model for target detection in hyperspectral imagery. The key innovative idea here is that hyperspectral pixels within a small neighborhood in the test image can be simultaneously represented by a linear combination of a few common training samples, but weighted with a different set of coefficients for each pixel. The joint sparsity model automatically incorporates the inter-pixel correlation within the hyperspectral imagery by assuming that neighboring spectral pixels usually consists of similar materials. The sparse representations of the neighboring pixels are obtained by simultaneously decomposing the pixels over a given dictionary consisting of training samples of both the target and background classes. The recovered sparse coefficient vectors are then directly used for determining the label of the test pixels. Simulation results on several real hyperspectral images show that the proposed algorithm based on the joint sparsity model outperforms the classical hyperspectral target detection algorithms, such as the popular spectral matched filters, matched subspace detectors, adaptive subspace detectors, as well as binary classifiers such as support vector machines.

8048-64, Session 13

High-spatial resolution hyperspectral spatially adaptive endmember selection and spectral unmixing

K. Canham, A. Schlamm, W. F. Basener, D. W. Messinger, Rochester Institute of Technology (United States)

Two of the many tasks which can be accomplished with hyperspectral imagery are linear spectral unmixing and endmember selection. The quality of the unmixing results depends on an accurate estimate of the number of endmembers used in the analysis. Too many estimated endmembers produce over fitting of the spectral unmixing results; too few estimated endmembers produce spectral unmixing results with large residual errors. Several statistical and geometrical approaches have been developed to estimate the number of endmembers, but many of these approaches rely on using the global dataset. The global approach does not take into consideration local area endmember variability, which is of particular interest in high-spatial resolution imagery. Here, the number of endmembers within local image tiles is estimated by using a novel, spatially adaptive approach. Each pixel is unmixed using the locally identified endmembers and global abundance maps are generated by classifying these locally derived endmembers. Comparisons are made between this new approach and an established method that uses Principal Component Analysis and Sequential Maximum Angle Convex Cone to estimate the number of endmembers and identify the spectra. Multiple sets of high-spatial resolution imagery are used in the comparison of methodologies and conclusions are drawn based on per-pixel residual unmixing errors.

8048-65, Session 13

Kernel-based weighted abundance constrained linear spectral mixture analysis

K. Liu, E. Wong, Univ. of Maryland, Baltimore County (United States); C. Chang, Univ. of Maryland, Baltimore County (United States) and National Chung Hsing Univ. (Taiwan)

Least Squares-based Linear Spectral Mixture Analysis (LS-LSMA).has been widely used in various applications in hyperspectral imaging. Two extensions of LSMA have been investigated. One is to make the criterion used by LSMA more effective. Since the least squares error (LSE) is generally not an optimal measure in classification, the LS-LSMA has been extended to Fisher's LSMA (FLSMA) with LSE replaced by Fisher's ratio. Later the LS-LSMA is further extended to Weighted Abundance Constrained-LSMA (WAC-LSMA) which turns out to be a general version of both LS-LSMA and FLSMA. The other is to extend LSMA to make nonlinear decisions. Recently, it has been shown that Kernel-based LSMA (K-LSMA) can be very effective for hyperspectral data sample vectors which are heavily mixed and also performs significantly better than LSMA without using kernels in multispectral image classification. This paper combines both approaches K-LSMA and WAC-LSMA to derive a most general version of LSMA, Kernel-based WACLSMA (KWAC-LSMA) which includes all the above-mentioned LSMA as its special cases. The utility of the KWAC-LSMA is further demonstrated by multispectral and hyperspectral experiments for performance analysis.

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8049-01, Session 1

Object classification using local subspace projection

J. L. Nealy, Univ. of Central Florida (United States); R. R. Muise, Lockheed Martin Missiles and Fire Control (United States)

We consider the problem of object classification from image data. Significant challenges are presented when objects can be imaged from different view angles and have different distortions. For example, a vehicle will appear completely different depending on the viewing angle of the sensor but must still be classified as the same vehicle. In regards to face recognition, a person may have a variety of facial expressions and a pattern recognition algorithm would need to account for these distortions. Traditional algorithms such as PCA filters are linear in nature and cannot account for the underlying non-linear structure which characterizes an object. We examine nonlinear manifold techniques applied to the pattern recognition problem. One mathematical construct receiving significant research attention is diffusion maps, whereby the underlying training data are remapped so that Euclidean distance in the mapped data is equivalent to the manifold distance of the original dataset. This technique has been used successfully for applications such as data organization, noise filtering, and anomaly detection with only limited experiments with object classification. For very large datasets (size N), pattern classification with diffusion maps becomes rather onerous as there is a requirement for the eigenvectors of an NxN matrix. We characterize the performance of a 40 person facial recognition problem with standard K-NN classifier, a diffusion distance classifier, and standard PCA. We then develop a local subspace projection algorithm which approximates the diffusion distance without the prohibitive computations and show comparable classification performance.

8049-02, Session 1

Method of recognition and pose estimation of multiple occurrences of multiple objects in visual images

D. Khosla, D. Huber, HRL Labs., LLC (United States)

Accurate and robust recognition of objects in cluttered natural scenes under varying view angles, object sizes and occlusions is a challenging problem. Local Feature Algorithms (LFA), e.g., SIFT, employ a set of keypoints located at stable regions in the image and has achieved moderate success in object recognition. However, the problem of recognizing and segmenting multiple objects in a scene, specifically multiple occurrences of the same object, is a far more complex problem than the recognition of a single object. For a scene known to contain multiple objects, the recognition algorithm must localize clusters of keypoints belonging to a single object, compensate for outlier noise caused by misclassification of keypoints, and process keypoint clusters to find the optimal object boundary and pose based on the training data. This paper describes such a method to process the keypoints generated by an LFA that both labels multiple objects in a scene as well as segments boundaries of the object based on the structure of its keypoints. In addition to preserving the ability to detect partially occluded objects, this algorithm also permits the identification of multiple instances of the same object class in the same scene. This is carried out efficiently using a probabilistic model that alleviates the need for multiple steps of keypoint classification and sorting into histograms that other multiple-object recognition algorithms suffer. We will describe the algorithm in detail and show quantitative results of applying it to various public domain computer vision datasets.

8049-03, Session 1

Bio-inspired ‘surprise’ for real-time change detection in visual imagery

D. Huber, D. Khosla, HRL Labs., LLC (United States)

Change detection and identification in real-time visual imagery has diverse surveillance and reconnaissance applications. Such methods typically employ a high probability of detection front-end that analyzes the entire scene and extracts regions of interest. These regions are then advanced to additional algorithmic stages for detailed analysis and/or identification. The front-end must work in real-time (or as quickly as frames can be retrieved from the sensor), or there will be a backlog of frames to process, and must have high detection performance, as any event that is not detected by these algorithms cannot be analyzed by subsequent algorithms in the system. Bio-inspired visual attention or saliency algorithms have received much recent interest as such a front end. However, saliency algorithms may not work well for video of complex natural scenes, since they do not differentiate between continuously saliency and transient saliency. A surprise algorithm that employs temporal integration of saliency across multiple frames can make this distinction, and consequently exhibits a much lower rate of false alarm than the saliency algorithm. In this paper, we propose a system and method to compute the surprise of a scene using video imagery that applies only a small additional calculation to the base saliency (or attention) algorithm. This simplicity allows it to be mapped to hardware that conforms to low size, weight, and power constraints and can also run at or near real-time. We will describe the approach, system and present preliminary results on interesting real-world videos.

8049-04, Session 1

Hybrid photometric and correspondence-based georegistration

S. A. Merritt, Naval Air Warfare Ctr. Weapons Div. (United States)

Image and video registration are critical components in many image exploitation processing chains such as target mensuration, ATR, and change detection. Registration algorithms are typically classified as either area-based or feature-based. We demonstrate that these algorithm classes are somewhat complementary, with feature-based methods excelling in complex, strong-gradient imagery, and area-based methods excelling in smoothly-varying imagery. We propose a hybrid registration framework that mathematically combines both area-based and feature-based components. The proposed framework builds upon our past research into fast 2D-to-3D area-based registration that enables accurate registration with even high-obliquity imaging geometries and high-relief scenes. As such, the method incorporates a 3D model, derived from LiDAR, SAR or stereo reconstruction, and for each uncertain target image performs a six degrees-of-freedom (6DOF) optimization over the acquiring sensor’s 3D position and 3D orientation. The proposed method augments these existing methods by developing and incorporating feature-based pose estimation that is robust to false correspondence. The resulting algorithm simultaneously optimizes a global image photometric similarity metric while maximizing the cardinality of the set of feature correspondences that are geometrically consistent with the postulated 6DOF transform. The algorithm is agnostic to the source of feature correspondences, but is demonstrated in this paper using feature correspondences generated by the scale-invariant features transform (SIFT) developed by Lowe. Preliminary results demonstrate the algorithm’s improved robustness and accuracy through comparison with both purely feature-based and purely area-based algorithms.

Return to Contents

8049-05, Session 1

Perspective transformation and image warping for wide-baseline scene matching

H. Chen, M. C. Tarnowski, C. Stutts, Applied Research Associates, Inc. (United States)

A new image perspective transformation and warping algorithm is developed that can transform an image to a different image as if it is taken from a camera at any different viewing angle, presume that the image scene can be approximated as a planar surface. Conventional scene/object matching with correlation method has difficulties with object rotation, scale and viewing angle changes. Current state-of-the-art matching methods (e.g., SIFT) can deal with rotation and scale changes, but still have problems with large viewing angle changes (wide-baseline problem).

This newly developed image projective warping method corrects the rotation, scale, and viewing angle differences between images, and thus make the conventional correlation matching and SIFT matching method still work even under large viewing angle, rotation, and scale differences between images. Forward and backward projection equations are derived using analytic geometry. In the derivations, the scene surface is presumed to be planar. However, even for a scene surface with large height/depth variance, if we know the height/depth functions with the surface (e.g., a 3D terrain map), we can still derive equations for accurate image projective warping. Applications on wide-baseline scene matching will be presented. Another capability of this method is to generate a much detailed training dataset (at small angle steps) for automatic target recognition (ATR) tasks from a coarser real measurement (at large angle steps).

8049-06, Session 1

Non-invasive eye control technology based on single CCD camera

J. Su, Harbin Univ. of Science and Technology (China); K. Han, Harbin Engineering Univ. (China)

For the inaccurate pupil extraction of existing eye tracking technology which based on a single CCD camera, inaccurate gaze coordinates positioning, and too many restrictions on the posture ect, this paper proposed a non-intrusive eye tracking technology based on a single-CCD camera. First it introduced the principle of corneal reflection and used five near-infrared light source as system light source. It initialized eye position quickly and accurately by using the gray value of the image. Then it proposed a fitting method which used direct least squares ellipse fitting to fit circularly and removed noise until the center of the ellipse was fixed, and finally get the accurate pupil center. By using the cross-ratio invariance principle, it mapped the coordinate and caculated the eye coordinate accurately. Experiments show that the system can adapt to human's natural head turning better without wearng extra equipment.

8049-07, Session 1

Metal object detection using a forward-looking polarimetric ground penetrating radar

C. S. L. Chun, E. H. 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 captured data on the scattering matrix for targets for frequencies 1.35-2.14 GHz. From the scattering matrix we calculated the target's polarizability angle, skip angle, and target magnitude. These quantities are invariant to rotations about the sensor-to-target axis. Our measurements on a mine-like object and a one foot length of pipe suggested that, in general, metal targets of dimensions on the order of a wavelength and buried in dry sand had skip angles in the range of +/-80 deg. However, measurements on the dry sand background alone had skip angles occupying the entire range of +/-180 deg. Similarly, the polarizability angle for the buried metal target, in general, varied much less over the frequency range than the polarizability angle for the sand alone. The target magnitude as function of frequency showed interference patterns due to the scattering centers at edges. The target magnitude for the sand alone did not show the periodicity of interference patterns. We will describe our polarimetric GPR and present an algorithm for detecting buried metal targets which uses the polarizability angle, skip angle, and target magnitude. We will describe our evaluation of the performance of this algorithm using measured data.

8049-40, Session 1

Evaluation of methods for computation of CID in a distributed composite tracking system

C. J. Stanek, Northrop Grumman Corp. (United States)

No abstract available

8049-09, Session 2

Informative representation learning for automatic target recognition

C. F. Hester, U.S. Army Research, Development and Engineering Command (United States); K. K. Dobson, U.S. Army Aviation and Missile Command (United States)

Informative representations are those representations that do more than reconstruct the data; they have information embedded implicitly in them. Methods for embedding information in subspace bases are created using sparsity and information theoretic measures. Moreover, the representations should be compressive for utilization in real-time Automatic Target Recognition. We present a theory of informative bases and demonstrate some practical examples of bases learning using infrared imagery. Sparsity and entropy measures are used to drive the learning process to extract the most informative representation. Relations will be drawn between informative representations and the quadratic correlation filter.

8049-10, Session 2

Time-dependent moments for a nonstationary noise model

L. Cohen, A. Ahmad, Hunter College (United States)

We describe a reverberation noise model where the noise is composed of the sum of elementary signals and where these signals are space and time dependent. The resulting noise is hence non-stationary. This is in contrast to most work where one assumes some statistical properties such as random arrival times, amplitude, or phases, and assumes specific distributions for those factors. The aim of this paper is to present new results regarding time dependent noise and in particular we present explicit results for the moments of the noise and how they evolve to stationarity.

8049-11, Session 2

MaxMin signal design for optimal detection in signal-dependent noise

B. Hamschin, P. J. Loughlin, Univ. of Pittsburgh (United States)

Detection of underwater or buried objects using active sonar has been

shown to be improved by designing the transmit sonar pulse based on the known impulse response of the object. However, in practice precise knowledge about the object's impulse response may be unavailable. Furthermore, a transmit pulse optimized for one object state may yield significantly worse performance if the object is actually in a different state (e.g. orientation or burial depth). We propose an extension to a recent approach that derived a signal that maximizes the probability of detecting a single object with known impulse response in the presence of signal dependent noise (e.g. clutter or reverberation). In our extension, we derive a signal that maximizes the worst-case probability of detection associated with an assumed set of objects, thereby designing a signal that is robust to imprecise knowledge about the true object. Simulations demonstrate the improved performance of this approach compared to transmitting an LFM pulse or a signal optimized for an object state different from the actual state.

8049-12, Session 2

Reverberation probability distribution for intensity

L. Cohen, A. Ahmad, Hunter College (United States)

A standard model for reverberation noise is to take the noise as a sum of elementary signals. In our model the elementary signals are chosen from a spatial distribution and are evolved in a medium that may contain dispersion. By way of simulation, we study the probability distribution for amplitude and intensity for the noise at different space-time points.

We show how the distribution sometimes evolves to a Rayleigh and we discuss how the evolution depends on various parameters involved, such as the width of the elementary signals, the width of the initial spatial distribution and at the space-time point where the observation are being made.

8049-13, Session 2

Impact of range-dependent propagation on classification of underwater objects by their sonar backscatter

P. J. Loughlin, V. T. Gomatam, Univ. of Pittsburgh (United States)

As underwater sound (e.g. sonar) propagates, it can change because of effects of the propagation channel, such as dispersion and absorption, among others. Accordingly, the backscatter from identical objects can look different at different ranges from the object, resulting in propagation-induced variability that could degrade automatic classification performance. In previous work, features of the propagating wave that are invariant to the effects of dispersion and absorption in range-independent channels were developed. Although these features lose this invariance in range-dependent channels, we show via simulation that they are still useful features for classification of steel shells in such channels.

8049-14, Session 2

An adaptive algorithm for subpixel target detection using the spectral information divergence measure

W. A. Sakla, U.S. Dept. of Defense (United States); A. A. Sakla, Univ. of South Alabama (United States)

The detection of subpixel targets in hyperspectral images remains a challenging problem. Over the years, a collection of algorithms have been developed that address this problem using statistical and physics-based approaches. In this paper, we have developed an adaptive unmixing algorithm for subpixel target detection using the spectral information divergence (SID) criterion. The SID is an information-theoretic measure which compares the similarity between two hyperspectral signatures by measuring the probabilistic discrepancy between them. The proposed algorithm is adaptive in the sense that the spectra in the hyperspectral image are iteratively unmixed using the SID as a criterion for unmixing. Consequently, the need to perform endmember identification and/or fractional abundance estimation is avoided with the proposed algorithm.

We have inserted subpixel target signatures into an urban hyperspectral scene with varying abundance ratios to assess the performance of our proposed algorithm. The subpixel target signatures have been generated using the familiar linear mixing model (LMM), which assumes that the spectra are composed of unique spatially nonoverlapping materials. Current approaches to subpixel target detection such as the orthogonal subspace projection (OSP) algorithm and the adaptive cosine/coherence estimate (ACE) detector have been implemented and run on the data. Detection results in the form of receiver-operating-characteristic (ROC) curves indicate that our proposed subpixel detection algorithm can yield higher detection rates than the OSP and ACE algorithms.

8049-15, Session 2

Curvilinear target detection using spatial spectroscopy

J. M. Coggins, BAE Systems (United States)

Curvilinear targets include roads, blood vessels, rivers, handwriting, and wires on a printed or integrated circuit. We demonstrate target detection mainly on road networks. Detection of these targets can be difficult due to varying widths, intersections, obscurations, and appearance changes. Each of these confusion types is illustrated. Multiscale geometric methods can be used to detect curvilinear targets in the presence of these confusing structures. Multiscale, geometric decomposition is the central image analysis method in spatial spectroscopy. In prior work, however, geometric invariant features were developed at a single, usually infinitesimal, scale, while measurements across scale were not combined in ways consistent with the nonlinear combinations used in differential geometry. Criteria for combining multiscale measurements of geometric structure are provided and demonstrated for road networks. Techniques include the use of gauge coordinates, higher-order (>2) derivatives, and combinations of geometric measurements across scale and space to specify the targets. In particular, we show a method in which a 2-D manifold embedded in a feature space of high dimension (about 60) allows simultaneous representation and recognition of the effects of scale and geometry.

8049-16, Session 3

Activity recognition

A. J. Hoogs, Kitware, Inc. (United States)

No abstract available

8049-17, Session 3

3D object model-based neural network approach for activity recognition

B. Li, Lockheed Martin Systems Integration-Owego (United States)

In this paper, we propose a 3D model based neural network approach for activity recognition. First, we propose a continous 3D model to represent a sequence of agents. This 3D model helps to capture the spatio-temporal information that includes both macro and micro motion of agents. Based upon the continuous 3D model representation, we develop 3D primitive object theory to group a sequence of agent video images. This 3D primitive objects contain the information of the type of activity of agents. Thus, the activity recognition can be directly operated on the 3D primitive objects, instead of the raw video images. In order to

catch both macro and micro motion, we develop the distributed moment approach for feature representation of the 3D primitive objects. For the classifiers, we use multilayer perceptron to train and do the classification that provides a fast classification in a complex environment. We have implemented this new approach and conducted a sequence of tests that show a high performance for activity recognition from video images.

8049-18, Session 3

Superresolution for dismounted human detection at long ranges

A. Bell, Institute for Defense Analyses (United States)

This research investigates the design of fast, low-power algorithms that detect humans at various ranges. Novel superresolution (SR) algorithms are derived to solve the challenging problem of correct classification at long ranges. The technical approach to this project has two parts: a state-of-the-art classifier for dismounted human detection; and, superresolution enhancements to the first classifier for detection at long ranges. In the first part, a classification system exhibits good performance (via a receiver operating characteristic, ROC, curve) in the detection of humans engaged in walking, standing, and running activities. The primary methods employed include the recent histogram of oriented gradients (HOG) technique as the feature vector and a custom designed support vector machine (SVM) classifier. The performance limits for this first system are depicted in terms of ROC curves and computational complexity. In particular, this classifier (HOG+SVM) is tested extensively to determine system performance as a function of range. The current literature does not reflect an understanding of how HOG for human detection holds up as range increases. This established relationship between system performance and range informs the second part of this work: SR techniques for improving detection at long ranges. Three distinct SR methods are investigated: a Bayesian, model-based approach that addresses blur, motion, sub-sampling and noise issues; a wavelet-based approach that incorporates a multi-resolution perspective; and, a simple frequency-based approach that illustrates the computational complexity vs. performance trade-off. The results indicate new insights into those factors and techniques that provide the best performance for dismounted human detection at long ranges.

8049-19, Session 3

Human body tracking using LMS-VSMM from monocular video sequences

H. Han, Z. Chen, L. Jiao, Y. Fan, Xidian Univ. (China)

A new model-based human body tracking framework with learned-based theory is proposed in this paper. Most of previous research in human body tracking employed the stochastic optimization technique to search the optimal state in a high-dimensional state space, which need solve a global optimization issue, but seldom works performed a framework of multiple models to track human for the challenging problems, such as uncertainty of motion styles, imprecise detection of feature points and ambiguity of joints location. For this reason, we introduced a likely model set-variable structure multiple models (LMS-VSMM) framework to track articulated human motion in monocular images sequences. In this paper, human key joint points are selected as image features, which are detected automatically and the undetected points are estimated with Particle filters, multiple motion models are learned from CMU motion capture database instead of learning from image features and capture data with ridge regression method for direct tracking. In tracking, motion models currently in effect switches from one to another in order to match the present human motion mode. The motion model activation rules are designed on the basis of the changes in projection angle of kinematic chain, and topological and compatibility relationship among them. It is terminated according to their model probabilities. And likely model set schemes of VSMM is used to estimate the quaternion vectors of joints rotation. Experiments based on real images sequences and simulation videos proved this human tracking framework is efficient with respect to 3D pose and 2D projection.

8049-20, Session 3

Human detection based on curvelet transform and integrating heterogeneous features

H. Han, Y. Fan, Xidian Univ. (China)

A method in curvelet transform and integrating heterogeneous features for human detection is proposed in this paper. First of all, the descriptors based on the second generation curvelet transform(CTD) is proposed, it concatenated the edge and texture feature vectors. To capture edge features, we concatenated the statistic measures such as energy, entropy, standard deviation, max value and contrast computed from the blocks, which is partitioned from the sub-bands of all the scales. To get texture features, we partitioned the lowest frequency sub-band coefficient into overlapped blocks. Four co-occurrence matrixes were computed for each block. And some descriptors such as angular second-moment, contrast, correlation, sum of variance, sum of average and entropy are computed from the co-occurrence matrix, which are concatenated as the texture feature vector.

And then three feature extraction methods are integrated for human detection in static images, such as Histogram of Oriented Gradient(HOG), Granularity-tunable Gradients Partition descriptors(GGP), and the CTD. Computational Cost Normalized classification Margin is used to determine the order of the feature to be evaluated. The next feature is evaluated only when the examined features are not confident enough. Threshold of confidence of each type of feature is determined by the probability the feature being evaluated.

The experimental results on the basis of INRIA and MIT human database showed that the Curvelet transformation method and integrating heterogeneous feature increased the detection accuracy compared to HOG feature trained with SVM classifier, GGP and the proposed feature trained with AdaBoost classifier.

8049-21, Session 4

Purposeful interpretation of video

M. D. Desai, Defense Advanced Research Projects Agency (United States)

No abstract available

8049-22, Session 4

Detection and tracking of people and their body parts in infrared

J. Kai, M. Arens, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

In both, civil surveillance tasks and military threat assessment, people's actions are a focus of attention. A prerequisite for action interpretation is a stable tracking of people to built meaningful trajectories. In more sophisticated applications like the assessment of a person as threat or no threat in military applications, not only trajectories on the agent level are of interest, but also an interpretation on the level of limbs provides indispensable information.

This paper addresses these tasks and introduces an integrated approach to detect and track people and their body parts. For that, we introduce a generic, Implicit Shape Model (ISM) based detection and tracking strategy that employs only local image features (SIFT) and thus works independently of underlying video data specifics like color information - making it applicable to both, data acquired in the visible and in the infrared spectrum. By integrating bottom-up tracking-by-detection techniques with top-down model based strategies we tackle (i) identity maintenance in tracking and (ii) tracking through short term occlusions, which are specifically hard to address in thermal data, in an integrated approach that extends the ISM object detector for tracking purposes.

We evaluate the proposed system in infrared sequences acquired from a

moving camera in urban terrain and show, that despite camera motion, our system is able to correctly track multiple people and their body parts in difficult real-world scenarios.

8049-23, Session 4

An implicit shape-model based approach to identify armed persons

S. Becker, J. Kai, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

In addition to detecting and tracking persons via video surveillance in public spaces like airports and train stations, another import aspect of a situation analysis is the appearance of objects in the periphery of a person. Not only from a military perspective, in certain environments, an unidentified armed person can be an indicator for potential threat. In order to become aware of an unidentified armed person and to initiate counteractive measures, the ability to identify persons carrying weapons is needed.

In this paper we present a classification approach, which fits into an Implicit Shape Model (ISM) based person detection and is capable to differentiate between unarmed persons and persons in an aiming body posture. The approach relies on SIFT features and thus is completely independent of sensor-specific features which might only be perceivable in the visible spectrum. For person representation and detection, a generalized appearance codebook is used. Compared to a single person detection strategy with ISM, an additional training step is introduced that allows interpretation of a person hypothesis delivered by the ISM. During training, the activity of the codebook and positions of participated features are stored for the desired classes, in our case persons in an aiming posture and unarmed persons. With the stored information, we are able to calculate weight factors for every feature participating in a person hypothesis in order to derive a specific classification model.

Our model was validated using an infrared dataset which shows persons in aiming and non-aiming body postures from different angles.

8049-25, Session 4

Multiframe correlation filtering for activity recognition using quadratic correlation filters

S. K. Chen, S. R. Stanfill, A. Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

We address the target detection problem by formulating it as a quadratic correlation filter (QCF) design problem, which has the advantage of using shift invariant linear filters. We then extend this technique to activity recognition by introducing a probabilistic measure on each target that incorporates specific motion types. The result is activity classification on detections based on movement and persistent action. In this paper we present the theories behind the QCF design and the multi-frame probabilistic framework, and demonstrate the performance improvement in the multi-frame technique over the single-frame technique, with the use of air-to-ground colored video data.

8049-26, Session 5

The importance of performance modeling for ATR

E. Zelnio, Air Force Research Lab. (United States)

No abstract available

8049-27, Session 5

Practical optimal processing in hyperdimensional spaces via domain-reducing mappings

M. F. Fernández, T. Aridgides, F. A. Sadjadi, Lockheed Martin Maritime Systems & Sensors (United States)

No abstract available

8049-28, Session 5

Baseline processing pipeline for fast automatic target detection and recognition in airborne 3D ladar imagery

S. Roy, J. Maheux, Defence Research and Development Canada (Canada)

It has been proven that 3D ladar imagery has a strong potential for automatic target detection (ATD) and automatic target recognition (ATR); ladars enhance target information, which may then be exploited to yield higher recognition rates and lower false alarms. Although numerous techniques have been proposed for both 3D ATD and 3D ATR, no single approach has proven capable of systematically outperforming all other techniques for every possible scenario. In this context, this paper describes a set of fast 3D ATD/ATR algorithms designed to process cooperative targets in airborne 3D ladar imagery. This algorithmic chain consists of four modules: detection, segmentation, classification and recognition. In each module, fast algorithms were implemented, some of which stem from open literature while others were designed in-house. The purpose of this algorithmic chain is to provide a baseline approach for efficient processing of simple scenarios. The ultimate goal of this work is to characterize and compare algorithms with respect to increasingly complex scenarios, in hopes of progressing towards an adaptive processing pipeline for context-driven 3D ATD/ATR. In this paper, the four modules of the baseline processing pipeline are first described. Preliminary test results obtained with real airborne ladar imagery are then presented, in which fast and accurate 3D ATD/ATR is performed with a library of 20 scanned vehicles. Finally, a demonstration is presented to illustrate how this baseline approach may be expanded to tackle more complex scenarios, such as non-cooperative targets concealed under vegetation.

8049-29, Session 5

Integrating LPR with CCTV systems: problems and solutions

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A new generation of high resolution IP surveillance cameras now allows one to apply video processing and recognition techniques on live video feeds for the purpose of automatically detecting and identifying objects and events of interests. This paper addresses the particular application of detecting and identifying vehicles passing though a checkpoint. This application is of interest to border services agencies and is also related to many other applications. With many commercial automated License Plate Recognition (LPR) systems deployed worldwide, this seemingly resolved problem still poses many unresolved technological challenges. The key problem of fusing noisy character strings detected by LPR/OCR software is solved by applying a post-processing filter that groups all detected character strings into "bags" corresponding to passing vehicles using Levenshtein distance [1] and the timestamp information (see figure 2). The ground truth and the additional information about all passing vehicles, including those that do not exhibit detectable license plates, is detected using the Video Analytic Platform (VAP, see figure 3) which is an in-house built software that uses advance video recognition algorithms capable of robustly detecting moving vehicles in outdoor environments [2].

8049-31, Session 5

Anomaly detection in hyperspectral imagery using stable distribution

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The most common distribution used in the literature is the Gaussian distribution. The use of Gaussian distribution in most cases ensures an analytical solution, and most of the available algorithms are developed based on the Gaussian model. Recent research on signal modeling has led to the realization that many natural phenomena can be represented by distributions of a more impulsive nature. Anomaly regions can be represented better by stable distribution compared to alternate techniques. Designing detectors under the Gaussian assumption of background may lead to degraded performance in terms of excessive false alarms and increased error rate.

Anomaly detector is widely used for hyperspectral detection applications due to the inherent fluctuations in spectral signatures. Signal and image processing research community did not pay attention to stable distribution until 1993 although it is well known in the Mathematics community. The concept of stable distribution received great attention in the last decade due to its success in modeling data which are too impulsive to be accommodated by Gaussian distribution.

In this work, we propose a new technique, where the background is modeled using the stable distribution for robust detection of outliers. This technique is especially suitable for hyperspectral imagery showing impulsive behavior of the data. The outliers of the distribution can be considered as potential anomalies or regions of interests (ROIs). We effectively utilize the stable model for detecting targets in impulsive hyperspectral data. To decrease the false alarm rate, it is necessary to compare the ROI with the known reference using a suitable technique, such as the Euclidian distance. This representation compensates a drawback of the Gaussian model, which is not well suited for describing signals with impulsive behavior. In addition, thresholding is considered to avoid misclassification of targets.

To investigate the performance of the proposed algorithm, we developed simulation software using the MATLAB software package. For testing purposes, we use four real life hyperspectral datasets - CASIBO1, CASIBO3, HYDICEBO1, and HYDICEBO3, respectively. Each dataset contains three versions of images - noise free, 5% noisy and 10% noisy images. The targets are man-made objects and show very different property from surrounding. Test results show that the proposed technique is efficient for all the datasets. All targets are detected without false alarms.

8049-32, Session 5

Multisensor ISR in geo-registered contextual visual dataspace (CVD)

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Current ISR (Intelligence, Surveillance, and Reconnaissance) systems require an analyst to observe each video stream, which will result in analyst overload as systems such as ARGUS or Gorgon Stare come into use with many video streams generated by those sensor platforms. Full exploitation of these new sensors is not possible using today's one video stream per analyst paradigm. The Contextual Visual Dataspace (CVD) is a compact representation of real-time updating of dynamic objects from multiple video streams in a global (geo-registered/annotated) view that combines automated 3D modeling and semantic labeling of a scene. CVD provides a single integrated view of multiple automatically-selected video windows with 3D context. For a proof of concept, a CVD demonstration system performing detection, localization, and tracking of dynamic objects (e.g, vehicles and pedestrians) in multiple infrastructure camera views was developed using a combination of known computer vision methods, including foreground detection by background subtraction, ground-plane homography mapping, and appearance model-based tracking. Automated labeling of fixed and moving objects enables intelligent context-aware tracking and behavior analysis and will greatly improve ISR capabilities.

8049-33, Session 5

Integration of low-level and ontology derived features for automatic weapon recognition and identification

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The present paper is a natural continuation of the work reported in [1]. The main components, stages and functions of a system to be designed for automatic identifying of weapons that may pose a security threat are discussed there. The current study will develop and elaborate the above mentioned components in order to bring the system to an autonomous, fast and accurate stage of performance.

A challenge for such a system comes from a large variety of existing weapons. Also, the number of weapons is constantly growing. Moreover the visible characteristics of some of the existing weapons change over the time, due to new design or elaboration. To cope with these problems ontology is to be developed and kept updated. Since the manual building and updating of the ontology is a resource intensive process, an algorithm for automating this task is proposed in the paper.

Thus, an example weapon ontology containing both low and high level knowledge about its subjects is to be presented. In addition a description of the main components building each weapon will be provided as well. The image segmentation stage will be used to derive, from an input image (or video sequence), low level features of interest. These features will act as input data to a clustering approach which will partition the ontology. Therefore the search for a particular weapon (or even a weapon's component) will be narrowed down to a single cluster with low level features most close to the low level features extracted from the input image.

[1] N.M.Sirakov, S. Suh, S.Attardo, 2010, "Automatic Object Identification Using Visual Low Level Feature Extraction And Ontological Knowledge", Proc of Society for Design and Process Science-SDPS, Dallas, Texas, June 6-11, 2010, pp.1-9, ISSN: 1090-9389.

http://sdps.omnibooksonline.com/2010/index.html

8049-41, Session 5

Applying visual saliency to the automatic target recognition domain

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No abstract available

8049-34, Session 6

Predicting new views of an object from an existing image by parametrized predictions on the manifold

A. Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

We present a novel method for predicting new views of an object from an existing image. This is done by first characterizing and parameterizing the underlying manifold on which the different views of the objects lie. Then, given a particular view of the object, we estimate the appearance of the same object at others points along the manifold. This method holds particular promise for rapidly generating new training images of an object from a few existing images without explicit data collection. The method

has an advantage over conventional computer graphics techniques in that it can predict the “hidden view” based on the current observation.

8049-35, Session 6

Redefining automatic target recognition (ATR) performance standards

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Present descriptors for ATR performance are inadequate for use in comparing algorithms that are purported to be a solution to the problem. The use of receiver operator curves (ROCs) is a defacto standard, but they do not communicate several key performance measures, including (i) intrinsic separation between classes in the input space, (ii) the intrinsic complexity induced by the algorithm, ands (iii) a measure of the generalization of the proposed solution. Previous work by Sims has addressed distortion of the evaluation sets to indicate an algorithm’s capability (or lack thereof) for generalization and handling of unspecified cases. This paper addresses the rethinking of the summary statistics used for understanding the performance of a solution. We propose new approaches for solution characterization, allowing algorithm performance comparison in an equitable and insightful manner. This paper proffers some examples and suggests directions for new work from the community in this field.

8049-36, Session 6

Analytic performance model for grayscale quantization in the presence of additive noise

A. R. Nolan, G. S. Goley, Etegent Technologies, Ltd. (United States)

Synthetic aperture radar (SAR) exploitation algorithms rely on the use of features which ideally represent the target information in a manner that is robust to noise and calibration artifacts. In this paper we focus on characterizing class separability of the grayscale quantization feature in the presence of additive noise. Because this feature is a nonlinear mapping, modeling its behavior in the presence of noise requires the use of simplifying assumptions. To make the problem tractable, we treat the additive noise as an independent identically distributed process. We also limit our analysis to deterministic pairings of samples, i.e. the noise is assumed to change only the distance to a particular minimum exemplar for a given class, rather than choose an alternate minimum exemplar. Using these two simplifying assumptions, we derive an analytic approximation for the variance of the effective distance between target classes. The resulting analytic model generates receiver operator characteristics for various additive noise assumptions. This sensor exploitation performance model is contrasted with Monte Carlo experiments. These comparisons are performed in the context of a nearest neighbor classification algorithm for multiple targets.

8049-37, Session 6

Variability and robustness of scatterers in HRR/ISAR ground target data and its influence on the ATR performance

R. Schumacher, H. M. Schimpf, J. Schiller, Fraunhofer FHR (Germany)

The most challenging problem in ATR is the extraction of robust target features which describe the target unambiguously. These features have to be robust and invariant in different senses, in time, translation and rotation. Especially for ground moving targets in military applications an irregular target motion is typical so that a strong variation of the backscattered radar signal with aspect and depression angle makes the extraction of stable and robust features more difficult. In ATR based on HRR profiles and / or ISAR images it is crucial that the reference dataset consists of stable and robust features depending on the target aspect and depression angle amongst others. Also a robustness of the identification result between target variants is requested.

In this paper the variability of the backscattered radar signals of target scattering centers is analyzed for different HRR profiles and ISAR images from measured datasets of ground targets. Especially the dependency of the depression angle is analyzed regarding the to the ATR of large strip SAR data with a large range of depression angle by using available (I)SAR datasets as reference. In this work the robustness of these scattering centers are analyzed, by extracting their amplitude, phase and position. Therefore measures for variability, similarity, robustness and separability are defined. The backscattered radar signals of the target scattering centers are classified in different categories: strong, medium and low signals with low, medium and high variability of appearance. Beside this other types of features (geometrical, statistical, generic), which can be derived especially from ISAR images, are applied for the ATR-task.

8049-38, Session 6

The influence of multipath on ship ATR performance

H. M. Schimpf, Fraunhofer FHR (Germany)

The classification of potentially hostile ships by means of automatic target recognition (ATR) becomes more and more important for applications like harbour protection and ship self defence in times of asymmetric threat and piracy.

Very often, the task of detecting and classifying a ship has to be performed by sensors that are located close to the sea surface either onboard a ship or on the coast. Due to the shallow looking angles and to the special conditions of the sea surface and of the atmosphere immediately above the sea surface (marine boundary layer), the influence of multi-path and of atmospheric duct phenomena plays an important role. Scatterers are affected in a different way depending on their height above the sea surface. As a consequence, the amplitude relations between different scatterers on a ship depend strongly on the distance between the radar and the ship that has to be classified. This means that HRR (high range resolution) profiles and ISAR images that are the basis of extracting ATR features, are also a function of distance.

These effects are demonstrated based on measurements performed by the MEMPHIS radar at 35 GHz and the MARSIG radar at 17 GHz. Both radars were developed and are operated by Fraunhofer FHR (formerly FGAN). In both cases the radar was installed fixed on the coast at a height of 19m above the sea surface. The target ships followed courses away from or towards the radar as well as circular courses at distances between 1km and 8km.

The measurements are complemented by simulations using the TERPEM model which describes multipath and duct phenomena as a function of measurement geometry and meteorological parameters.

The paper concludes with some suggestions how the effects of multipath on ATR can be mitigated, and how more stable estimates of HRR profiles may be obtained using a multi-temporal or multi-frequency approach.

8049-39, Session 6

A comparison of machine learning methods for target recognition using ISAR imagery

K. D. Uttecht, C. X. Chen, J. C. Dickinson, T. M. Goyette, R. H. Giles, Univ. of Massachusetts Lowell (United States); W. E. Nixon, National Ground Intelligence Ctr. (United States)

The ability to accurately classify targets is critical to the performance of automated target recognition (ATR) algorithms. Supervised machine learning methods have been shown to be able to classify data in a variety of disciplines with a high level of accuracy. This poster compares the performance of a variety of machine learning techniques specifically designed to classify ground targets using two-dimensional radar imagery. Three machine learning models: Decision Tree, Bayes, and Support Vector Machine, were compared to determine which model best classifies targets with the highest accuracy. X-band signature data acquired in scale-model compact ranges were used in this work. ISAR images were compared using several techniques including two-dimensional crosscorrelation and pixel by pixel comparison of the image against a reference image. The highly controlled nature of the collected imagery was ideally suited for the intercomparison of the machine learning models. The resulting data from the image comparisons were used as the feature space for testing the accuracy of the three types of classifiers. Classifier accuracy was determined using N-fold cross validation.

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8050-01, Session 1

Road network estimation through GMTI track fusion

M. G. Alford, M. Scalzo, A. Bubalo, G. E. Wood, E. C. Jones, Air Force Research Lab. (United States)

Road networks and associated traffic flow information are topics that have an innumerable number of applications, ranging from highway planning to military intelligence. Despite the importance of these networks, archival databases that often have update rates on the order of years or even decades have historically been the main source for obtaining and analyzing road network information. This somewhat static view of a potentially changing infrastructure can cause the information to therefore be incomplete and incorrect. Furthermore, these road databases are not only static, but rarely provide information beyond a simple two-dimensional view of a road, where divided high-ways are represented in the same manner as a rural dirt road. It is for these reasons that the use of Ground Moving Target Indicator (GMTI) data and tracks to create road networks is explored. This data lends itself to being able to not only provide a single static snapshot of a network that is considered the network for years, but to provide a consistently accurate and updated changing picture of the environment. The approach employed for creating a road network from GMTI tracks includes a technique known as Continuous Dynamic Time Warping (CDTW), as well as a general fusion routine.

8050-02, Session 1

Measures of nonlinearity for single target tracking problems

E. C. Jones, M. Scalzo, A. Bubalo, M. G. Alford, B. Arthur, Air Force Research Lab. (United States)

The tracking of objects and phenomena exhibiting nonlinear motion is a topic that has application in many areas ranging from military surveillance to weather forecasting. Observed nonlinearities can come not only from the nonlinear dynamic motion of the object, but also from nonlinearities in the measurement model. Many techniques have been developed that attempt to deal with this issue, including the development of various types of filters, such as the Extended Kalman Filter (EKF) and the Unscented Kalman Filter (UKF), variants of the Kalman Filter (KF), as well as other filters such as the Particle Filter (PF). Determining the effectiveness of any of these techniques in nonlinear scenarios is not straightforward. Testing needs to be accomplished against scenarios whose degree of nonlinearity is known. This is necessary if reliable assessments of the effectiveness of nonlinear mitigation techniques are to be accomplished. In this effort, three techniques were investigated regarding their ability to provide useful measures of nonlinearity for representative scenarios. These techniques were the Parameter Effects Curvature (PEC), the Normalized Estimation Error Squared (NEES), and the Normalized Innovation Squared (NIS). Results indicated that the NEES was the most effective, although it does require truth values in its formulation.

8050-03, Session 1

Toward a computationally efficient approach for improving target tracking using grid-based methods

M. E. Silbert, The George Washington Univ. (United States) and Naval Air Systems Command (United States); S. Sarkani, T. Mazzuchi, The George Washington Univ. (United States)

Although the Kalman filter is efficient and effective for computing state estimates of a moving target, it can produce poor results when tracking a maneuvering target. The problem is that the Kalman filter must employ large plant noise error and large tracking gates to keep the target in track. However, this results in larger errors in the state estimate as well as larger uncertainties for these state estimates. To track these maneuvering targets, a better approach would be to exploit the physical constraints of the target to restrict the possible future states to only those that the target could have possibly transitioned. Unfortunately, the Kalman filter cannot fully capture the physical constraints of the target motion. To address this problem, a few general approaches have been pursued including variations of the Kalman filter (e.g., the Extended Kalman filter (EKF) and the Interacting Motion Model (IMM)), particle filters, and grid-based filters. Grid-based filter are a mix of standard Kalman filter techniques and particle filters. Although grid-based filters can be effective, most of the literature has avoided them due to their perceived exponential time and space computational requirements. A new approach for using grid-based filter has been developed that can track targets moving in two dimensions by using a well-confined, two-dimensional grid. As a result, this grid-based approach is enormously more computationally efficient and can effectively exploit the physical constraints of the target. This paper will describe this grid-based filter approach, including the inclusion of the physically constrained target motion model. The paper will then compare the tracking performance of this grid-based filter against the Kalman filter for various maneuvering target scenarios. The improvement in the target state estimation process using this grid-based filter will be shown and analyzed via statistical analysis.

8050-04, Session 1

The effect of disparate sensors on tracking perfomance

C. A. Rea, M. E. Silbert, Naval Air Systems Command (United States)

The ability to accurately track multiple targets using multiple sensors (e.g. multiple radars) is an important problem. However, often the sensors used are different, with different accuracies and different detection capabilities. It becomes problematic to determine how best to combine the data from these sensors. Since each sensor provides information, and information is additive, then theoretically the best estimate should be obtained by combining the information from all sensors. However, in practice, this addition of information does not always work as expected. Often the best solution is to simply select the best sensor and ignore the rest (i.e. 'best-of-breed'). This effectively results in a multiple sensor system behaving like a single sensor system. It is suspected that the reason the combining of multiple sensors does not perform as theoretically predicted is because the lesser sensor systems are more likely to contain misassociations. These misassociations cause increased tracking errors which can become more pronounced when combining the data from the sensors. The paper tests this hypothesis by studying the degradation of fusion performance that typically occurs when tracking with multiple disparate sensors. This paper will then address how best to exploit multiple sensor tracking when using sensors of differing quality.

8050-05, Session 1

A multiple IMM approach with unbiased mixing for thrusting projectiles

T. Yuan, Y. Bar-Shalom, P. K. Willett, Univ. of Connecticut (United States); D. F. Hardiman, U.S. Army Research, Development and Engineering Command (United States)

This paper presents a multiple interacting multiple model (MIMM) procedure to estimate the state of thrusting/ballistic projectiles in the atmosphere for the purpose of impact point prediction (IPP). Given a very short time span of observations, the strong interaction between drag and thrust in the dynamic model, in the sense of ambiguity in the estimation, significantly affects the estimation performance and the final IPP accuracy. This leads to the need to use an MIMM estimator with various initial drag coefficient estimates. The modes of each IMM estimator are for the thrusting and the ballistic phases and different extended Kalman filters (EKF) are used as the mode-matched filters with different dimension states. A novel unbiased mixing procedure for an IMM is introduced to deal with state estimates with unequal dimension, as is the case for the thrusting and ballistic models. The IPP is carried out at the end of the observation period by using the most probable mode of the selected IMM estimator, the latter being the one with the highest likelihood.

8050-06, Session 1

Tracking system to maximize engagement envelope of a data-linked weapon

J. M. Davies, J. F. Ralph, Univ. of Liverpool (United Kingdom)

The measure of performance for any missile is its ability to intercept a target in a variety of engagement scenarios this is known as the weapon's engagement envelope It can be considered to be area where any target within that area can be successfully hit . The reachable set becomes smaller due to the limitations of the guidance commands which can be applied at various points during the flight of the weapon as it approaches the target.

Once a target recognizes it has been detected it is likely to perform maneuvers to try and invade tracking and eventual interception. This paper will discuss the results of an integrated tracking and pursuit strategy implemented within a tracking system, designed to maximize the engagement envelope of a data linked weapon tracking a fast maneuvering target.

The system calculates in real time, the engagement envelope of the weapon and the predicted location of the target. Controls are applied to the weapon using a data link to perform maneuvers in such a way as to overlap as much of the engagement envelope of the missile over the predicted location of the target, thus maximizing the probability of a successful interception.

8050-07, Session 2

Efficiency of the composite position measurements from satellite-based LOS

R. W. Osborne III, Y. Bar-Shalom, Univ. of Connecticut (United States)

A common issue in target tracking is having to deal with nonlinearities in measurement models and/or target motion models. A motion model for a target of interest can often be easily formulated in a linear framework when the motion is considered in a Cartesian coordinate system. For many sensors, however, the measurement will be a nonlinear function of the Cartesian position of the target and, possibly, of smaller dimension (e.g., a line-of-sight (LOS) measurement). In order to avoid the use of nonlinear filtering techniques in such cases, it would be desirable to combine multiple nonlinear measurements into a single Cartesian measurement, with a suitable measurement covariance matrix for use in a linear filter. The proposed method combines two satellite-based LOS measurements, assumed to be synchronized, into a single composite Cartesian measurement via a maximum likelihood (ML) estimation framework. The ML estimate is shown to be an efficient estimator, and as such, the covariance matrix obtainable from the Cramer-Rao lower bound (CRLB) would provide a consistent measurement noise covariance matrix for use in a target tracking filter.

8050-08, Session 2

Multitarget smooth variable structure filter: theory, design, and implementation

S. A. Gadsden, D. Dunne, S. Habibi, T. Kirubarajan, McMaster Univ. (Canada)

The smooth variable structure filter (SVSF) is a relatively new predictor-corrector estimation method based on sliding mode theory. It has recently been shown to work extremely well in a single-target scenario, performing near or better in some cases to the popular Kalman and particle filters (KF and PF). This paper extends the concepts of the SVSF to a multi-target domain. The common tracking algorithms (KF and PF) are replaced by the SVSF, and are implemented using both the multi-hypothesis tracking (MHT) and joint probability data association (JPDA) approaches. The SVSF formulated for multi-target tracking is implemented on a tracking testbed, and is compared with other methods in terms of accuracy, robustness to modeling errors, and miss distance.

8050-09, Session 2

Maximum likelihood probabilistic multihypothesis tracker applied to multistatic sonar data sets

S. C. Schoenecker, Naval Undersea Warfare Ctr. (United States); P. K. Willett, Y. Bar-Shalom, Univ. of Connecticut (United States)

The maximum likelihood probabilistic multi-hypothesis tracker (ML-PMHT) is an algorithm that works well against low-SNR targets in an active multistatic framework with multiple transmitters and multiple receivers. The ML-PMHT likelihood function allows for multiple targets as well as multiple returns from any given target in a single scan, which is realistic in a multi-receiver environment where data from different receivers is combined together. Additionally, the likelihood ratio can be optimized very easily and rapidly with the expectation-maximization (EM) algorithm. Here, we apply ML-PMHT to two multistatic data sets: the TNO Blind 2008 data set and the Metron 2009 data set. Results are compared with previous work that employed the Maximum Likelihood Probabilistic Data Association (ML-PDA) tracker, a slightly more complicated algorithm with a different likelihood ratio formulation.

8050-10, Session 2

Wide-area video exploitation (WAVE) joint data management for layered sensing

E. P. Blasch, Defence Research and Development Canada (Canada); G. S. Seetharaman, Air Force Research Lab. (United States)

Emerging technologies facilitate increased data collection for wide area sensing; however, with the advent of high performance computing techniques, joint data management concepts of operations are important to fully realize the performance of the new sensing capability. In this paper, we explore the various issues surrounding Wide-Area Video Exploitation (WAVE) in a layered-sensing environment to include (1) Survey of automated video exploitation technologies data management

needs, (2) description of the data workflow, and (3) evaluation through performance measurements that highlight the improved efficiency and effectiveness of WAVE techniques. Key to enabling WAVE systems are improvements in Joint Data Management such as (1) data collection, construction, and transformation, (2) feature generation, extraction and selection, and (3) information evaluation, presentation, and dissemination).

8050-11, Session 2

Information-theoretic sensor management analysis

E. P. Blasch, Defence Research and Development Canada (Canada); I. Kadar, Interlink Systems Sciences, Inc. (United States); C. Yang, Sigtem Technology, Inc. (United States)

In this paper, we compare the information theoretic measures of the Kulback-Leibler (KL), Renyi, and Csiszar divergence formulations for a sensor management. Information-theoretic measures have been well suited for sensor management as they afford comparisons between distributions. The difference in distributions can also be measured as entropy formulations to discern the communication channel capacity (i.e. Shannon limit). In this paper, we formulate a simultaneous tracking and ID (STID) scenario and compare the various performance metrics to determine which measures might be appropriate for sensor management given the dynamics of the scenario.

8050-12, Session 3

Optimal threshold policies for radar resource management in GMTI systems

V. Krishnamurthy, E. J. Miehling, The Univ. of British Columbia (Canada); B. Balaji, Defence Research and Development Canada (Canada)

This paper deals with the resource management of a single GMTI radar when faced with tracking multiple, non-maneuvering targets. The goal is to devise a switching scheme to optimally trade-off tracking performance and radar usage. The general problem involves first designing a macro-manager which determines which of the L targets has the highest tracking priority, then second, devising a micro-manager responsible for specifying the optimal time to continue tracking the given target. We abstract the state of our system to be the error covariance matrix of each target, of which we estimate via an extended Kalman filter. We consider the possibility for missed detections by treating the arrival of a given observation to be a random process with probability of detection less than one. This results in the state update, normally following the deterministic algebraic Riccati equation, to now be stochastic. The macro-manager chooses the target with the highest track uncertainty. The micro-manager follows a policy determined by solving a stochastic optimization problem. We give sufficient conditions on the structure of the cost functions to ensure that the micro-manager's optimal scheduling policy takes a threshold form with respect to positive definite ordering. With knowledge of the existence of this curve in L-1 dimensional space, we can approximate it by a linear hyperplane. This approximation is carried out offline via the Simultaneous Perturbation Stochastic Approximation (SPSA) algorithm. With this scheduler, we see a 5-10% reduction in track estimate error over the widely used myopic switching scheme.

8050-13, Session 3

Efficient exchange of information in a distributed tracking environment

P. J. Shea, E. Blake, Black River Systems Co. (United States)

Modern tracking and fusion settings involve multiple platforms in different locations, tracking different target tracks, focusing on different regions of interest, while using different update rates, and sensor resolutions with the goal of providing increased situation awareness in the region by fusing together the diversity of information from each platform. In this paper, a decentralized, distributed fusion architecture is presented along with results and trade studies comparing performance to that of a centralized fusion architecture. The decentralized distributed architecture is designed to work with legacy tracking systems and uses an efficient message passing scheme to share information and coordinate tracks across a diverse group of platforms. This system does not rely on a central node and allows for track information to be maintained at the local level while utilizing track information from other platforms to increase situation awareness. We compare the performance between our distributed approach and a centralized system using simulated airborne sensors operating in overlapping regions of interest with target densities and routes chosen to demonstrate tradeoffs between the different architectures. Preliminary results show that the decentralized distributed system provides similar performance to the centralized fusion system in terms of situation awareness relative to traditional tracking metrics, but at the cost of using an increased communication bandwidth to provide frequent updates to neighboring platforms. Results demonstrate the tradeoff between flexibility and optimality - configuration of the distributed decentralized system to provide increased flexibility and robustness comes at the cost of reduced situation awareness as compared to the centralized system.

8050-14, Session 3

Optimal update with multiple out-of-sequence measurements

S. Zhang, Y. Bar-Shalom, Univ. of Connecticut (United States)

In multisensor target tracking systems receiving out-of-sequence measurements from local sensors is a common situation. In the last decade many algorithms have been proposed to update with an OOSM optimally or suboptimally. However, what one faces in the real world is multiple OOSMs, which arrive at the fusion center in arbitrary order, e.g., in succession or interleaved with in-sequence measurements. A straightforward approach to deal with this multi-OOSM problem is by sequentially applying a given OOSM algorithm; however, this simple solution does not guarantee optimal update under the multi-OOSM scenario. The present paper discusses the differences between the single-OOSM processing and the multi-OOSM processing, and presents the general solution to the multi-OOSM problem, called the complete in-sequence information (CISI) approach. Given an OOSM, in addition to updating the state at the most recent time, the CISI approach also updates the states between the OOSM time and the most recent time, including the state at the OOSM time. Three CISI methods with different computational requirements are developed in this paper: the information filter-equivalent measurement (IF-EqM) method, the CISI fixed-point smoothing (CISI-FPS) method and the CISI fixed-interval smoothing (CISI-FIS) method. Numerical examples are given to show the optimality of these CISI methods under various multi-OOSM scenarios.

8050-15, Session 3

Stability of out-of-sequence measurement processing: an open problem

L. Chen, BAE Systems Advanced Information Technologies (United States); N. Moshtagh, Scientific Systems Co., Inc. (United States)

In many applications where communication delays are present, measurements with earlier time stamps can arrive out-of-sequence, i.e., after state estimates have been obtained for the current time instant. To incorporate such an Out-Of-Sequence Measurement (OOSM), many algorithms have been proposed in the literature to obtain or

approximate the optimal estimate that would have been obtained if the OOSM had arrived in-sequence. When OOSM occurs repeatedly, one approximate estimate as a result of incorporating an OOSM in the past has to serve as the basis for incorporating yet another OOSM in the future. The question of whether the “approximation of approximation” is well behaved, i.e., whether approximation errors accumulate in a recursive setting, has not been adequately addressed in the literature. This paper draws attention to the stability question of recursive OOSM processing filters, formulates the stability problem in a specific setting, and presents some positive simulation results. Our hope is that more research will be conducted in the future to rigorously establish stability properties of these filters.

8050-16, Session 4

Bayesian unified registration and tracking

R. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); A. I. El-Fallah, Scientific Systems Co., Inc. (United States)

Multitarget detection and tracking algorithms typically presume that sensors are spatially registered-i.e., that all sensor states are precisely specified with respect to some common coordinate system. In actuality, sensor observations may be contaminated by unknown spatial misregistration biases. This paper demonstrates that these biases can be estimated by exploiting the data collected from a sufficiently large number of unknown targets, in a unified methodology in which sensor registration and multitarget tracking are performed jointly in a fully unified fashion. We show how to (1) model single-sensor bias, (2) integrate the biased sensors into a single probabilistic multiplatform-multisensor-multitarget system, (3) construct the optimal solution to the joint registration/tracking problem, and (4) devise a principled computational approximation of this optimal solution.

The approach does not presume the availability of GPS or other inertial information.

8050-17, Session 4

Distributed PHD filter-based bias removal in PCL system

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Bias removal is an essential step in the direction of arrival (DOA) based passive coherent location (PCL) radar tracking system. In a typical PCL system, the sensors report direct as well as multipath target return signals. When multipath target returns from distinct and unknown propagation models are exploited, the accuracy of the DOA from the reflected surface become crucial. In practical systems, although it is necessary to reduce the directional ambiguities, the placement of receivers closed to each other results in larger bias in the estimation of DOA signals, especially when the targets move off boresight. The estimation errors in multipath reflection surface angle also introduce bias in the DOA measurements. In typical PCL environment, removing DOA bias in direct and multipath measurements is highly desirable as it enhances the accuracy of tracking. This study investigates the aforementioned problem in target tracking using a network of multiple sensing platforms. Each sensing platform makes multiple, noisy measurements with an unknown bias of an underlying, time-varying state that describes the monitored system. In this study, we propose a distributed implementation of a sequential Monte Carlo based probability hypothesis density (PHD) algorithm. Simulation results are presented to demonstrate the efficiency of the proposed algorithm for target tracking from a network of receivers.

8050-18, Session 4

Multivehicle decentralized fusion and tracking

A. I. El-Fallah, A. Zatezalo, R. K. Mehra, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States)

In this paper, 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.

8050-19, Session 4

Multimodel filtering of partially observable space object trajectories

A. Zatezalo, A. I. El-Fallah, R. K. Mehra, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); K. D. Pham, Air Force Research Lab. (United States)

In this paper, we present methods for multimodel filtering of space object states based on the theory of finite state time nonhomogeneous cadlag Markov processes, and the filtering of partially observable space object trajectories. The state and observation equations of space objects are nonlinear and therefore it is hard to estimate the conditional probability density of the space object trajectory states given EO/IR, radar, or other nonlinear observations. Moreover, space object trajectories can suddenly change due to abrupt changes in the parameters affecting a perturbing force, or due to unaccounted forces. Such trajectory changes can lead to the loss of existing tracks, and may cause collisions with vital operating space objects such as weather or communication satellites. The presented estimation methods will aid in preventing the occurrence of such collisions, and provide warnings for collision avoidance.

8050-20, Session 4

On the differences between the probability hypothesis density (PHD) filter and the multitarget multi-Bernoulli (MeMBer) filter

D. E. Clark, Heriot-Watt Univ. (United Kingdom); T. Wood, Oxford Univ. (United Kingdom); B. B. Vo, The Univ. of Western Australia (Australia); B. Ristic, Defence Science and Technology Organisation (Australia); B. T. Vo, The Univ. of Western Australia (Australia)

The Probability Hypothesis Density (PHD) filter and multi-target multi-Bernoulli filter are both approximations based on the Finite Set Statistics formulation of multi-object Bayes filtering. A sequential Monte Carlo implementation of the PHD filter was recently developed to efficiently exploit the filter output for accurate and reliable state estimation, and to model the births of targets. This was extended to allow efficient resampling and track continuity in a similar manner to the Gaussian mixture implementation of the PHD filter. By adopting a track-oriented approach for the PHD filter, it has a close resemblance to the multi-target multi-Bernoulli filter. In this paper, we discuss the theoretical differences between the two track-based filters and present simulated results.

8050-21, Session 4

On the ordering of the sensors in the iterated-corrector probability hypothesis density (PHD) filter

S. Nagappa, D. E. Clark, Heriot-Watt Univ. (United Kingdom)

The iterated-corrector Probability Hypothesis Density (PHD) filter is a computationally efficient and tractable approximation to the multi-sensor multi-target tracking problem. The PHD filter requires the assumption that the predicted multi-object distribution a multi-object Poisson distribution. As a result of this approximation, the ordering of the multi-sensor solution gives different results depending on the order of the update. In this paper, we study the effect of the ordering for simulated scenarios and show that the state estimates can be improved for each target by choosing the ordering of the sensors according to observations within each target gate.

8050-22, Session 4

A tracker based on a CPHD filter approach for infrared applications

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The PHD filter was developed to address the problem of multi-sensor multi-target tracking in a unified and tractable manner. The PHD filter is able to estimate the number of targets present in the scene, and the positions of each of the different targets. In order to derive a closed-form expression for the PHD filter, Mahler assumed that the predicted density before the update was a Poisson multi-object density. Subsequently, Mahler developed the CPHD, which relaxes this assumption to independent, identically distributed (i.i.d.) multi-object densities with arbitrary cardinality distributions. In addition to the PHD filter which propagates only the first moment of the multi-target density, the CPHD filter also propagates the cardinality distribution of the number of targets which are present on the scene. Consequently, the number of targets is estimated more precisely than in the PHD filter, and the first moment multi-target distribution too. Nevertheless, this improvement has an expensive cost since the complexity of the filter is cubic in the number of observations. A closed form solution to the CPHD filter was derived in the special case of Gaussian Mixture, that is to say that we assume that the PHD is a Gaussian Mixture and the dynamic and observation model are linear and Gaussian. In this paper, we propose to include tracking techniques with a modified CPHD filter, including clustering of the regions of the PHD and gating. We improve the tracker developed in order to solve the multi-target conflict (a same measurement is a candidate for several tracks) using a 2-D assignment method. We evaluate the data association approach and compare our algorithm with the CPHD filter in terms of the OSPA multi-object distance metric. The paper provides also results of the algorithms on real IR data scenarios demonstrating the results for tracker performance.

8050-23, Session 4

The set IMMJPDA filter for multitarget tracking

D. Svensson, L. Svensson, Chalmers Univ. of Technology (Sweden); D. Crouse, Univ. of Connecticut (United States); M. Guerriero, Elettronica S.p.A. (Italy); P. K. Willett, Univ. of Connecticut (United States)

The Set JPDA (SJPDA) filter is a recently developed multi-target tracking filter that utilizes the relation between the density of a random finite set and the ordinary density of a state vector to improve on the Joint Probabilistic Data Association (JPDA) filter. One advantage with the filter is the improved accuracy of the Gaussian approximations of the JPDA, which result in avoidance of track coalescence. Another advantage is an improved estimation accuracy in terms of a measure which disregards target identity. In this paper we extend the filter to also consider multiple motion models. As a basis for the extension we use the Interacting Multiple Model (IMM) algorithm. The resulting filter, called Set IMMJPDA, can be seen as an adjustment of the classic IMMJPDA filter. In the paper, we derive the new filter and discuss its advantages compared with the conventional filter. We also present simulation results for a two-target tracking scenario, which show improved tracking performance for the SIMMJPDA filter when evaluated with a measure that disregards target identity.

8050-24, Session 4

Dempster’s combination is a special case of Bayes’ rule

R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States)

Bayes’ rule and Dempster’s combination are typically presumed to be radically different procedures. This paper demonstrates that measurement-update using Dempster’s combination is a special case of measurement-update using Bayes’ rule. The demonstration is based on an analogy with the Kalman filter. Suppose that the data are linear-Gaussian point measurements. Then ask, What additional assumptions must be made so that the single-target recursive Bayes filter can be solved in algebraically closed form? The Kalman filter is what results. In similar fashion, suppose that the data are Dempster-Shafer “uncertain measurements.” Then ask, What additional assumptions must be made so that the single-target recursive Bayes filter can be solved in algebraically closed form? Dempster’s combination is what results. Stated differently: both the Kalman data-update equations and Dempster’s combination are corrector steps of the recursive Bayes filter, when it is restricted to two different types of measurements.

8050-25, Session 5

Acoustic and imagery semantic labeling and fusion of human-vehicle interactions

A. H. Shirkhodaie, V. Elangovan, A. Rababaah, Tennessee State Univ. (United States)

Analysis of the Human-Vehicle Interactions (HVI) helps in identifying cohesive patterns of activities representing pertinent potential threats. This paper presents a technical approach for fusion of imagery and acoustic data representing Human-Vehicle Interactions in a Persistent Surveillance System (PSS). To aggregate task specific information from imagery and acoustic data streams, a two-phase approach is presented. Primarily, we describe the concept of HVI and our vehicle zoning strategy to localize human locations relative to the target vehicle and acoustic signatures generated by eight different HVI activities. In the first phase, we present two competing techniques for feature extraction - the first technique applies a discrete wavelet transform and the second technique uses a short-time Fourier transform for generating feature vectors from the HVI non-stationary acoustic signatures. A correlation-based classifier is designed for classifying of vehicular acoustic events and generating semantic labels for classified acoustic signatures. In the second phase, we employ an imagery technique for context-based semantic labeling of HVI activities. An ontology-based approach is proposed for spatiotemporal tracking of HVI activities as well as establishing correlation and association among detected HVI events to a certain

HVI taxonomy. The fusion of acoustic and imagery data is realized at the decision-level and a fusion process is proposed for aggregating information from acoustic and imagery data processing phases. This paper presents our experimental work for the collection of calibrated data and demonstrates the reliability and effectiveness of the proposed fusion process in proper semantic labeling of HVI activities.

8050-26, Session 5

Adaptive characterization, tracking, and semantic labeling of human-vehicle interactions via multimodality data fusion techniques

A. H. Shirkhodaie, V. Elangovan, A. Rababaah, Tennessee State Univ. (United States)

Analysis of Human Vehicle Interaction (HVI) helps in identifying cohesive patterns of activities that when collectively considered and analyzed could reveal potential threats. Such capability is in demand for Persistent Surveillance Systems (PSS) where individual HVI or crowd activities with vehicles are pertinent. In this paper, we present a technique for Zoning of Vehicle (ZoV) and an ontology-based approach for localization and characterization of traceable HVI activities. To semantically generate labels describing HVI activities, we combine the decisions from multi-source sensors, including surveillance cameras, a PTZ camera with powerful zoom, and an array of acoustic sensors. We have shown that low resolution surveillance cameras are sufficient to detect the whereabouts of humans around vehicles. Such surveillance camera, however in cooperation with a powerful PTZ camera, can perform keen assessment of HVI activities that in turn improve the ability of the system to properly characterization individual HVI activities and semantically generating meaningful labels describing HVI linguistically. Furthermore, we have demonstrated that by combing imaging and acoustic data at decision level, a higher degree of confidence can be realized for describing the HVI activities with appropriate traceability. To demonstrate application of this new technique, we conducted both indoor and outdoor experiments. This paper presents the results of our experimental work and demonstrates effective and adaptive fusion of these multiple sensory sources towards achievement of efficient semantic messages describing HVI activities for improvement situational awareness.

8050-27, Session 5

Structure learning of Bayesian network using a cloud-based adaptive immune genetic algorithm

S. Qin, Zhejiang Univ. (China); F. Lin, Zhejiang Univ. (China) and George Mason Univ. (United States); K. Chang, George Mason Univ. (United States)

A new BN structure learning method using a cloud-based adaptive immune genetic algorithm (CAIGA) is proposed. Since the probabilities of crossover and mutation in CAIGA are adaptively varied depending on X-conditional cloud generator, it could improve the diversity of the structure population and avoid local optimization. This is due to the stochastic nature and stable tendency of cloud model. Moreover, offspring structure population is simplified by using immune theory to reduce its computational complexity. The experiment results reveal that this method can be effectively used for BN structure learning.

8050-28, Session 5

Study of most probable explanations in hybrid Bayesian networks

W. Sun, K. Chang, George Mason Univ. (United States)

In addition to computing the posterior distributions for hidden variables in Bayesian networks, one other important inference task is to find the most probable explanations (MPE). MPE provides the likely configurations to explain the evidence and helps to manage hypotheses for decision making. In recently years, researchers also take the relevance into account and proposed a new concept called most relevant explanation (MRE). In general, exact or even approximate methods to find MPE/MREs are NP-hard. In this paper, we first review the current state-of-the-art in the literature to compare various explanation methods. We then present an approximate algorithm by combining message propagation and genetic methods, particularly aiming to accommodate hybrid Bayesian networks. Simulated experiments show promising results.

8050-29, Session 5

Fusion and Gaussian mixture based-classifiers for SONAR data

V. Kotari, K. Chang, George Mason Univ. (United States)

Underwater mines are inexpensive and highly effective weapons. They are difficult to detect and classify. Hence detection and classification of underwater mines is essential for the safety of naval vessels. This necessitates formulation of highly efficient classifiers and detection techniques. Current techniques primarily focus on signals from one source. Data fusion is known to increase the accuracy of detection and classification. In this paper, we formulated a fusion-based classifier and a Gaussian mixture (GM) based classifier for classification of underwater mines. The emphasis has been on SONAR signals due to their extensive use in current naval operations. The classifiers have been tested on real SONAR data from UC Irvine repository. The performance of both GM based classifier and fusion based classifiers clearly demonstrate their superior classification accuracy over conventional single source cases and validates our hypothesis.

8050-30, Session 5

Sequential fusion

C. M. Schubert Kabban, Air Force Institute of Technology (United States); K. E. Daly, Lewis and Clark College (United States); D. A. Zitelli, S. N. Thorsen, U.S. Air Force Academy (United States); M. E. Oxley, Air Force Institute of Technology (United States)

A classification system such as an Automatic Target Recognition (ATR) system might yield better performance when fused sequentially than in parallel. Most fused systems have parallel architecture, but, the medical community often uses sequential tests due to costs constraints. We define the different types of sequential fusion and investigate their characteristics. We compare parallel fused systems with sequential fused systems. Another goal of this paper is to compare competing sequential fused systems to arrive at an optimal architecture design given the systems at hand. These systems may be legacy systems whose performances are well known. If these systems have known Receiver Operating Characteristic (ROC) curves/manifolds then we derive a formula that yields the ROC curve/manifold for the resultant sequentially fused system, thus, enabling one to make these comparisons. This formula is distribution free. We give examples to demonstrate the utility of our method, and show that one can play “what if” scenarios.

8050-32, Session 6

Twelve dubious methods to solve a first-order linear (highly) underdetermined PDE for exact particle flow nonlinear filters

F. E. Daum, Raytheon Co. (United States)

We have invented a new theory of exact particle flow for nonlinear

filters. This generalizes our theory of particle flow that is already many orders of magnitude faster than standard particle filters and which is several orders of magnitude more accurate than the extended Kalman filter for difficult nonlinear problems. The new theory generalizes our recent log-homotopy particle flow filters in three ways: (1) the particle flow corresponds to the exact flow of the conditional probability density corresponding to Bayes' rule; (2) roughly speaking, the old theory was based on incompressible particle flow (like subsonic flight in air), whereas the new theory allows compressible flow (like supersonic flight in air); (3) the old theory suffers from obstruction of particle flow as well as singularities in the equations for flow, whereas the new theory has no obstructions and no singularities. Moreover, our basic filter theory is a radical departure from all other particle filters in three ways: (a) we do not use any proposal density; (b) we never resample; and (c) we compute Bayes' rule by particle flow rather than as a point wise multiplication. We have made hundreds of numerical experiments to test this new theory, using several classes of examples: quadratic & cubic nonlinearities of the measurements, stable & unstable dynamical systems, linear systems, multimodal probability densities, and radar tracking problems. It turns out that the computational complexity of particle filters (for optimal accuracy) depends on the following parameters, which we vary in our numerical experiments: dimension of the state vector of the plant, stability or instability of the plant (as gauged by the eigenvalues of the plant), initial uncertainty of the state vector of the plant, signal-to-noise ratio of the measurements, and the process noise of the plant. Particle filters generally suffer from the curse of dimensionality, whereas our filter substantially mitigates this effect for the examples studied so far, for plants with dimension up to 30. Other particle filters generally do not exploit any smoothness or structure of the problem, whereas our new theory assumes that the densities are twice continuously differentiable in x (the state vector of the plant), and we assume that the densities are nowhere vanishing.

We design the particle flow using the solution of a first order linear (highly underdetermined) PDE, like the Gauss divergence law. We analyze 11 methods for solving this PDE, including an exact solution for certain special cases (Gaussian and exponential family), solving Poisson's equation, separation of variables, generalized method of characteristics, direct integration, Gauss's variational method, optimal control, generalized inverse for linear differential operators, and a second homotopy inspired by Gromov's h-principle. The key issues are: (1) how to select a unique solution; (2) stability of the particle flow; and (3) computational complexity to solve the PDE.

8050-33, Session 6

Numerical results for exact particle flow filters

F. E. Daum, J. Huang, Raytheon Co. (United States)

We show numerical experiments on a new theory of exact particle flow for nonlinear filters. This generalizes our theory of particle flow that was already many orders of magnitude faster than standard particle filters and which is several orders of magnitude more accurate than the extended Kalman filter for difficult nonlinear problems. The new theory generalizes our recent log-homotopy particle flow filters in three ways: (1) the particle flow corresponds to the exact flow of the conditional probability density; (2) roughly speaking, the old theory was based on incompressible flow (like subsonic flight in air), whereas the new theory allows compressible flow (like supersonic flight in air); (3) the old theory suffers from obstruction of particle flow as well as singularities in the equations for flow, whereas the new theory has no obstructions and no singularities. Moreover, our basic filter theory is a radical departure from all other particle filters in three ways: (a) we do not use any proposal density; (b) we never resample; and (c) we compute Bayes' rule by particle flow rather than as a point wise multiplication.

8050-34, Session 6

The exact fundamental solution for the Benes filter: a Feynman path integral derivation

B. Balaji, Defence Research and Development Canada (Canada)

In prior work, it was demonstrated that the continous-time nonlinear filtering can be formulated and solved in terms of Feynman path integrals (FPIs). Specifically, it was shown that the fundamental solution for the continuous-discrete and continuous-continuous nonlinear filtering problems can be formally written in terms of the FPIs.

The FPI approach is particularly significant as it has played a central role in the advances in modern theoretical physics and many areas of modern mathematics. It was demonstrated that even the simplest and poorest approximation of the FPI provides a remarkably accurate solution when the time steps are small, which if often the practical case.

Although in general the FPI cannot be solved exactly, there are some cases where an exact solution is derivable. One such example is the quantum simple harmonic oscillator (QSHO) that is of fundamental importance in that it arises in several different areas in theoretical physics. The general FPI formula for the fundamental solution is used to show that the nonlinear filtering problem with Benes drift is related to the QSHO problem. The FPI is then manipulated directly to arrive at the exact fundamental solution.

The correctness of the solution is verified via simulations. The results are used to solve filtering problems with Benes drift but with nonlinear measurement models, using both sparse grid and Monte Carlo approaches. The resulting solutions are superior and more efficient than other solutions, such as those based on direct discretization of the SDEs.

8050-35, Session 6

Impact of radar system parameters on trajectory inference using stochastic context-free grammars

B. Balaji, A. Wang, Defence Research and Development Canada (Canada)

The GMTI tracking problem can be solved using the VS-IMM where the kinematic model, or mode, of the moving object depends on the road direction and the terrain type. Depending on the direction of motion, and hence the resulting target trajectory, the mode sequence computed by the VS-IMM can be viewed as a higher-level output of the tracker. In fact, the tracker of a radar may be viewed as a string generating device whose mode sequence outputs characterize target motion patterns based a stochastic context-free grammar (SCFG).

SCFGs have the ability to capture the long range dependencies and the recursively embedding structures in patterns by allowing more complicated rules than the Markov models. SCFG is more general than a Markov model and has lowest entropy. Finally, there exists parsers that can parse any string sequence arising from a SCFG in polynomial time.

In the previous paper, it was shown that the SCFG approach to trajectory inference was demonstrated for data collected using DRDC Ottawa's experimental airborne radar (XWEAR). The data used in the analysis was collected in a persistent surveillance scenario, which enabled good quality tracking (and meta-level tracking) even in the presence of many missed detections.

In this paper, the robustness of the SCGF-based automated trajectory inference is investigated against various realistic airborne GMTI system parameters such as measurement model errors, revisit time, and when the probability of detection is not unity. The various filtering algorithms, such as the UKF/CKF/PF and its VS-IMM variants are investigated.

8050-36, Session 6

The multitarget set JPDA filter with target identity

D. Svensson, L. Svensson, Chalmers Univ. of Technology (Sweden); M. Guerriero, Elettronica S.p.A. (Italy)

The Set JPDA (SJPDA) filter is a recently developed multi-target tracking filter that utilizes the relation between the density of a random finite set and the ordinary density of a state vector to improve on the Joint Probabilistic Data Association (JPDA) filter. One advantage with the filter is the improved accuracy of the Gaussian approximations of the JPDA, which result in avoidance of track coalescence. In the original presentation of the SJPDA filter, the focus was on problems where target identity is not relevant, and it was shown that the filter performs better than the JPDA filter for such problems. However, the filter is not restricted to such problems, and in this paper we show that the SJPDA filter can also be used for problems where labeling of targets is of interest, and that it has beneficial properties for those problems as well. The key aspect is that the filter is capable of presenting track-to-target probabilities. Thus, in difference to the JPDA filter which, although being very uncertain, presents the labeled tracks without uncertainties, the SJPDA filter can present the set of tracks together with the probabilities that they belong to each of the present targets. Apart from being of interest to the user, the label probabilities also enable a better description of the posterior density function. Further, we present simulation results for a two-target scenario with intermittently closely spaced targets and show the evolution of the average track-to-target probabilities of the SJPDA filter over time, for different track separations.

8050-37, Session 7

Information fusion measures of effectiveness for decision support

E. P. Blasch, P. Valin, E. Bossé, Defence Research and Development Canada (Canada)

For decades, there have been discussions on measures of merits (MOM) that include measures of effectiveness (MOE) and measures of performance (MOP) for system-level performance. As the amount of sensed and collected data becomes increasingly large, there is a need to look at the architectures, metrics, and processes that provide the best methods for decision support. In this paper, we overview some information fusion methods in decision support and address the capability to measure the effects of the fusion products on user functions. Decision support implies that information methods augment user decision making as opposed to the machine making the decision and displaying it to user. We develop a list of suggestion MOM that facilitate decision support.

8050-38, Session 7

Toward more robust exploitation of the asymmetric threat: binary fusion class extensions

R. T. Antony, SAIC (United States); J. A. Karakowski, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States)

The paper defines three distinct classes of binary fusion as an extension to an evolving first-principles-based theoretical fusion framework under development for several years. The three fusion classes are discussed relative to both conventional hard target and text-based information fusion applications. The paper's focus, however, will be on non-traditional data sources because of its importance to the development of a comprehensive fusion theory. The concept of entity specificity is then introduced to generalize the three-class fusion problem. Finally, fusion class 1 and 2 products from a prototype fusion system developed for the US Department of the Army are presented to clarify the concepts; class-3 fusion will be addressed more extensively in a future paper

8050-39, Session 7

Probabilistic programming for assessing capability and capacity

A. Pfeffer, S. A. Harrison, Charles River Analytics, Inc. (United States)

Answering the questions "What can the adversary do?" and "What will the adversary do?" are critical functions of intelligence analysis. These questions require processing many sources of information, which is currently performed manually by analysts, leading to missed opportunities and serious mistakes. We have developed a system for Assessment of Capability and Capacity via Intelligence Analysis (ACACIA) to help the analyst assess the capability, capacity, and intention of a nation state or non-state actor. ACACIA's approach is to construct a Bayesian network (BN) to model the objectives and means of an actor in a situation. However, a straightforward BN implementation is insufficient, since the objectives and means are different in every situation. Furthermore, we cannot simply construct a separate BN for every situation, since different situations might share some of the same elements, and we wish to apply knowledge about an element gained from one situation to another situation containing the same element. In addition, different elements of the same kind (e.g., means) share the same model structure with different parameters. We use probabilistic programming (PP) to address these issues. PP is an approach to probabilistic representation that uses the power of programming languages to construct models. Using the PP language Figaro, we construct a simple program that generates BNs for diverse situations while maximizing sharing. We use machine learning to learn the parameters of the program from training instances. Experiments show that ACACIA is capable of making reasonably accurate inferences and that machine learning effectively improves ACACIA's performance.

8050-40, Session 7

Effects of operation parameters on multitarget tracking in proximity sensor networks

Q. Le, Hampton Univ. (United States); L. M. Kaplan, U.S. Army Research Lab. (United States)

Proximity (or binary) sensors are simple devices that report whether or not they detect an object. A binary sensor can consist of a passive device such as an acoustic microphone where it reports a detection when the energy of the signal computed over an integration period exceeds a threshold. In essence, it acts as a tripwire sensor. In such a network, the no detection report is as valuable as a detection report. Previous work has revealed the potential of target localization via a mesh network of proximity sensors by proposing localization methods for the single target case. Our more recent work investigated the ability of the proximity sensor network to resolve and localize a known number of targets as a function of parameters such as sensor density and sensing range (or sensitivity). This paper extends our recent work by investigating the performance of multi-target tracking when the number of targets is not known a priori. Specifically, the paper investigates the performance of a modified version of the probability hypothesis density (PHD) filter for various operation parameter settings of the sensor model and network size. The PHD filter originally proposed by Mahler assumes that the measurements are associated to one target. The PHD filter is modified for proximity sensors where the measurements are intertwined with all targets in the scene. The goal of this work is to expose insights about how target separation distance, sensor density and sensor sensitivity affects PHD tracking performance.

8050-41, Session 8

An information matrix fusion (IMF)-based heterogeneous track-to-track fusion algorithm

X. Tian, Y. Bar-Shalom, Univ. of Connecticut (United States); E. P. Blasch, Defence Research and Development Canada (Canada); K. D. Pham, Air Force Research Lab. (United States); G. Chen, I-Fusion, Inc. (United States); Y. Ting, Univ. of Connecticut (United States)

In a distributed tracking system, the fusion of local tracks from local target states are used to obtain global track state estimates. In the literature, most Track-to-Track Fusion (T2TF) algorithms assume that local trackers use the same motion model (or the same set of models in the case of multiple model filtering) and that the local tracks are compatible with one another. However, there are exceptions where the motion models used by the local trackers are different which result in different target states. For example, one local tracker obtains range and angle target measurements using a radar, where the target motion is modeled in Cartesian coordinates using the position, velocity and acceleration. Another local tracker may use only angle and angle rate target measurements. The use of two different motion models raises the problem of Heterogeneous Track-to-Track Fusion (HT2TF). In this paper, we propose an Information Matrix Fusion (IMF) HT2TF. We assume that the local tracks, although being heterogeneous, are all consistent and are approximately independent. The IMF HT2TF algorithm fuses the information gains from the local tracks and improves tracking accuracy while maintaining consistency. The degradation in fusion accuracy due to the model mismatch will also be evaluated.

8050-42, Session 8

Object discovery, identification, and association

V. Kumar, Univ. of Missouri-Kansas City (United States); J. Metzler, M. H. Linderman, J. S. Jones, M. G. Alford, A. Bubalo, M. Scalzo, Air Force Research Lab. (United States)

A tracking process captures the state of an object. The state of an object is defined in terms of its dynamic and static properties such as location, speed, color, temperature, size, etc. The set of dynamic and static properties for tracking very much depends on the agency who wants to track. For example, police need a different set of properties to track people than the Air Force to track a vehicle. The tracking scenario also affects the selection of parameters. Tracking is done by a system referred to in this paper as a "Tracker." It is a system that consists of a set of input devices such as sensors and a set of algorithms that process the data captured by these input devices. The process of tracking has three distinct steps (a) object discovery, (b) identification of discovered object, and (c) object introduction to the input devices. In this paper we focus mainly on the object discovery part with a brief discussion on introduction and identification parts. We develop a formal tracking framework (model) called "Discover, Identify, and Introduce Model (DIIM)" for building efficient tracking systems. Our approach is heuristic and uses reasoning leading to learning to develop a knowledge base for object discovery. We also develop a tracker for the Air Force Research Laboratory program NCET.

8050-43, Session 8

Target signature agnostic tracking with ad-hoc network of omni-directional sensors

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Ad-hoc networks of simple, omni-directional sensors present an attractive solution to low cost, easy deployable, fault tolerant, target tracking systems. Due to power constraints, large amount of data exchanges between sensors are not desirable and only sufficient statistic should be sent. Additionally, the high possibility of tracking man-made targets necessitates that tracking algorithm is resilient to countermeasures. In this paper we present a tracking algorithm that relies on the measured signal power. Due to the fact that target signature is rarely stationary and possibly specifically crafted to avoid tracking, target power is not appropriate for adding to the system state equation, thus having to be estimated on the fly which reduces tracking quality. To remove target position dependency on the target power, a transformation to another coordinate system is introduced. Using a simple signal propagation model, analysis is conducted on the front-end processing on the sensor to derive noise statistics in the transformed space and demonstrate that the observation in the new coordinates is linear and with Gaussian noise. It is also demonstrated that for several widely accepted models for target movement, under certain conditions the proposed transformation produces a linear system model with additive Gaussian noise. As a result, the problem of sensing target position with omni-directional sensor can be adapted to the conventional Kalman filter framework. To validate the proposed methodology, simulations are conducted under different noise, target movement, and sensor density conditions. The presented results demonstrate that the proposed technique performs well and presents a viable solution for low-cost, power efficient target tracking.

8050-44, Session 8

A sensor reduction technique using Bellman optimal estimates of target agent dynamics

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Reducing the number of sensors in a sensor network is of great interest for a variety of surveillance and target tracking scenarios. The time and resources needed to process the data from additional sensors can delay reaction time to immediate threats and consume extra financial resources. There are many methods to reduce the number of sensors by considering hardware capabilities alone. However, by incorporating an estimate of environment and agent dynamics, sensor reduction for a given scenario may be achieved using Bellman optimality principles. We propose a method that determines the capture regions where sensors can be eliminated. A capture region is defined as a section of the surveillance field, where using a causal relationship to the other sensors, an event may be determined using fast marching semi-Lagrangian (FMSL) solution techniques. This method is applied to a crowded hallway scenario with two possible exits, one primary, and one alternate. It is desired to determine if a target deviates from the crowd and moves toward the alternate exit. A proximity sensor grid is placed above the crowd to record the number of people that pass through the hallway. Our result shows that the Bellman optimal approximation of the capture set for the alternate exit identifies the region of the surveillance field where sensors are needed, allowing the others to be removed.

8050-45, Session 8

Real-time sensor fusion technique for acoustic and seismic sensors

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Sensor fusion plays a vital role in many security applications and sensor networks. The feature level sensor fusion of passive acoustic and seismic sensor is well recognized in the litrature. In the approaches, both sensors need to be processed and extracted features individually and then fused the information using different standard algorithms. There are two problems in these approaches. One, in case of sensor network

applications where many seismic and acoustic sensors are deployed in different locations, the number of processing steps and the feature vectors are increased, hence these approaches are computationally expansive for real-time data. Second, if one of the sensor contain bad data, these approaches fail to recognize.

In this paper, a new approach is used to fuse the raw data of the acoustic and the seismic sensors based on correlation. This method distributes the weighted value based on the correlation energy of one signal with the other signal plus the correlation energy of the signal itself. Since the weighted value is direct proportion with the energy of correlation, we can calculate the weighted value of the acoustic sensor signal by calculating the correlation energy of that sensor with the siesmic sensor plus the correlation energy of the acoutic sensor itself and vice versa. Then multiply the weighted value of each sensor with its signal and add them to get the result of fusion. Since the weighted value is determined after performing correlation analysis for the real-time data so it adjusts the weighted values for every frame. The sensor that has bad data or failure state, has lower weighted value. Also the acoustic and the seismic sensors have different modalities, therefore we need to normalize the sensor's data in terms of desired mean and variance before applying this method so that the two sensor signals are adjusted with the same energy.

8050-67, Poster Session

Detecting large frequency weak signal in heavy noise background using nonlinear bi-stable system

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The stochastic resonance (SR) phenomenon of nonlinear bi-stable system (NBS) described by Langevin equation shows its unique advantage in detecting weak signals and provides a novel approach in weak signal detection. Nowadays, the application of detecting weak signals by NBS in large numbers of references are only fit for low frequency weak signal whose frequency are substantially less than 1Hz. Detection of large frequency weak signal under heavy noise is studied by NBS with numerical simulation in this paper.

The frequency of detecting weak signal is 500Hz and the signal-to-noise ratio (SNR) of input signal with heavy noise is -26.81 dB. With calculating numerically with appropriate parameters, the spectrum of output signal of NBS shows that the signal can be clearly observed and the output SNR is 14.29 dB. The results indicate that NBS is beneficial to large frequency weak signal detection and the SNR of weak signal can be improved consumedly. And further study results show that the noise with large frequency weak signal has been restrained intensively by the NBS. The larger the frequency is the more intensively restrained the noise is, which means that the NBS greatly restrains the high frequency noise and increases the output SNR. Meanwhile the noise is still strong in low frequency portion in the output spectrum. High-pass digital filtering technology is used to eliminate the influence of low frequency noise, and the detecting signal has been outstanding at time domain or frequency domain.

Based on this characteristic, a novel signal processing and recognition method is presented.

8050-68, Poster Session

Micro-Doppler analysis of human motion using 77 GHz radar

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During the past decade, there has been a large interest in new technologies for area surveillance, such as for detection and assessment of human activity in the vicinity of critical infrastructure sites. The approach in this work is by means of radar acquire Doppler information created by movements of parts of the human targets to detect and classify the targets, so called micro-Doppler. In the literature, work has been reported on using micro-Doppler for target characterization and classification. Many papers have been published about micro-Doppler signatures of human motion, e.g. [1, 2, 3, 4, 5, 6], as well as modeling of the micro-Doppler signatures by simple models of human gaits, e.g. [1, 2, 7]. Using both micro-Doppler and high range resolution is reported in [2, 8, 9]. At FOI we have earlier analyzed micro-Doppler of vehicles [10] and classified different human gaits using micro-Doppler [11]. We recently acquired radar data containing human micro-Doppler responses of one or two persons, with various ways and direction of movement and with or without carrying an object. A single or two persons at a time were moving diagonally toward or away from the radar as well as perpendicularly to the antenna boresight direction. The persons were walking or running without carrying an object, carrying a dummy weapon and walking/running with a blanket wrapped around the legs in order to conceal the legs. The radar used during the measurements is called SIRS 77 TD and is developed by SAAB. It is an FMCW (Frequency Modulation Continuous Wave) radar with a carrier frequency of 77 GHz. The measurement scenarios that were covered as well as the radar system used constitute a novelty compared to previous studies. The authors are confident that the achieved results will increase the knowledge about micro-Doppler signatures of humans, which is useful in the design of detectors and classifiers for radar-based area surveillance.

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8050-69, Poster Session

Study on recognition method based on distributed optical fiber sensor system

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A recognition method for intrusion events is studied, which is used in the distributed optical fiber sensor pre-warning system.In this pre-warning system,which is based on the principle of Sagnac optical fiber interferometer,an optical cable is laid along the monitoring area and the single mode optical fibers in the optical cable build up the distributed micro-vibrant measuring sensor. The system can judge whether intrusion events have occured by detecting the vibration signals along the area in real-time,extracting the eigenvectors of the vibration signals by the "energy" method based on time-frequency analysis and then recognized. Subsequently the positon of the intrusion events can be located. Finally,the data obtained at the area prove the effectiveness of this method.

8050-70, Poster Session

Visualization of hyperspectral images using bilateral filtering with spectral angles

J. Lee, A. Heo, W. Choi, S. H. Kim, D. Park, KAIST (Korea, Republic of)

In this paper, a new bilateral filter with spectral angles and a visualization scheme for hyperspectral images are presented. The conventional bilateral filter used to be implemented using a position vector and the intensity value at each pixel in the scene. Since hyperspectral image data can provide a spectrum vector which has hundreds of bands at each pixel, we propose a bilateral filter by using spectral angles. This bilateral filter with spectral angles can be used for extracting and preserving the spectrum edges of the hyperspectral image. The visualization scheme for hyperspectral images exploiting the bilateral filter with spectral angles has been also proposed. While the natural background is obtained by applying the conventional bilateral filter to ordinary images, the objects, which has the similar tristimulus intensity to the surroundings but a different spectrum, can be extracted by using the bilateral filter with spectral angles. The proposed scheme successfully separates these objects from the background. The simulation results show that the proposed scheme facilitates the anomaly detection and classification of objects in the hyperspectral scenes.

8050-71, Poster Session

Feynman path integrals, effective action, and metropolis-based Monte-Carlo methods for nonlinear filtering

B. Balaji, Defence Research and Development Canada (Canada)

In the standard approaches in filtering theory literature, the continuous filtering problem requires the solution of (stochastic) partial differential equations (PDEs). In particular, the Fokker-Planck-Kolmogorov forward equation needs to be solved for the continuous-discrete filtering problem and the relevant stochastic PDE is the Zakai stochastic PDE for the continuous-continuous filtering problem. The Feynman path integral (FPI) formulation of the continuous nonlinear filtering problem converts the solution of the (stochastic) PDE to a problem of solving an integral equation with the kernel provided by the FPI and is similar in form to discrete-time filtering. In other words, the FPI provides a unified framework to solve the discrete-time and continuous-time filtering problems. The FPI formulation also has the advantage of being more amenable to development of numerical algorithms.

In the terminology of statistical physics, the filtering problems naturally lead to "actions" that are arise from the state and measurement models. The action may be exactly known in a few cases, or an approximation may be used such as the Dirac-Feynman approximation, or some other improved action. Thus, filtering requires one to sample from the exponent of the effective actions, or Boltzmann function. Metropolis-type algorithms can be used to sample such Boltzmann functions, as in statistical physics, quantum mechanics and quantum field theory.

In this paper, some Metropolis-type algorithms are used to investigate nonlinear filtering performance. The performance is compared with other standard filtering algorithms in several (unimodal and multi-modal) examples, both in terms of complexity and accuracy.

8050-72, Poster Session

Target tracking based on video sequences

Y. Liu, Beijing Univ. of Posts and Telecommunications (China)

In view of the occlusion and real time in visual surveillance, a Camshift and Particle filter fusion algorithm is put forward based on multi-feature optimization. After particle propagation, it uses Camshift to optimize near the dynamic transformation center, which can get a new sampling sequence. Weight is calculated by Bhattacharyya distances of color feature and edge feature. It is to enhance the number of high weight in order to obtain a resampling sequence with high weight. Test analysis indicates that the method is robust to degeneracy problem and low computational complexity that can meet actual needs.

8050-73, Poster Session

Multiple model assignment for multipath-assisted multitarget tracking

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This study investigates the problem of multitarget tracking using multipath target returns from distinct and unknown propagation models. When multipath returns are not utilized appropriately within the tracker, (e.g., discarded as clutter or incorporated with incorrect propagation mode assumption) the potential information in the multipath returns is lost. Due to the higher variability in the measurements obtained from different multipath unknown reflection points, the classical single Markovian models are insufficient in addressing the aforementioned problem. The problem becomes more complex when non-target originated measurement returns are present due to false alarms or clutter. In this study, we propose a novel multiple model assignment approach in order to address the uncertainties associated with multipath returns. Moreover, we show the proposed method is capable of tracking multiple maneuvering targets by having a bank of multiple models each matched to different mode of target dynamics. Simulation results are presented to show the effectiveness of the proposed algorithm over single Markov models on a target tracking problem.

8050-74, Poster Session

Discussion and application of the homotopy filter

S. Choi, P. K. Willett, Univ. of Connecticut (United States); F. E. Daum, J. Huang, Raytheon Co. (United States)

Particle filters offer an intriguing way to solve non-linear/nonGaussian dynamic estimation problems, but they have limitations due to their inherent (and obvious) randomness. One popular and now quite old obviation is the unscented Kalman filter (UKF), in which the particles are "sampled" in a deterministic way. Another much more recent technique is the homotopy-based or particle-flow filter -- there is actually a whole family of such methods, so we will usually refer to these collectively in this paper as "DH" filters, after their developers and prime promulgators.

The DH filter does not (in principle) resample its particles. Instead, the particles are moved in a smooth way, from a space that reflects prior (predicted) knowledge to one that is updated according to the measurements.

The DH tracker has itself been rather difficult to track, owing to rapid development and often-radical retooling from its designers. However, working versions now exist, and the purpose of this paper is to attempt to explain some of this development an implementation, and to offer some comparison to other nonlinear filtering approaches.

Return to Contents

8050-46, Session 9

Sub-pixel registration of moving objects in visible and thermal imagery with adaptively thresholded segmentation

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Sub-pixel registration is critical in object tracking and image super-resolution. Motion segmentation algorithms utilizing the gradient can be applied prior to image registration to improve its accuracy and computational runtime. Instead of using a fixed threshold, adaptive thresholding is applied to segmentation to isolate small changes in regions inside a frame. In this paper, three motion segmentation and four image registration methods are tested to optimize the registration accuracy in visible and thermal imagery. Three motion segmentation methods, including difference product of an image set, flux tensor, and change in gradient over time, are quantitatively tested by comparing calculated regions of movement with accepted areas of motion.
Four image registration methods, including two optical flow, feature correspondence, and correlation methods, are tested in two steps: gross shift and sub-pixel shift estimations. 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. With fixed threshold, evaluations show that the flux tensor gives the best segmentation result and the feature correspondence and correlation registration methods produce top two most accurate sub-pixel registrations for well-defined objects. For not well-defined objects, the flux tensor gives noisy segmentation result and two optical flow and correlation methods produce the most accurate sub-pixel registration. The improvement of gross and sub-pixel registration through adaptive thresholding after motion segmentation is demonstrated using visible and thermal imagery.

8050-47, Session 9

Interactive target recognition in images using machine-learning techniques

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Imagery analysis systems utilize Automatic Target Recognition (ATR) methods in order to improve the accuracy of human-based analysis and save time. ATR performance with respect to these objectives varies greatly, depending on the applicability of the information it uses to on-site conditions. In many cases, ATR methods are developed off-line using limited prior information regarding specific targets, while human operators possess on-line updated information on targets that remains unused, and may have different targets in mind. In such cases, ATR holds little or no benefit for human-based analysis.

This paper presents an application for interactive target recognition (or ITR) in images, which utilizes the human operator's understanding of the scene. Its concept of operation consists of four stages: (a) An intuitive user-interface is used to acquire samples of target and background pixels from the imagery at hand; (b) The samples are fed into a machine-learning module that generates tailored algorithms for target recognition; (c) The tailored algorithms are applied to the imagery; (d) The results are displayed and dynamically controlled by the operator.

Should the image consist of several co-registered images, collected from various sensors, ITR enables ad hoc sensor fusion tailored to the operator's on-site needs.

The application is demonstrated on a set of airborne imagery. imagery analysis systems, designed for robust versatile work in limited-information environments, will benefit the most from ITR.

8050-48, Session 9

Optimal detection of objects in images and videos using electroencephalography (EEG)

D. Khosla, R. Bhattacharyya, P. Tasinga, D. Huber, HRL Labs., LLC (United States)

The "Rapid Serial Visual Presentation" (RSVP) protocol for EEG has recently been discovered as a useful tool for high-throughput filtering of images into simple "target" and "nontarget" categories [Thorpe, 1996]. This concept can be extended to the detection of objects and anomalies in images and videos that are of interest to the user (observer) in an application-specific context. For example, an image analyst looking for a moving vehicle in wide-area imagery will consider such an object to be "target" or "item of interest". The ordering of images in the RSVP sequence is expected to have an impact on the detection accuracy. In this paper, we describe an algorithm for learning the RSVP ordering that employs a user interaction step to maximize the detection accuracy while simultaneously minimizing false alarms. With user feedback, the algorithm learns the optimal balance of image distance metrics in order to closely emulate the human's own preference for image order. It then employs the fusion of various perceptual and bio-inspired image metrics to emulate the human's sequencing ability for groups of image chips, which are subsequently used in RSVP trials. Such a method can be employed in human-assisted threat assessment in which the system must scan a wide field of view and report any detections or anomalies to the landscape. In these instances, automated classification methods might fail. We will describe the algorithm and present preliminary results on real-world imagery.

8050-49, Session 9

Improved classification using image data fused via nonlinear dimensionality reduction

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We present a process for fusing multiple sensor modalities that leverages a nonlinear dimensionality reduction technique. In particular, diffusion map is used to embed high-dimensional images (or features from those images) as low-dimensional manifolds in an embedding space. We show that data taken from two different cameras looking at nearly the same scene, one operating in the visible domain, the other in the infrared, can be fused such that classification performance is improved. In this case, the sensors to be fused are composed of pixels containing scalar intensity data, although vector intensity data (as in hyperspectral imagery) can be handled as well. Each image is segmented into N x M sub-images that are treated as individual points in an N*M-dimensional space. The diffusion map technique is used to find an embedding that retains the essential relationships between the original points while using only the first D much less than N*M coordinates that truly represent different classes within the image. Each image taken with a different sensing modality is individually mapped into the same D-dimensional embedding space. The manifolds representing the images in this space can then be aligned and fused, accomplishing registration and fusion in a single step. The manifolds are aligned using an affine transformation and fusion is performed by, for example, adding the nearest neighbors from each manifold. Improved classification using a trained classifier such as a support vector machine is observed using the fused imagery. We describe the process for segmenting, embedding, and fusing the two images and present results.

8050-50, Session 9

Shape and texture fused recognition of flying targets

L. Kovács, Á. Utasi, A. Kovács, T. Szirányi, Computer and

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This paper presents a realtime image based method for detection and recognition of flying targets (e.g. planes, missiles) based on automatically extracted shape and object texture information for alerting, recognition and tracking. Targets are extracted based on robust background modeling and optical flow, objects recognition is done by comparisons to shape and texture based query results on a previously gathered real life object database, and multi-target tracking is performed by GPU-based KLT tracking. The application areas involve passive defense scenarios with cheap commodity hardware components (CPU, camera and GPS). The object detection uses background modeling robust against various noises and artifacts, e.g. clouds, lighting variations, vapor trails, etc. The object database is collected by automatic feature extraction on real life videos of planes, indexed into categories by a variation of BK-trees, with realtime retrieval. In the recognition phase, shape and texture information extracted from the database objects and the target are compared to provide a probable recognition, which is refined during the processing by augmenting the database with new object features. Application range depends on the resolution of the sensor and on the distance of the targets: in the case of small targets detection is performed, while the probability of recognition becomes higher when the target gets closer and when it can be viewed from multiple angles.

8050-51, Session 9

Millimeter-wavelength radar improves target identification

A. D. McAulay, Lehigh Univ. (United States)

Recently developed millimeter wave radar has advantages for target identification over conventional microwave radar which typically use lower frequencies. We describe the pertinent features involved in the construction of the new millimeter wave radar, the pseudo-optical cavity source and the quasi-optical duplexer. The long wavelength relative to light allows the radar beam to penetrate through most weather because the wavelength is larger than the particle size for dust, drizzle rain, fog. Further the mm wave beam passes through an atmospheric transmission window that provides a dip in attenuation. The higher frequency than conventional radar provides higher Doppler frequencies, for example, than X-band radar. We show by simulation that small characteristic vibrations and slow turns of an aircraft become visible so that the Doppler signature improves identification. The higher frequency also reduces beam width, which increases transmit and receive antenna gains. For the same power the transmit beam extends to farther range and the increase in receive antenna gain increases signal to noise ratio for improved detection and identification. The narrower beam can also reduce clutter and reject other noise more readily. We show by simulation that the radar can be used at lower elevations over the sea than conventional radar.

8050-52, Session 10

An optical tracker for the maritime environment

A. K. Bachoo, F. P. J. Le Roux, Council for Scientific and Industrial Research (South Africa); F. Nicolls, Univ. of Cape Town (South Africa)

Optical (visual) tracking is an important research area in computer vision with a wide range of useful and critical applications in defence and industry. The tracking of targets that pose a threat or potential threat to a country's assets and resources is a critical component in defence and security. In order to compliment radar sensing applications, an optical tracker provides additional functions such as target detection, target identification and intent detection at the visual level. A tracker for the maritime environment is an optical system that performs the automatic tracking of an above water target. Ideally, a track of the target is required for as long as is possible. Some examples of targets include boats, yachts, ships, jet-skis and aircraft.

A number of factors mitigate the performance of such a system - change in target appearance, target occlusions, platform vibration and scintillation in the atmosphere are some common examples. We present the implementation of a first generation system that is robust to platform vibration, target appearance changes and short term occlusions. The optical tracker is developed using a particle filter and appearance model that is updated on-line. The system achieves real-time tracking through the use of non-specialized computer hardware. Promising results are presented for a number of real-world videos captured during field trials.

8050-53, Session 10

Lane detection using road planar information

Q. He, Mississippi Valley State Univ. (United States); C. Chu, Univ. of Louisiana at Lafayette (United States)

Intelligent autonomous vehicles have been widely applied in the military, aerospace, and many other industries. These applications include land-mine detection for military and counterterrorism, patient transportation in hospitals, and many other dangerous works. One important capability of intelligent vehicles is navigation. The process of navigation is to extract environmental information and determine the appropriate motions to lead to the final destination. In practice, vision-based navigation plays a major role. In vision-based navigation systems, cameras, mounted on the vehicles, are the visual sensors. Path findings and plannings are accomplished from the image sequences captured by cameras.

Our work simplifies and improves the work by introducing road planar information. The following premises hold for paved roads.

1) Road surfaces are planar or could be approximated to be planar.

2) Road lanes are visible in the captured images even though shadows exist. So we can extract lanes through edge detectors.

3) Equal between-lane distance holds true.

4) If the road lanes are straight, then are equally spaced parallel.

5) All road lanes lie in one world plane and converge into a vanishing point.

We first detect all possible edges in the captured images. The straight lanes are extracted as straight lines. All parallel lines generate a vanishing point. Further, we recover the vanishing line on the road plane from equally spaced parallel lanes. All the road lanes and the vanishing line form a world plane. From property of parallelism of lanes in 3D space, the cross product among any two lanes equals to zero. Those detected lines with equal between-line distance, locating at a world plane with the vanishing line, will be regarded as the road lanes. Their experimental results show the computational efficiency and robustness against shadows and illumination variations in practice.

8050-54, Session 10

Detection and classification of poorly known aircraft with a low-resolution infrared sensor

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Knowledge of aircraft InfraRed Signature (IRS) is indispensable for assessing their detection probability, and thus their survivability in an hostile environment. For many reasons, the experimental approach is generally not feasible to evaluate the IRS dispersion. Computer programs, which enable to evaluate the IRS of aircraft and backgrounds, are therefore extremely valuable tools. Existing computer simulations of aircraft IRS do not account for the dispersion induced by uncertainty on input data, such as aircraft aspect angles and meteorological conditions. As a result, they are of little use to estimate the detection performance of IR optronic systems: in that case, the scenario encompasses a lot of possible situations that must indeed be addressed, but can not be singly simulated. In this paper, we focus on low resolution infrared sensors. The aircraft signature is vectorial, but only fills a small part of the image. We propose a methodological approach for predicting simulated infrared signature dispersion of poorly known aircraft, and estimating its detection probability. It is based on a sensitivity analysis, which identifies inputs that have negligible influence on the computed infrared signature and can be set at a constant value, on a Quasi-Monte Carlo survey of the code output dispersion, and on a level sets detection. Then, we perform a classification of different aircraft, thanks to Bayesian dense deformable template models estimation. This method is illustrated in a typical scenario, namely a daylight air-to-ground full-frontal attack by a generic combat aircraft flying at low altitude, and gives very satisfactory results.

8050-55, Session 10

Detection and classification of moving objects from UAVs with optical and IR sensors

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Small and medium sized UAVs like the German LUNA have long endurance and define in combination with sophisticated image exploitation algorithms a very cost efficient platform for surveillance. At Fraunhofer IOSB, we have developed the video exploitation system ABUL with the target to meet the demands of small and medium sized UAVs . Several image exploitation algorithms like multi-resolution, super-resolution, image stabilization, geo-coded mosaiking and stereo-images/3D-models have been implemented and are used with several UAV-systems.

Among these algorithms is the moving target indication (MTI) for real-time detection of moving objects with moving sensors, which will be the focus of this paper. Moving objects are of major interest during surveillance missions, but due to movement of the sensor on the UAV and small object size in the images, it is a challenging task to develop reliable detection algorithms under the constraint of real time demands on limited hardware resources.

Based on compensation of sensor motion by fast and robust estimation of geometric transformations between images, independent motion is detected relatively to the static background. By clustering the pixels of independent motion, regions of interest (ROIs) are generated as initial object hypotheses. False alarms (clutter) may occur due to changing illumination and aspect angles. Tracking is exploited to reduce the number of false alarms. In addition, a classification module is introduced to perform an appearance-based analysis of the ROIs. By extracting various texture features and testing different classifiers, we aim not only to reduce false alarms, but also to distinguish between object classes like vehicles and humans. Results are demonstrated with an experimental evaluation.

8050-56, Session 11

Adaptive statistical inferential methods for detection and classification in sensing systems

X. Chen, E. L. Walker, Southern Univ. and A&M College (United States)

In this paper, we investigate some fundamental problems of target detection and pattern classification in sensor systems. In many practical situations, the observational data may be expensive to acquire and the speed of decision can be affected by unnecessary amount of observational data. Motivated by the importance of accuracy and efficiency of sensor systems, we propose novel adaptive statistical inferential methods to reduce the amount of required observational data while achieving acceptable level of accuracy.

Toward this goal, we formulate the detection and classification problems in the general framework of multi-valued decision. In contrast to existing static methods, our approach is not based on a fixed amount of observational data. The classification and detection are performed in multiple stages. At each stage, the decision is made based on the data available on that stage. The data acquisition process is terminated if the decision can be made with acceptable level of reliability at that stage, otherwise next stage of observation is required. We have developed computational methods for the design of decision rules.

8050-57, Session 11

Channel-aware distributed classification using binary local decisions

M. Fanaei, M. C. Valenti, N. A. Schmid, V. K. Kulathumani, West Virginia Univ. (United States)

This paper considers the problem of distributed multi-hypothesis classification in the context of wireless sensor networks. The goal is to reliably classify the underlying hypothesis at a fusion center using very simple localized decisions at the individual sensor nodes. The decisions must be made despite the presence of faults both in local sensor decisions and in the transmission channels between the sensors and fusion center. Local sensor nodes make binary classifications based on their noisy observations and send their decisions to the fusion center through parallel additive Gaussian noise channels, and the fusion center uses these noisy local decisions to perform a global classification. In contrast with other similar approaches for multi-hypothesis classification with noisy binary decisions, our approach exploits the relationship between the influence fields of the different hypotheses and the accumulated local binary decisions as received by the fusion center. The main contribution is the formulation of local and fusion decision rules that maximize the probability of a correct global classification, along with an algorithm for optimizing the local and global decision thresholds. The performance of the proposed system is investigated through practical simulation scenarios. Simulation results show that the proposed approach could simplify decision making at the local sensors while achieving acceptable performance in terms of the global probability of correct classification.

8050-58, Session 11

Benchmark for detection algorithms of target signal observables with significant temporal characteristic

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We suggest methodolgy and benchmark for assessing the performance of detection algorithms based on temporal characteristic observable of the target signal. Using the generalized maximum likelihood (GMLT) test, we estimate a lower bound on the achievable performance and validate this by means of numerical simulations. We show that in certain cases our derived lower bound is approached by the best performing algorithms within a certain class.

The benchmark presented in this paper is based on a parametric model of the background, whose auto-correlation is identical to that of the data. After calibration, our model permits the use of the generalized maximum likelihood test.

8050-59, Session 11

Interacting multiple model estimators for tracking thousands of interacting, small targets in a complex plasma

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Tracking a large number of small targets is a challenging task. This work considers tracking approximately 3000 micron-sized particles in a complex plasma. Inter-particle screened-Coulomb interactions increase the complexity of the tracking problem, which is further complicated by highly nonlinear dynamics (such as a shock wave). Subsets of the particles are tracked in parallel by Interacting Multiple Model (IMM) estimators, with the results combined off-line. The IMM uses an extended Kalman filter (EKF) to perform the state estimation. From simulations, performance of the IMM estimators are compared with single EKFs, and track maintenance considerations are discussed.

8050-60, Session 11

Diversity detection in non-Gaussian noise employing the generalized approach to signal processing in noise with fading diversity channels

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In this paper, we consider the problem of M-ary signal detection based on the generalized approach to signal processing in noise over a single-input multiple-output channel affected by frequency-dispersive Rayleigh distributed fading and corrupted by additive non-Gaussian noise, modeled as spherically invariant random process. We derive both the optimum generalized detector structure and a suboptimal, reduced-complexity generalized detector applying the low-energy-coherence approach jointly with the generalized approach to signal processing in noise. Both generalized detector structure are canonical, i.e., they are independent of the actual noise statistics. We also carry out a performance analysis of both generalized receivers and compare with the conventional ones. The performance analysis is carried out with reference to the case that the channel is affected by a frequency-selective fading and for a binary frequency-shift keying signaling format. The results obtained through both a Chernoff-bounding technique and Monte Carlo simulations reveal that the adoption of diversity also represents a suitable means to restore performance in the presence of dispersive fading and impulsive non-Gaussian noise. It is also shown that the suboptimal generalized receiver incurs a limited loss with respect to the optimum generalized detector and this loss is less in comparison with the conventional receiver.

8050-61, Session 12

A survey of imagery techniques for semantic labeling of human-vehicle interactions in persistent surveillance systems

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Semantic labeling of Human-Vehicle Interactions (HVI) helps in fusion, characterization, and understanding cohesive patterns that when analyzed and reasoned, they may jointly reveal pertinent threats. Various Persistent Surveillance System (PSS) imagery techniques have been proposed in the past for identifying human interactions with various objects in the environment. Understanding of such interactions facilitates to discover human intentions and motives. However, without consideration of circumstantial context, reasoning and analysis of such behavioral activities is a very challenging and difficult task. This paper presents a current survey of related publications in the area of context-based HVI, in particular, it discusses taxonomy and ontology of HVI and presents a summary of reported robust imagery processing techniques for spatiotemporal characterization and tracking of human target in urban environments. The discussed techniques include model-based, shape-based and appearance-based techniques employed for identification and classification of objects. A detailed overview of major past research activities related to HVI in PSS with exploitation of spatiotemporal reasoning techniques applied to semantic labeling of the HVI is also presented.

8050-62, Session 12

A new research tool for hybrid Bayesian networks using script language

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While hybrid Bayesian networks become inevitable in real applications for complex systems, there are not much software tools to support it. Popular commercial Bayesian network tools such as Hugin, Netica, are either expensive or have to discretize continuous variables. In addition, some free programs existing in the literature, commonly known as BNT, GeNie/SMILE, etc, have their own advantages and disadvantages respectively. In this paper, we introduce a newly developed Java tool for model construction and inference for hybrid Bayesian networks. Via the representation power of the script language, this tool can build the hybrid model automatically based on a well defined string that follows the specific grammar. Furthermore, it implements several inference algorithms capable to accommodate hybrid Bayesian networks, including Junction tree algorithm for conditional linear Gaussian model, and direct message passing for general hybrid Bayesian networks. We conduct simulations with several typical hybrid models, and compare performance with other software. We believe this tool will be helpful for researchers in the field.

8050-63, Session 12

Indoor localization of medication packages using RFID

S. A. Mitilineos, G. E. Vastianos, O. E. Segou, D. M. Kyriazanos, S. C. A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece)

RF-based indoor localization is being thoroughly investigated during the past few years, since there is not yet an industry standard for accurate indoor localization and location based services (like the GPS for outdoor). Direction-of-Arrival (DoA), Time-of-Arrival (ToA), Received-Signal Strenth (RSS) and Ultra Wideband (UWB) techniques have been applied for indoor localization in recent literature, and techniques for accuracy improvement have been proposed [1-2]. Indoor localization of medication packages has been proposed within the context of the HMFM EU research project [3], in order to provide Ambient Assisted Living (AAL) services to elderly and visually impaired persons within their home environment.

More specifically, it is proposed that an RFID reading system, together with appropriate RFID tagging from the industry side, may provide localization of small and cheap medication packages. In order to overcome the need for multiple RFID readers and leverage costs for the end-user, it is proposed that an array of directional antennas is used instead, each of which covering a portion of the home environment. Input is obtained from each antenna sequentially, and the position of the medication package is calculated using either cell-id or scene analysis localization algorithms [1]. An experimental testbed has been setup within the premises of the National Center for Scientific Research “Demokritos”, comprising one RFID reader and 8 antennas covering a room with dimensions of . Initial experimental measurements resulted to average localization accuracies of less than 1.5m, which together with user-requirements input indicate that the proposed approach provides a sufficient means for indoor localization of medication packages for AAL platforms development.

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[2] Mitilineos, S.A., Goufas, J.N., Segou, O.E., and Thomopoulos, S.C.A., “WAX-ROOM: an indoor WSN-based localization platform”, Proceedings of the XIXth SPIE Conference on Signal Processing, Sensor Fusion and Target Recognition - SPIE Defense Security and Sensing 2010 Symposium, pp. 1-5, April 5-9, 2010, Orlando FL, USA.

[3] HearMe-FeelMe - “HMFM”, Research Project funded by the EU.

8050-64, Session 12

GPS signal modeling for location estimation in indoor environments using GPS repeaters

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RF-based indoor localization is rapidly emerging during the past few years, offering novel and value-added services to existing communications networks. Various techniques have been applied in the literature for indoor localization, including Direction-of-Arrival (DoA), Time-of-Arrival (ToA) and Received-Signal Strenth (RSS) based algorithms, as well as techniques for accuracy improvement [1-2]. However, there is not yet an industry standard for accurate indoor localization and location-based services like the GPS for outdoors.

Indoor localization of first responders has been proposed within the context of the DITSEF research project, in order to provide timely and efficient aftermath crisis management services in urgent situations [3]. To this end, extending GPS signal coverage indoors using repeaters has been proposed in order to develop seamless indoor-outdoor localization capabilities for continuity of service and leveraged accuracy [4]. However, propagation of GPS signals indoor is not sufficiently covered in the literature, due to the lack of indoor applications until now. In this context, an experimental testbed has been setup within the premises of the National Center for Scientific Research “Demokritos”, comprising GPS repeaters and receivers, a server for data collection and proprietary software for GPS-NMEA output decoding and measurements collection. Then, an experimental study of GPS signals indoor propagation in terms of Time-of-Arrival (ToA) and Received Signal Strength (RSS) is performed, taking into account repeater-receiver distance, multipath conditions, existence of walls etc. Furthermore, the repeater-generated signal repeatability is investigated under various environmental conditions, and conclusions are drawn regarding the feasibility of such a localization solution.

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[2] Mitilineos, S.A., and Thomopoulos, S.C.A., “Positioning accuracy enhancement using error modeling via a polynomial approximation approach”, Progress In Electromagnetic Research, Vol. 102, pp. 49-64, 2010.

[3] Digital & Innovative Technologies for Security & Efficiency of First responder operations - “DITSEF” (DITSEF-FP7-ICT-SEC-2007-1-225404), Research Project funded by the EU, http://www.ditsef.eu.

[4] Jardak, N. and Samama, N., “Indoor Positioning Based on GPS-Repeaters: Performance Enhancement using an Open Code Loop Architecture”, IEEE Transactions on Aerospace and Electronic Systems, Vol. 45, no.1, pp. 347 - 359, 2009

8050-65, Session 12

Low power, real time digital video stabilization using the HyperX parallel processor

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Coherent Logix has implemented a digital video stabilization algorithm for use in soldier systems and small unmanned air / ground vehicles that focuses on significantly reducing the size, weight, and power as compared to current implementations. The stabilization application was implemented on the HyperX architecture using a dataflow programming methodology and the ANSI C programming language. The initial implementation is capable of stabilizing an 800 x 600, 30 fps, full color video stream with a 50ms frame latency using a single 100 DSP core HyperX hx3100 processor running at less than 3 W power draw. By comparison an Intel Core2 Duo processor running the same base algorithm on a 320x240, 15 fps stream consumes on the order of 40+W. The HyperX implementation is an overall 100x improvement in performance (processing bandwidth increase times power improvement) over the GPP based platform. In addition the implementation only requires a minimal number of components to interface directly to the imaging sensor and helmet mounted display or the same computing architecture can be used to generate software defined radio waveforms for communications links. In this application, the global motion due to the camera is measured using a feature based algorithm (11 x 11 Difference of Gaussian filter and Features from Accelerated Segment Test) and model fitting (Random Sample Consensus). Features are matched in consecutive frames and a control system determines the affine transform to apply to the captured frame that will remove or dampen the camera / platform motion on a frame-by-frame basis.

8050-66, Session 12

Adaptive event detection for nonintrusive load monitoring

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Nonintrusive load monitoring (NILM) is a technique that monitors changes in the voltage and current going into a house and deducing what appliances are used in the house as well as their individual energy consumption. In this method, current and voltage sensor data are collected from the main electrical feed of a residential building. Normally the changes in steady state are used to describe in a distinct way the power draw of most home appliances of the time. In other words, when an individual appliance changes its state from off to on, for example, the average change in the total power of the house would be used to identify to the mentioned appliance. The NILM method has been demonstrated as an effective tool for evaluating and monitoring appliance energy usage in residential building or shipboard electro-mechanical systems.

In this paper, we develop a framework of adaptive event detection and classification of appliance from voltage and current sensor measurement in a real-world setting. We will develop a series of signal processing techniques including short time Fourier transform (STFT) and event detectors such as goodness-of-fit in order to maximize the detection of probability while controlling the level of false positive rate. We combine the transient signals as well as the steady-state signals from the current and voltage sensor reading in order to produce more accurate estimation of total energy assumption as well as the classification of different appliances.

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8051-01, Session 1

Fast synthetic aperture radar imaging with a streamlined 2D fractional Fourier transform

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The 2-D Fractional Fourier Transform (FRFT) has been shown to be applicable to the Synthetic Aperture Radar (SAR) imaging problem. Streamlined versions presented here make the 2-D FRFT comparable with and slightly faster than the Range Doppler (RD) and Extended Chirp Scaling (ECS) methods. The 2-D FRFT is streamlined by eliminating redundancy due to the fact that the same fractional angle is applied to each pulse in the SAR phase history's range dimension while one other fractional angle is applied across each range-gate in the phase history's azimuth dimension. Eliminating the redundancy and approximating the 2-D Fractional Fourier Transform operation in each dimension produces several streamlined 2-D FRFT methods as well as a very fast approximate 2-D FRFT. The computational order of the fast approximate 2-D FRFT is less than that of other corrective SAR imaging techniques. In practice the 2-D FRFT of N by M SAR phase history data requires kMNlog N + kMNlog M operations where k=480, while the streamline 2-D FRFT requires 10MNlog (M+N)+5MN operations and the approximate 2-D FRFT requires 10MNlog (M+N)+2MN+480(M+N) operations. Examples of SAR imaging with these streamlined and approximate 2-D FRFTs are given along with a comparison of the computational speed and impulse response (IPR) of the full, streamlined and approximate 2-D FRFT, and the RD and ECS methods of SAR imaging. The IRP of the 2-D FRFT algorithms is between that of the RD and ECS algorithm while the IPR of the approximate and streamlined 2-D FRFTs is somewhat better than that of 2-D FRFT.

8051-02, Session 1

A comparison of SAR imaging algorithms for high-squint angle trajectories

M. Horvath, B. D. Rigling, Wright State Univ. (United States)

This paper compare the back projection and polar format algorithms for SAR scene image reconstruction for missile-borne imaging scenarios. Missile-borne imagers introduce several complexities into the SAR image formation process because of their high, non-constant velocities, large squint angles, and typically non-straight flight paths. This paper discusses the effects of these complexities on both of the above mentioned algorithms. Computer simulations are used to demonstrate the findings using representative missile trajectories and simulated phase histories for ideal point targets.

8051-03, Session 1

Extensions to polar formatting with spatially variant post filtering

W. L. Garber, R. W. Hawley, Matrix Research Inc. (United States)

No abstract available

8051-04, Session 1

A butterfly algorithm for synthetic aperture radar imaging

L. Demanet, Massachusetts Institute of Technology (United States); M. Ferrara, N. Maxwell, J. Poulson, Matrix Research Inc. (United States); L. Ying, The Univ. of Texas at Austin (United States)

No abstract available

8051-05, Session 1

Ultrasonic tomographic imaging using a propagation and backpropagation method

Y. Jin, C. Dong, Univ. of Maryland Eastern Shore (United States); M. Ferrara, K. L. Priddy, Air Force Research Lab. (United States)

Tomographic imaging has wide applications in radar, optical and acoustical medical imaging. In tomographic imaging, the goal is to reconstruct target (scatterer) image from the measurement data, which can also be formulated as an inverse scattering problem. The problem we will address in this paper is image reconstruction from time-harmonic ultrasonic data, which requires determining the acoustical potential function of the scatterer in the Helmholtz equation Delta u + k^2 (1-f) u = 0 from boundary measurements of various solutions of the equation from different boundary conditions. In this equation, f determines the physical properties of the scatterer, while k is the wave number and u is the time-harmonic sound wave. Born and Rytov approximations have been used for some time to accomplish this task, but are not precise enough. We recognize that the above equation, as well as many other well known wave equations shows the bilinear structure, special numerical means can be developed to solve the acoustical inverse scattering problem.

In this paper, we develop an iterative numerical method for acoustical image reconstruction using the propagation and back-propagation method. We will show that this iterative method achieves fast convergence. In particular, the developed method is suitable for large wave number k (i.e., in the very high frequency region). We also utilize a recursive updating approach to calculate the acoustical potential function in 360 degrees on an imaging plane, thus achieving stable and fast convergence. Our algorithm will be verified by numerical models. The developed method can potentially lead to novel numerical approach for tomography applications in radar such as synthetic aperture radar in Giga Hertz region.

8051-06, Session 1

Aperture weighting technique for video synthetic aperture radar imaging

R. W. Hawley, W. L. Garber, Matrix Research Inc. (United States)

We present a technique for aperture weighting for use in video synthetic aperture radar (SAR). In video SAR the aperture required to achieve the desired cross range resolution typically exceeds the frame rate period. As a result there can be a significant overlap in the collected phase history used to form consecutive images in the video. Video SAR algorithms seek to exploit this overlap to avoid unnecessary duplication of processing. When no aperture weighting or windowing is used one can simply form oversampled SAR images from the non-overlapping sub-apertures using coherent back projection (or other similar techniques). The resulting sub-aperture images may be coherently summed to

produce a full resolution image. A simple approach to weighting for sidelobe control is to weight the sub-apertures during summation of the images. Our approach involves producing two or more weighted images for each sub-aperture which can be linearly combined to approximate any desired aperture weighting. In this method we achieve nearly the same sidelobe control as weighting the phase history data and forming a new image for each frame without losing the computation savings of the sub-aperture image combining approach.

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8051-07, Session 1

Video-like image exploitation for MISAR image sequences taken from small UAVs

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The miniature SAR-system MiSAR has been developed by EADS Germany for lightweight UAVs like the LUNASystem. MiSAR adds to these tactical UAV-systems the all-weather reconnaissance capability, which is missing until now. Unlike other SAR sensors, that produce large strip maps at update rates of several seconds, MiSAR generates sequences of SAR images with approximately 1 Hz frame rate.

A image exploitation approach for MISAR image sequences has already been presented in [1].

In [2], the ABUL system has been presented which is an experimental platform for the integration of advanced image processing modules like mosaicing, stabilization, and image enhancement. Furthermore, ABUL is suited for for photo interpreters (PI) of tactical drones with a user friendly MMI.

In this contribution, the adaption and extention of ABUL for MISAR image sequences from small UAVs is presented. The special characteristics of the images (e.g. stearing or paning from a non-stabilized platform, side looking mapping geometry of SAR) have to be managed both by the military PIs and by the image processing components.

Additional features like mosaic geocoding, superresolution, etc. have been optimzied for MISAR.

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8051-08, Session 1

3D ISAR imaging of objects through 2D rotations

Z. Qiao, G. Garza, J. Lopez, The Univ. of Texas-Pan American (United States)

In our paper, we study three dimensional Inverse Synthetic Aperture Radar (ISAR) imaging of objects through two dimensional rotations. ISAR is an equivalent form of SAR that consists of a set of stationary radar antennas and a moving target scene. A two-dimensional ISAR image with high resolution in the range dimension is achieved via wide-bandwidth transmissions, whereas high resolution in the azimuth direction is achieved via target translational and/or rotational motion. The case in which a target scene is rotating about a single axis of rotation has been studied in a great detail, and it has been shown that high-resolution 2D images of such a target scene can be formed using a mono-static/bi-static ISAR system. In this paper, we consider a second axis of rotation so that the target is undergoing rotational motion in two dimensions. Two algorithms for forming a 3D image of such a target scene are presented in detail. Our imaging algorithms are derived from a scalar wave equation model. The first of which is based on a far-field Fourier Transform inversion scheme, whereas the second algorithm is based off a filtered back projection inversion scheme, which does not require the use of a far-field approximation. Finally, we will show the 3D simulations for the two algorithms.

8051-09, Session 1

An algorithm for wide aperture 3D SAR imaging with measured data

F. A. Lee-Elkin, L. Potter, The Ohio State Univ. (United States)

Three dimensional (3D) airborne synthetic aperture radar (SAR) allows extraction of 3D scene features that may be useful to both automated algorithms and human observers. One of the greatest current technical challenges for typical 3D SAR sensors is that residual uncertainties in the radar position have a disastrous affect on 3D imaging. Limited success has already been achieved in addressing this challenge for narrow aperture 3D SAR and those results are utilized here. This paper describes a method in which 3D surfaces generated from narrow apertures are co-registered, non-coherently merged, and filtered to form a wide aperture 3D reflectivity surface estimate. Results from eight circular passes by an X-Band SAR sensor are shown.

8051-10, Session 1

Computationally efficient FBP-type direct segmentation of synthetic aperture radar images

H. C. Yanik, Z. Li, B. Yazici, Rensselaer Polytechnic Institute (United States)

In many applications, synthetic aperture radar (SAR) images are subjected to automated pattern recognition algorithms that require segmentation of the reconstructed images. A typical data processing chain includes image reconstruction followed by a segmentation step and pattern analysis. In this paper, we introduce a filtered-backprojection (FBP) type image segmentation method applied to SAR received signal that bypasses the image reconstruction step.

We first model the SAR received signal with an arbitrary flight trajectory as a Fourier Integral Operator (FIO). We next present an FBP-type method to recover and enhance the visible edges of the scene to be imaged. The FBP-type segmentation involves a backprojection step that is given by the L^2-adjoint of the phase of the FIO and a filtering step. We design the filter so that the resulting point spread function of the FBP operator is a differential operator behaving in a desirable manner for each pixel reconstructed.

While we focus primarily on the segmentation of SAR images, the method is applicable to other type of applications where the projection data are modeled as FIOs, such as synthetic aperture sonar and geophysical imaging.

8051-41, Session 1

Sparse near-field radar imagery for quick RCS analysis

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The Radar Cross Section quantifies the reflectivity of an object interacting with an EM wave. It is usually quantified indoor, i.e. inside anechoic

chambers, with scatterer maps generated by radar imagery. Classical reconstruction techniques, such as the Fourier-based polar format algorithm or backprojection methods, are slow. Indeed, they require many measurements, regularly and sufficiently spaced, in frequency and angle. Consequently, there are significant interests to develop fast RCS methods, which can be easily used outdoor and are able to deal with sparse measurements and various artefacts due to near field attenuation, antenna pattern, etc.

It is shown that in this context of attenuated and incomplete data, the scatterer map reconstruction is an ill-posed inverse problem. It can be solved with regularization methods, with the introduction of additional information. In which case, the map is produced by minimization of a criterion, including constraints and penalisations. It can also be considered in a probabilistic framework, leading to Bayesian inference and sampling methods. It is possible to evaluate the image reliability, i.e. the uncertainty on the scatterer map. It is illustrated for near-field RCS imaging system, based on a linear array.

8051-12, Session 2

Performance analysis of sparse 3D SAR imaging

C. Austin, R. L. Moses, The Ohio State Univ. (United States)

No abstract available

8051-13, Session 2

Toeplitz embedding for fast iterative regularized imaging

R. Ahmad, L. Potter, The Ohio State Univ. (United States)

No abstract available

8051-14, Session 2

Doppler synthetic aperture radar imaging

L. Wang, Nanjing Univ. of Aeronautics and Astronautics (China); B. Yazici, Rensselaer Polytechnic Institute (United States)

Traditional synthetic aperture radar uses wideband waveforms to provide high range resolution. We consider a synthetic aperture radar imaging system where the transmitter transmits ultra-narrowband or single-frequency continuous waveforms. Due to the high-Doppler-resolution nature of the transmitted waveforms, we refer to the system under consideration as Doppler synthetic aperture radar (DSAR).

As compared to the traditional SAR system, DSAR requires a relatively simple and low-cost transmitter, and in some cases does not even need a dedicated transmitter. Existing electronic signals, such as radio and television signals and cell phone signals can be used as the illumination sources of DSAR. These waveforms are continuous, ultra-narrowband, and have high Doppler resolution.

Radar imaging with ultra-narrowband waveforms has been presented in the literature before [1-6]. The imaging of rotating objects using a single-frequency continuous wave (CW) illumination was investigated theoretically in [1,2] ,and recently studied experimentally in [3]. The imaging of stationary objects using ultra-narrowband or narrowband CW with spatially distributed radars has been studied in [4,5]. All of these studies use tomographic image formation methods that rely on trading the resolution achieved by bandwidth with the resolution achieved by spatial diversity. An alternative approach to mono-static synthetic aperture imaging using high-Doppler-resolution measurements was discussed in [6]. However, both the resolution analysis and the imaging method presented are limited to the straight flight path and flat topography. Furthermore, an approximate implementation of imaging method based on Radon-Hough transform relying on detecting the lines associated with scatterers is not applicable in practice.

We present a novel filtered-backprojection (FBP) type image formation method for bi-static DSAR. Our method first correlates the received signal with a scaled or frequency-shifted version of the transmitted signal over a finite time window. The high-frequency analysis of the resulting model shows that the correlated received signal is the projections of the scene onto the bi-static iso-Doppler curves. We use microlocal techniques to develop a FBP reconstruction of the scene. The analysis of the point spread function (PSF) of the imaging operator shows that the reconstructed images preserve the location and orientation of the singularities at the intersection of the bi-static iso-Doppler and iso-Doppler-rate curves. We show that the resolution of the image is directly related to the length of the support of the windowing function, the carrier-frequency of the transmitted waveform, and the sampling rate of the aperture. Unlike the previous approaches in the literature, [1-6], our approach backprojects the correlated received signal onto iso-Doppler curves as opposed to iso-range curves, and takes advantage of the velocity as well as the acceleration of the antennas in a certain direction to form a high resolution SAR image using ultra-narrowband waveforms. We present numerical experiments to validate the theoretical analysis and demonstrate the performance of the image reconstruction method.

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8051-15, Session 2

Combining synthetic aperture radar and space-time adaptive processing using a single-receive channel

C. Bryant, Matrix Research Inc. (United States); E. Ertin, L. Potter, The Ohio State Univ. (United States)

No abstract available

8051-16, Session 2

Observations of clutter suppression in bistatic VHF/UHF-band synthetic-aperture radar

L. Ulander, B. Flood, P. Frölind, A. Gustavsson, T. Jonsson, B. Larsson, D. Murdin, R. Ragnarsson, G. Stenström, Swedish Defence Research Agency (Sweden); R. Baqué, H. Cantalloube, P. Dreuillet, O. Ruault du Plessis, ONERA (France)

Double-bounce scattering is often a dominating scattering mechanism in VHF/UHF-band synthetic-aperture radar (SAR), for example, in HH-polarized images of forestland and buildings. A vertical tree or wall standing on horizontal ground provides a large radar cross section for a monostatic radar in the backscattering direction through the double-

bounce mechanism. In such situations, bistatic SAR will offer a significant advantage compared to monostatic SAR since the double-bounce reflectivity decreases by separating the incident and scattering angle in the elevation plane (bistatic elevation angle). Typical targets, e.g. vehicles, have a smaller vertical extent above the ground and are thus less affected by a bistatic elevation angle. Observations in the lower VHF-band of these effects have been made in past research by employing an airborne transmitter and ground-based receiver. In this paper, we analyze new data collected by two airborne SAR systems operating in the high VHF- and low UHF-band. The Swedish SAR system LORA operated together with the French SAR system SETHI and collected data in different bistatic geometries using the frequency band 220-460 MHz and HH-polarization. The two systems were synchronized using the 1PPS GPS-signal which controlled the 10 MHz master oscillators. Data were collected over two test sites in Sweden including both forestland and buildings. The processed bistatic SAR images have been analysed and show clutter suppression as well as target-to-clutter enhancement over forestland and buildings, and the effect increases with bistatic elevation angle. The full paper will give supporting results.

8051-17, Session 2

Spatially variant interference suppression method based on superresolution algorithm for synthetic aperture radar

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Synthetic Aperture Radar (SAR) often suffers from interference from various radio sources. In general, notch filters or band elimination filters have been utilized to eliminate such interference signal; however, if the bandwidth of the interference signal is relatively wide, the gap in the spectrum caused by the band elimination filter could significantly distort the shape of the point spread function (PSF).

We propose an algorithm to suppress the interference with wide bandwidth while maintaining the image quality. Instead of completely suppressing the signal within the interference contaminated band, the proposed algorithm maintains the desired signal component. The algorithm applies to a SAR image and it consists of following steps: First, 2-D Fourier transform is applied to obtain the spatial frequency domain signal. Second, two dimensional Capon's minimum variance method is applied to the interference free band, and so called super-resolution image is generated. Third, a "mask pattern" is generated from the super-resolution image through a non-linear transformation. This mask pattern acts as an interference suppression filter which maintains the signals with high SCNR (Signal to Clutter and Noise Ratio) while suppressing the signal with low SCNR. By applying this mask pattern to the SAR image, the interference suppressed image is obtained.

The algorithm has been tested with a simulated interference contaminated image generated from a real 10cm resolution airborne Ku band SAR image. It has been shown that the image quality, the shape of the PSF corresponding to the high intensity signal, in particular, has been improved compared to the band eliminated image.

8051-18, Session 2

High-resolution interrupted SAR imaging via iterative adaptive techniques

D. Vu, L. Xu, J. Li, Univ. of Florida (United States)

Modern radar systems have multiple duties including searching, tracking and the automatic classification of targets. Switching in and out of these modes leads to an incomplete phase history data for synthetic aperture radar (SAR) imaging. This corruption of the phase history data is also prevalent during SAR missions facing high RF interferences. While reconstruction of SAR images is still possible, the imaging quality however will be severely degraded. In this paper, we present two high-resolution interrupted SAR imaging algorithms: the Iterative Adaptive Approach (IAA) and the Sparse Learning via Iterative Minimization (SLIM) method. Both algorithms are nonparametric/semi-parametric techniques, and can be used to significantly improve the interrupted SAR imaging quality, in terms of both imaging resolution and lower sidelobe levels, which is evidenced by SAR images with low ghost artifacts. In addition, we consider fast implementations of these algorithms using, for example, the Conjugate Gradient (CG) and Gohberg-Semencul (GS) factorization techniques. Our proposed algorithms fully exploit the Vandermonde structure of steering matrices and maximize the usages of the Fast Fourier Transforms (FFT), resulting in much lower computational complexities as well as much reduced memory requirements. We demonstrate the effectiveness of the SSR-based interrupted SAR imaging algorithms via several numerical examples, and also show that the proposed fast implementations can reduce the computational complexities and memory requirements by two orders of magnitude.

8051-19, Session 2

CBP-based multichannel autofocus for near-field SAR imaging

H. J. Cho, D. C. Munson, Jr., Univ. of Michigan (United States)

MultiChannel Autofocus (MCA) assumes that there exits a region of low return in the focused image and solves for the correction filter that minimizes the energy in the presumed low-return region. Provided that the low-return region is precisely known, the algorithm yields a superior restoration compared to other autofocus algorithms. Fourier-domain MCA (FMCA) is a generalization of this algorithm that works for wider ranges of look angles. However, both MCA and FMCA assume a planar wavefront, which makes them inapplicable to near-field imaging scenarios where there is significant amount of curvature.

We propose an autofocus algorithm that builds upon MCA, with a modification that takes into account wavefront curvature. In this setting, the demodulated data can no longer be interpreted as 2-D Fourier samples of the underlying image. Therefore, we make use of the linear relationship between the correction filter and the reconstructed image via Convolution Back-Projection (CBP) along curves.

Under the far-field assumption, our algorithm is equivalent to FMCA with a Jacobian-weighted 2-D periodic sinc-kernel interpolator when the presumed low-return regions are the same. While the performance of FMCA can be improved by using an optimal 2-D polar-to-Cartesian interpolator, our algorithm has the distinct advantage of being able to select the presumed low-return region within a continuous set of coordinates. We present simulation results showing that our algorithm outperforms other algorithms for various ranges of look angles and amount of curvature.

8051-20, Session 2

Windowing functions for focused range-Doppler imaging

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When one applies the standard Fourier technique to a rotating object, the result is smeared if the sampling window is too long (the object motion is not linear). The major obstacle is that windowing functions for sidelobe control require constant sample rates. There are techniques in the literature to "focus" the image for larger sampling windows by resampling and interpolating to make the data set look like a constant sampled linear doppler shift. Sidelobes are controlled but the resampling and interpolation creates artifacts in the result.

The method described in this paper takes a different approach. If we let R(t) = A exp(j sin (r t)) , be the return of a rotating object (r = rotation rate), then we can evaluate the transform F(x) = integral of R(t) exp(-j x sin(r t)). For sidelobe control, we show that standard window functions can still be used if a correction factor is applied. We derive the correction factor to the windowing function that allows constant sampling in the time domain and bypasses the issues of resampling and interpolation.

Examples of the technique are presented in the paper. Results with

Hamming weighting show a sidelobe level of -40 dB which mimics the performance of Hamming weighing when the scatterer motion is linear. As no assumption the weight function is assumed, any weighting function may be substituted. The method may be applied to a variety of applications including reentry vehicles and ground mapping.

8051-21, Session 2

A transformation between on-center and off-center point scatterers for circular synthetic aperture radar

L. J. Moore, Air Force Research Lab. (United States)

No abstract available

8051-22, Session 2

Two-stage backprojection on synthetic aperture radar data using multiple GPUs

W. Chapman, S. Ranka, S. Sahni, M. S. Schmalz, Univ. of Florida (United States); B. Elton, U. Majumder, L. J. Moore, Air Force Research Lab. (United States)

No abstract available

8051-40, Session 2

InSAR processing using a GPGPU

A. Rogan, R. Carande, Neva Ridge Technologies, Inc. (United States)

General purpose graphical processing units or GPGPUs have emerged in recent years as the power horse behind many large scale computing efforts. For example, the recent unveiling of the world's fastest supercomputer has achieved this feat by utilizing the lower cost and higher performing GPGPUs. Additionally, in the past year the synthetic aperture radar (SAR) community has started to utilize GPGPUs as well. The utilization of GPGPUs to date has been limited mainly to SAR image formation and in this capacity tremendous performance improvements over the same CPU based algorithm have been demonstrated. However, image formation is only one of many necessary steps towards SAR image exploitation. Image registration, filtering, interpolation and interferometric flattening are equally important steps in obtaining many of the desired output products such as coherence change detection (CCD) products and terrain adjusted interferograms. We will demonstrate that by transitioning the entire SAR image exploitation processing chain from image formation through product generation onto a GPGPU, it is possible to achieve more than an order of magnitude in performance improvements. In this paper we will review results presented at last year's SPIE conference regarding SAR image formation and present new results obtained for coherent exploitation of SAR data including CCD and interferometric SAR processing. In addition to presenting these results, we will discuss challenges associated with migration of CPU-based exploitation algorithms to the GPGPU environment, as well as to discuss possible future improvements using these powerful new devices and associated software tools.

8051-23, Session 3

Along-track interferometry for simultaneous SAR and GMTI: application to gotcha challenge data

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This paper is concerned with the detection and localization of slowly moving targets in cultural clutter using a circular SAR (CSAR) system. Here, the sensor platform orbits the area of interest along an imperfect circular trajectory, while interrogating the entire scene with continuous pulsed illumination (this is also known as "spotlight" mode). For large areas of interest a relatively wide transmitted beam is required, which increases the overlap in Doppler space between moving targets and stationary clutter. Thus, the detection of moving targets in clutter is a major challenge since nearly all target signatures will lie within the endo-clutter region. Images of moving targets are not well-focused using standard SAR processing since their signatures are blurred and warped as well as being spatially shifted in the cross-range coordinate. We have developed a novel clutter cancellation technique for CSAR moving target detection and localization which has shown promising results when applied to the Gotcha SAR-based GMTI Challenge data set. Our technique is a variation of "Along Track SAR Interferometry" (AT-InSAR) which, unlike STAP-based approaches, will be appropriate for challenging urban and/or mountainous environments where clutter is non-homogeneous across range bins. It is a single-pass technique that utilizes two or more channels which are spatially separated in cross-range. A new aspect of our approach vs. existing AT-InSAR is an improved means for estimating the range-rate and azimuth of target signatures which are Doppler-shifted to overlay strongly interfering clutter. Our approach is conceptually simple and computationally efficient since the main processing step is a 2-dimensional FFT.

8051-24, Session 3

Ground moving target indication via multichannel airborne SAR

D. Vu, B. Guo, L. Xu, J. Li, Univ. of Florida (United States)

We consider moving target detection and velocity estimation for multi-channel synthetic aperture radar (SAR) based ground moving target indication (GMTI). Via forming velocity versus cross-range images, we show that small moving targets can be detected even in the presence of strong stationary ground clutter. Furthermore, the velocities of the moving targets can be estimated, and the misplaced moving targets can be placed back to their original locations based on the estimated velocities. An iterative adaptive approach (IAA), which is robust and user parameter free, is used to form velocity versus cross-range images for each range bin of interest. Moreover, we discuss calibration techniques to combat near-field coupling problems encountered in practical systems. Furthermore, we present a sparse signal recovery approach for stationary clutter cancellation. We conclude by demonstrating the effectiveness of our approaches by using the Air Force Research Laboratory (AFRL) publicly-released Gotcha airborne SAR based GMTI data set.

8051-25, Session 3

Persistent SAR change detection with posterior models

G. E. Newstadt, Univ. of Michigan (United States); E. Zelnio, Air Force Research Lab. (United States); A. O. Hero III, Univ. of Michigan (United States)

No abstract available

8051-26, Session 3

Analysis of SAR moving grid processing for focusing and detection of ground moving targets

D. E. Hack, M. A. Saville, Air Force Institute of Technology (United States)

SAR Moving Grid Processing (SAR-MGP) is a SAR-GMTI technique that detects moving targets by hypothesizing a particular target motion, then imaging to a moving grid that simulates the same motion. The use of a moving image grid focuses rigid-body targets with equivalent motion while defocusing the stationary clutter background, improving the target signal-to-interference plus noise ratio (SINR) and increasing detectability. This paper investigates the detection performance improvement due to SAR-MGP for translating point targets moving in the presence of uniform clutter backgrounds. First, the mapping between a point target's kinematic state and its signature in the moving image grid is presented. Next, the detection problem is formulated as a likelihood ratio test in a manner similar to that presented by Newstadt et al. Detection performance is then evaluated through Monte Carlo analysis over different scenarios including varying degrees of mismatch between the hypothesized and actual target's translational motion, and different types and strengths of clutter background. The results are interpreted in terms of the composite SINR resulting from each scenario. Finally, SAR-MGP is applied to specific segments of the AFRL SAR-GMTI Challenge dataset. Due to the large number of possible target trajectories, SAR-MGP is appropriate when there is a priori information about expected target trajectories, such as when a target has a pre-existing track, or when performing trip-wire detection on specific road segments which have a priori vehicle velocity models. This paper concludes with a discussion about how SAR-MGP can be incorporated into such detection and tracking algorithms.

8051-27, Session 3

Waveform-diverse moving-target spotlight SAR

M. Cheney, Rensselaer Polytechnic Institute (United States); B. Borden, Naval Postgraduate School (United States)

We develop the theory for a synthetic-aperture radar that makes use of a variety of different waveforms. We consider the case when there are multiple targets moving independently in the scene while the radar data are acquired. We assume that the targets are moving linearly, but we allow the antenna to fly an arbitrary, known, flight path and allow it to transmit a sequence of arbitrary, known waveforms.

Our development is restricted to monostatic radar configurations, in which a single antenna is used for both transmitting and receiving. The problem is formulated in terms of forming an image in phase space, where the independent variables include not only the position of the target but also its vector velocity.

In our analysis, we deliberately include the case of waveforms whose duration is sufficiently long that the targets and/or platform move appreciably while the data are collected, and consequently the start-stop approximation is not appropriate.

A formula for phase space (position and velocity) imaging is developed, and we provide a formula for the point-spread function of the corresponding imaging system. This point-spread function is expressed in terms of the ordinary radar ambiguity function.

As an example, we show how the theory can be applied to the problem of estimating the errors that arise when target and antenna motion is neglected during the transit time of each pulse.

8051-28, Session 3

Passive imaging of moving targets using distributed apertures in multiple-scattering environments

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With the rapid growth of broadcasting stations, mobile phone base stations, communication and navigation satellites, as well as relatively low cost and rapid deployment of receivers, passive radar imaging using transmitters of opportunity has emerged as an active area of research in recent years.

A number of passive moving target detection and imaging approaches have been presented in the literature[1-18]. We present a new passive image formation method for moving targets using a sparse array of receivers and non-cooperative transmitters of opportunity operating in multiple-scattering environments, to reconstruct the distribution of targets in position and velocity spaces. To the best of our knowledge, our method is the first in the literature that exploits multiple-scattering for passive imaging of moving targets.

Without loss of generality, we use the shoot-and-bounce model to model the wave propagation in multiple-scattering environments. We develop a new passive measurement model that relates the Doppler as well as the delay information measured at a receiver location to the delay and Doppler information measured at other receiver locations due to a hypothetical moving target in position and velocity spaces. We use the new passive measurement model to address the moving target imaging problem as a position- and velocity-resolved binary hypothesis testing, which has its root in Generalized Likelihood Ratio Test (GLRT) [19, 20]. The test-statistic produced by the hypothesis testing can be viewed as a superposition of filtered, delayed and scaled (or dilated) correlations of measurements at different receivers. We use the position- and velocity-resolved test-statistics to form an image in position and velocity spaces. We analyze the resolution of the reconstructed images under different imaging scenarios including different number of receive elements (receivers) and different types of transmitted waveforms. Our analysis demonstrates the improvements in the point spread function of the reconstructed images when multiple scattering is exploited, as well as the potential artifacts and limitations. We present numerical simulations to verify the analysis and to demonstrate the performance of our passive moving target imaging algorithms.

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8051-29, Session 3

The physics of vibrating scatterers in SAR imagery

D. B. Andre, D. Blacknell, D. B. Muff, M. Nottingham, Defence Science and Technology Lab. (United Kingdom)

Measurement times for synthetic aperture radar (SAR) image collection can take from the order of seconds to minutes, and consequently the technique is subject to imaging artefacts due to variation in target Radar Cross Section (RCS) and target motion. For example imaged moving targets can be displaced and unfocussed. This is also the case for vibrating targets, where the vibration may be modulated in phase and amplitude either separately or together. Current understanding of this phenomenon can be somewhat esoteric however this paper puts forward and demonstrates a visual based explanation via the physics of vibrating scatterers in the Fourier domain of SAR images. The approach employs lines of constant target vibration phase, or isovibes, mapped onto the image Fourier support. Determining the isovibe gradient magnitude and direction allows the formation of a one-to-one mapping of the radar energy from the Fourier domain to the image domain. This is essentially due to the Fourier conjugate relation between phase ramps and displacements. Applications for this technique include tools for the discrimination and characterisation of vibrational scatterer artefacts to aid imagery analysts.

8051-30, Session 4

Low-complexity, rate-efficient SAR raw data compression

S. Rane, P. T. Boufounos, A. Vetro, Mitsubishi Electric Research Labs. (United States); Y. Okada, Mitsubishi Electric Corp. (Japan)

Synthetic Aperture Radar (SAR) Image Formation is a computationally expensive procedure that, in the case of satellite SAR, cannot be performed on board a satellite. It is thus necessary to transmit a large quantity of raw data to the ground station for processing. Satellite communication bandwidth restrictions necessitate significant compression for such a transmission, while computational constraints impose strict complexity requirements on the compression scheme. Unfortunately, raw data do not exhibit strong correlation patterns, and therefore are not as easily compressible as formed images.

In this paper we develop an efficient, yet lightweight, lossy compression scheme using transform coding followed by block-adaptive quantization and entropy coding. The implementation of our method is sufficiently lightweight to fit on two FPGA chips on-board the satellite. In addition, we explore the effect of design parameters, such as transform size, and lightweight on-board signal preprocessing, such as de-chirping, in the compression performance.

Although standard evaluation methods of compression schemes evaluate the rate versus distortion performance on the signal being compressed, this domain is not informative for SAR applications. Instead we measure the distortion in both the magnitude and the phase of the image, as reconstructed from the compressed raw data. We demonstrate that our approach has comparable or better performance with other significantly more complex state-of-the-art compression approaches.

8051-31, Session 4

Feature phenomenology and feature extraction of civilian vehicles from SAR images

C. Paulson, Univ. of Florida (United States); E. Zelnio, L. Gorham, Air Force Research Lab. (United States); D. Wu, Univ. of Florida (United States)

I know that this is after the deadline, but I was up at Wright Patterson AFB after the deadline and Ed Zelnio said that he wanted me to enter into the SPIE conference. First the abstract must go through public release before I can post it in here. Ed said just go ahead apply, but to use this as a place marker holding a spot.

8051-32, Session 4

Comparison of the HRRP phase gradient statistics between ships and sea surfaces using alpha-stable distribution

D. Jiang, X. Xu, BeiHang Univ. (China)

Phase fluctuation is one of the inherent characteristics of an extended radar target. In general, the phase gradient characteristic has much to do with a target's structure as well as its motion mode.

In this work, the complex high resolution range profiles (HRRPs) for a typical ship on time-varying sea surface are numerically generated and used for phase gradient analysis. The primary objective of this work is to compare the phase fluctuation characteristics of ships with that of the sea surface based on HRRPs. The statistics of the HRRP phase gradient are studied using alpha-stable distribution. Numerical simulation results show that the HRRP phase gradients of a ship on sea surface behave significantly different from that of the sea clutter, suggesting that the statistics of HRRP phase gradient statistics provides useful information for ship discrimination from sea clutter.

The paper consists of the following sections: 1. Introduction; 2. A Time-Varying Multi-Path Scattering Model; 3. Phase Gradient Calculation from High Resolution Range Profiles; 4. Phase Gradient Statistics; 5. Numerical Simulation and Analysis; References.

8051-33, Session 4

Prediction of coherent change detection performance in synthetic aperture imagery

D. Blacknell, D. B. Andre, Defence Science and Technology Lab. (United Kingdom)

Coherent Change Detection (CCD) is a powerful technique for detecting changes between two SAR collects. Since coherence uses complex correlation it is very sensitive to changes in phase between the two images. Thus, the phase changes from quite subtle ground disturbances

will result in a loss of coherence which can be detected against an undisturbed background. A key requirement for effective use of CCD is that the background remains coherent between the imaging collects. However, coherence loss can result from a number of factors. Firstly, the achievable coherence will decrease as the two collects diverge from the perfect situation of coincident geometries. Secondly, the background scene will vary over time dependent on the ground type and on environmental conditions. Thus there will be coherence loss over time so that CCD will become increasingly ineffective. In planning CCD collects, it is thus important to predict the achievable background coherence and hence the degree to which changes will be detectable.

A method of CCD performance prediction is described based on (1) a simple analysis of the frequency support overlap between the two collects which encapsulates the imaging geometry effects (2) a method of relating environmental effects to average scatterer disturbance which can be assessed empirically. The strength of this approach is that, once the average disturbance for a particular environmental effect has been established from one system, it can be extrapolated to all other systems since mean disturbance is system-independent. Validation and application of this approach using simulated examples will be presented.

8051-34, Session 4

Predicting the effectiveness of SAR imagery for target detection

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We present an image quality metric and prediction model for synthetic aperture radar (SAR) imagery that addresses exploitation both by automated tools such as automatic target detection (ATD), as well as imagery analysts. This paper describes the development of two separate General Image Quality Equations (GIQEs): one to predict Radar National Imagery Interpretability Ratings Scale (Radar NIIRS) and one to predict ATD performance. The NIIRS GIQE is most significantly influenced by resolution, depression angle, and depression angle squared. The inclusion of several image metrics is shown to moderately improve performance. Our development of an ATD GIQE showed that resolution and clutter characteristics (e.g., clear, forested, urban) are the dominant explanatory variables for predicting ATD performance. Inclusion of image metrics in the ATD model also increases modeling performance, with a significantly more pronounced improvement than for the NIIRS model. Our analysis shows that a relationship exists between ATD and NIIRS models, as indicated by a correlation coefficient of 0.69. However, this correlation is not strong enough to recommend a single GIQE be used to predict both the interpretability of an image by an analyst and the performance of an exploitation algorithm. The empirical analysis rests on a limited set of imagery data. We conclude with recommendations for model extension and validation.

8051-35, Session 4

Derived operating conditions for ATR performance understanding

J. Blackburn, Air Force Institute of Technology (United States); J. Mossing, A. R. Nolan, T. D. Ross, E. Zelnio, Air Force Research Lab. (United States)

Sensor data exploitation algorithms have non-intuitive performance sensitivities, partly because humans so effortlessly perform the desired exploitation. This failure of intuition has led to problems in performance characterization. To counteract this, the sensor exploitation (or ATR) community is making a special effort to explicitly treat “operating conditions” (OCs) in ATR assessments. OCs are the things that affect ATR performance. Although a subjective concept, OCs have proven to be a useful construct in empirical performance understanding. There is now a growing movement to capture ATR performance understanding in analytic or, at least, computational, models. These models take OCs as inputs and produce performance measures (Pd, Pfa, Pid, etc.). These models will typically take raw OCs, such as sensor resolution and target size, and compute “derived OCs”, e.g., pixels-on-target. The derived OCs play a role similar to that of features in a pattern recognition system. This paper introduces a categorization of derived OC dimensions that was suggested after 15 years of interpreting ATR test results. These categories include 1. clarity - information content of the sensor data, 2. uniqueness - degree of difference between the classes, 3. conformity - degree of similarity between ATR training and operational OCs, and possibly others. The clarity category is well developed by the sensor community, e.g., as image quality measures or sensor performance models. The others are less well developed, but pockets of relevant work exist and are brought into this context. The objective of this paper is to enrich and facilitate ATR performance theory and modeling dialog.

8051-36, Session 4

Joint sparse representation-based automatic target recognition in SAR images

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We propose an automatic target recognition (ART) method for multi-view SAR images by utilizing and generalizing the recently developed sparse representation and compressive sensing theory. Sparse representation based classification (SRC) method has been proven to be an effective classifier. In this paper, we generalize the SRC method to joint sparse representation based classification (J-SRC) method to explore the correlations between different views for improving the recognition performance. Experiments are carried out on Moving and Stationary Target Acquisition and Recognition (MSTAR) dataset to verify the effectiveness of the proposed method.

8051-37, Session 4

Target classification in synthetic aperture radar using map-seeking circuit technology

C. K. Peterson, P. Murphy, P. A. Rodriguez, The Johns Hopkins Univ. (United States)

Synthetic aperture radar (SAR) is a valuable intelligence asset because of its proven operational capability to image targets both day and night amid any type of weather. It provides precise geolocation accuracy and identification capability. Conventional target recognition approaches in SAR include template matching and feature-based classification approaches. However, unlike with visual imagery, SAR presents a unique challenge in that many features, such as scattering centers, are extremely pose dependent and can “wink” in and out even with minor viewing geometry changes. This makes standard dimensionality reduction techniques such as finding invariant subspaces much less effective. Instead, a high-dimensional state space must be accommodated in either the templates or features. The high dimensionality translates to computational costs that can preclude real-time processing on conventional processor hardware.

This work implements a highly efficient bio-inspired template-based approach, the Map Seeking Circuit (MSC) algorithm, for target recognition in SAR which has up to now only been applied to panchromatic and electro-optical imagery. MSC is based on neurobiological evidence that reciprocal forward and backward processing paths that can map 3D models into 2D images and vice versa are required to perform visual cognition. Instead of exhaustively searching the entire high dimensional transform space, the MSC searches a superposition hypersurface defined by the inner product of forward and backward superpositions involving adjustable weighting coefficients to estimate the location and 3D pose of targets of interest. We apply MSC to real SAR datasets to

show that the MSC is an effective and efficient approach for classifying targets.

8051-38, Session 4

Radar target classification using morphological image processing

J. A. Jackson, Air Force Institute of Technology (United States); P. Brady, Cedarville Univ. (United States)

Morphological processing is commonly used in image processing. We study its suitability for use in synthetic aperture radar (SAR) image enhancement and target detection. Morphological operations are defined by mathematical set operations. The dilation and erosion operations grow or shrink image features that match to a predefined structuring element. The opening and closing operations are combinations of successive dilation and erosion. These morphological operations can visually emphasize scattering of interest in an image. We investigate whether these operations can also improve target classification performance. We apply the same operator to both a test image and a reference image; then we compute the cross-correlation (matched-filter) between the two transformed images. We compare the results to the matched-filter response of the original images. If the match score increases, we declare an improved ability to detect a target. We apply the morphological operators to simulated and measured SAR data and evaluate target classification performance.

8051-39, Session 4

Automatic target recognition from highly incomplete SAR data

C. Du, G. Rilling, M. E. Davies, B. Mulgrew, The Univ. of Edinburgh (United Kingdom)

The automatic target recognition (ATR) performance of SAR with subsampled raw data is investigated in this paper. Two schemes are investigated. In scheme A, SAR images are reconstructed from subsampled data by applying compressed sensing (CS) techniques and then targets are classified using either the mean-squared error (MSE) classifier or the point-feature-based classifier. Both classifiers recognize a target by using the magnitude information of dominant scatterers in the image.

They fit nicely with the CS framework considering that CS approaches can efficiently recover the bright pixels in SAR images. In scheme B, the smashed-filter classifier is employed without image formation. Instead it makes the classification decision by directly comparing the observed subsampled data with data simulated from reference images. The impact of various subsampling patterns on ATR is investigated since CS theory suggests that some patterns lead to better performance than others.

Simulation results show that compared with SAR images formed by the conventional back-projection algorithm, CS reconstructed images always lead to much higher recognition rates for both the classifiers in scheme A. The MSE classifier works better than the point-feature-based classifier because the former takes into account both the magnitudes and locations of bright pixels while the latter uses the locations only. The smashed-filter classifier is computationally efficient and can accurately recognize a target even with strong subsampling if appropriate reference images are available. Its application in practice is difficult because it is sensitive to the phases of complex-valued SAR images, which vary too much for different observation angles.

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8052-01, Session 1

Requirements on active (laser) tracking and imaging from a technology perspective

J. F. Riker, Air Force Research Lab. (United States)

In the Science and Technology (S&T) community, we frequently pursue technologies that are perhaps not mature enough for operational transition in a number of areas. The area of active tracking and active characterization of space objects is one of those areas. In this paper, we will lay out the requirements on such tracking and imaging systems from a pure technology perspective, including top level scenario-driven requirements and tracing down to camera-level requirements. That is, we will consider the various components of the tracking and imaging mission only from a performance standpoint, and use that to derive some performance limitations on the system. The operational community will then have to decide whether such requirements are permissible in view of other constraints such as system cost.

8052-02, Session 1

HEL-JTO beam control technology research and development programs

D. C. Herrick, Air Force Research Lab. (United States)

The High Energy Laser Joint Technology Office (HEL-JTO) funds tri-service beam Control technology development appropriate for tactical laser weapons. This talk describes current R&D interests in tracking, beam pointing, boresighting, adaptive optics and physical phenomenology of interest to weapon designers. The research call and proposal process for Industry, Government and Academic institutions will be set out. Recently funded efforts will also be described.

8052-03, Session 1

Improved mission effectiveness of HEL systems with phased array beam control

K. Probst, Core Group, Inc. (United States)

Phased Array systems are attractive candidates for future HEL weapons. The beam control and imaging technologies for these systems are evolving rapidly. Current concepts provide for random access beam pointing, multiple beam formation and control, scaled lethality levels, multiple simultaneous aimpoints and engagements, and multi-functionality for each subaperture. This paper will look at the impact of these unique capabilities of phased array systems on overall HEL weapon mission effectiveness in multiple target environments. Short and long range missions will be evaluated for airborne, ship based, and ground based applications. Advantages and drawbacks of phased array systems will be discussed, and emerging beam control and imaging technologies relevant to phased arrays will be reviewed.

This abstract for a proposed DEPS presentation discusses DARPA sponsored work conducted under the Adaptive Photonic Phase Locked Element Program (APPLE) managed by DARPA/MTO.

8052-04, Session 1

Conformal apertures: concepts and requirements

E. A. Watson, Air Force Research Lab. (United States)

An architecture for a conformal aperture that is based on a collection of subapertures will be considered. Requirements for the subapertures, such as phasing, steering, and time delay will be addressed.

8052-05, Session 1

Influence of aero-optical disturbances on acquisition, tracking, and pointing performance characteristics in laser systems

M. R. Whiteley, MZA Associates Corp. (United States)

No abstract available

8052-06, Session 1

Multi-aperture coherent imaging

N. Miller, Ladar and Optical Communications Institute (United States)

Airborne imaging systems strive to provide both high angular resolution images and low system volume/weight. An imaging system composed of multiple, small apertures has the potential to acheive both aims. We describe the design of a coherent imaging sub-aperture which uses a digital holographic technique to measure both the amplitude and phase of the target return wavefront. We describe how the complex fields measured at each of the spatially separated apertures are synthesized into a composite image whose angular resolution exceeds that of an image from a single sub-aperture. We present experimental results of imaging extended targets (2D resolution charts and 3D scale models) at simulated ranges of a few kilometers using an indoor compact range designed for this purpose. We also present preliminary experimental results of imaging through turbulence simulated by phase screens in our indoor compact range. We discuss the potential advantages of using multi-aperture imaging systems over monolithic aperture systems in the presence of atmospheric turbulence.

8052-07, Session 2

Preliminary performance comparison of a synchronous and an asynchronous multisensor tracker

A. T. Alouani, Tennessee Technological Univ. (United States)

This paper uses simulated target tracks to compare the performance of two track fusion approaches: synchronous and asynchronous. The synchronous track fusion is known as the Bar- Shalom-Campo fusion rule. The asynchronous track fusion is recently developped via collaboration between the author and reserachers from NSWC.

It is first shown that the Bar- Shalom-Campo fusion rule can be derived as a special case of the proposed asynchronous one. Then the impact on track quality of ignoring asynchronicity, when synchronous track fusion is used with asynchronous sensors, is evaluated using Monte Carlo simulations.

8052-08, Session 2

Track initialization for multistatic active sonar systems

C. G. Hempel, T. Luginbuhl, S. C. Schoenecker, Naval Undersea Warfare Ctr. (United States)

Modern sonar receiver buoys can provide useful estimates of the range and bearing angle of echoes from multi-static active transmissions. System concepts involving large numbers (i.e., 25 or more) of receiver buoys and multiple source buoys have been investigated via simulation. These system architectures pose serious challenges for the designers of tracking algorithms especially when the data contains significant amounts of clutter and can be transmitted to a central location and registered to a common frame of reference. In particular, most existing track initialization methods will either initialize far too many tracks, or have difficulty initializing low SNR contacts, or fail to operate in real time from excessive computational burden.

This paper investigates several modifications of a track initialization method developed by one of the authors for mono-static applications based on applying Page's test to data partitioned into Hough Transform bins. Prior applications of this method to simulated multi-static data involved relatively few receivers which allowed the data from each receiver to be processed sequentially as individual scans. When the number of receivers is greater and the clutter density is moderate (e.g., one false detection per 5 square kiloyards) or worse this method fails to process in real time on modern work station computers.

Two modifications are considered here: forming the Hough bins in a lower dimensional space and combining the data from each receiver at each transmission cycle and processing it as a single update. In the mono-static application the Hough bins are formed in the four dimensional space of position, course and speed. Here the dimension of the Hough bin space is reduced to two; the traditional range and angle space. This reduces the total number of Hough bins formed and hence the computational burden but may not localize the target requiring additional processing of the data in the Hough bin where the target was detected to fully initialize the track. The other modification is to incorporate the independent assignment model used in the Probabilistic Multi-Hypothesis Tracking (PMHT) algorithm in the formulation of Page's test to handle the eventuality of having multiple target detections in a combined scan of data. High fidelity multi-static simulated data sets from the Multi-Static Tracking Working Group (MSTWG) will be used to assess the viability of the modified track initialization algorithm for the intended applications.

8052-10, Session 2

Simulations of a hybrid active-segmentation and Fitts correlator tracker

J. Riley, MZA Associates Corp. (United States)

No abstract available

8052-11, Session 2

HEL-generated extinction effects and degradation of USAF BILL/TILL-ATR multispectral infrared algorithms (case study GHADR 110)

C. A. Paiva, BSM Research Associates (United States)

This comprises continued research addressing missile exhaust plume ionization; such ionization as a function of altitude, exhaust plume expansions, reverse exhaust flows and HEL-generated plasma. It is demonstrated that these processes affect the USAF multi-wavelength Discriminating Interceptor Technology Program (DIT)'s infrared and millimeter wave fused system. Target case study is the Iranian IRBM (extended range) liquid/solid propellant: GHADR 110. Boost-phase missile exhaust plumes have been shown to generate a variety of very challenging exhaust-plasma and electromagnetic extinction effects. As a result the HEL fluence (energy in the bucket), and is expected to also decrease in intensity. The overall engagement event results in HEL plasma-plume plasma interactions (absorption-scattering) reducing energy on the infrared focal plane. Specifically such exhaust 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). Missile expanded and reversed exhaust plumes are shown to generate very severe propagation extinction fields within the Prandtl-Meyer and HEL engagement regimes. This further results in inadequate automatic target recognition and pattern reference library efficiencies. Unique plasma-plasma interactions occur when non-symmetric 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 missiles, and dedicated 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 designators and primaries. 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 after-burning characterizations for the new boost-phase Iranian: GHADR-110, and North Korean TAEPODONG-2/III ICBM missile systems which are in production.

8052-12, Session 2

Performance analysis of embedded real-time video tracking systems

D. A. Scott, O. Mise, GE Intelligent Platforms (United Kingdom)

Video tracking architectures for small low-power embedded systems are severely constrained by their limited processing capacity and must therefore be highly efficient to meet modern performance requirements. Consequently the various design trade-offs have a direct impact on the overall system performance. Some of the more critical architectural aspects concern issues such as the maintenance of multiple independent tracks, cue-to-track handover processes, internal bandwidth allocation and also sequential versus concurrent scheduling methods.

In this paper we present a comparative analysis of the overall tracking system performance between a newly developed video tracking architecture designed specifically for high performance applications and its widely field-proven predecessor. In each case the embedded systems are required to robustly track multiple targets and accurately control the sensor platform in real-time. The key focus is on evaluating the different system behaviours through simulation and testing and then analysing the results to identify how the various design methodologies affect the overall performance.

The evaluation in based on test framework and a set of metrics for estimating tracking performance. Conventional metrics appropriate to multi-target video-tracking applications have been selected to provide a generalized and meaningful characterisation of the system and also to allow easier comparison with other video tracking systems. The selected set is extended further with additional architecture-specific metrics to extract a finer level of granularity in the analysis. The tracking system is evaluated within the test framework using a broad spectrum of real and synthetic video imagery across multiple scenarios.

8052-13, Session 2

Passive ranging of dynamic rocket plumes using infrared and visible oxygen attenuation

R. A. Vincent, M. R. Hawks, Air Force Institute of Technology (United States)

Atmospheric oxygen absorption bands in observed spectra of boost phase missiles can be used to accurately estimate range from sensor to target. One method is to compare observed values of band averaged absorption to radiative transfer models. This is most effective using bands where there is a single absorbing species. This work compares spectral attenuation of two oxygen absorption bands in the near-infrared (NIR) and visible (Vis) spectrum, centered at 762nm and 690 nm, to passively determine range. Spectra were observed from static tests of both surface-to-air missile simulators at 405m range and a full-scale solid rocket motor at 900m range. The NIR O2 band provided range estimates accurate to within 3% for both tests, while the Vis O2 band had range errors greater than 15%. A Falcon 9 rocket launch at an initial range of 13km was also tracked and observed for 90 seconds after ignition. The Vis O2 band provided dynamic range estimates accurate to within 8% error for the first 30 seconds of tracked observation. The NIR O2 band, however, overestimated dynamic range with an error no less than 20%. Rocket plumes are expected to be significantly brighter at longer wavelengths, but absorption in the NIR band is nearly ten times stronger than the Vis band, causing saturation at shorter path lengths. An atmospheric band is considered saturated when all the in-band frequencies emitted from the rocket plume are absorbed before reaching the sensor. The trade between signal to noise and saturation is discussed. Additionally, since response time is paramount for boost phase missile defense, methods for reducing dependence on line-by-line algorithms to speed calculations are also presented.

8052-14, Session 2

Quantitative analysis of the improvement in high-zoom maritime tracking due to real-time image enhancement

A. K. Bachoo, J. P. de Villiers, Council for Scientific and Industrial Research (South Africa); F. C. Nicolls, Univ. of Cape Town (South Africa); F. P. J. Le Roux, Council for Scientific and Industrial Research (South Africa)

This work aims to evaluate the improvement in the performance of tracking small maritime targets due to real-time enhancement of the video streams from high zoom cameras on pan-tilt pedestal. Due to atmospheric conditions these images can frequently have poor contrast, or exposure of the target if it is far and thus small in the camera's field of view. A 300mm focal length lens and machine vision camera were mounted on a pan-tilt unit and used to observe the False Bay near Simon's Town, South Africa. A ground truth data-set was created by performing a least squares geo-alignment of the camera system and placing a differential global position system receiver on a target boat, thus allowing the boat's position in the camera's field of view to be determined. Common tracking techniques including level-sets, Kalman filters and particle filters were implemented to run on the central processing unit of the tracking computer. Image enhancement techniques including multi-scale tone mapping, interpolated local histogram equalisation and several sharpening techniques were implemented on the graphics processing unit. This allowed the 1.3 mega-pixel 20 frames per second video stream to be processed in real-time. A quantified measurement of each tracking algorithm's robustness in the presence of sea-glint, low contrast visibility and sea clutter - such as white caps - is performed on the raw recorded video data. These results are then compared to those obtained using data enhanced with the algorithms described.

8052-15, Session 2

Quantitative analysis of the improvement in omnidirectional maritime surveillance and tracking due to real-time image enhancement

J. P. de Villiers, A. K. Bachoo, Council for Scientific and Industrial Research (South Africa); F. C. Nicolls, Univ. of Cape Town (South Africa); F. P. J. Le Roux, Council for Scientific and Industrial Research (South Africa)

Tracking targets in a panoramic image is many senses the inverse problem of tracking targets with a narrow field of view camera on a pan-tilt pedestal. In a narrow field of view camera tracking a moving target, the object is constant and the background is changing. A panoramic camera is able to model the entire scene, or background, and those areas it cannot model well are the potential targets and typically subtended far fewer pixels in the panoramic view compared to the narrow field of view. The outputs of an outward staring array of calibrated machine vision cameras are stitched into a single omnidirectional panorama and used to observe False Bay near Simon's Town, South Africa. A ground truth data-set was created by geo-aligning the camera array and placing a differential global position system receiver on a small target boat; allowing its position in the array's field of view to be determined. Common tracking techniques including level-sets, Kalman filters and particle filters were implemented to run on the central processing unit of the tracking computer. Image enhancement techniques including multi-scale tone mapping, interpolated local histogram equalisation and several sharpening techniques were implemented on the graphics processing unit. An objective measurement of each tracking algorithm's robustness in the presence of sea-glint, low contrast visibility and sea clutter - such as white caps - is performed on the raw recorded video data. These results are then compared to those obtained with the enhanced video data.

8052-16, Session 3

New generation inductive position encoding techniques for EOI, radar, and missile systems

M. A. Howard, Zettlex UK Ltd. (United Kingdom)

Optical encoders offer good measurement performance but are often too delicate for many defense and security applications.

Inductive devices such as resolvers and linear transformers are a more robust alternative and have been the engineer's traditional choice since the 1950s. Nevertheless, they are bulky, heavy, expensive and lack precision.

A new generation of inductive technology offers reliable, high precision position measurement in harsh environments. Such environments may include extreme temperatures, foreign matter, aggressive chemicals, electromagnetic radiation, harsh shock or vibration.

The new techniques have recently been deployed in some European UAVs, missiles and EOI/ISTAR equipment. Compared to traditional inductive techniques, the new approach offers >90% weight and volume reduction as well as a step change in measurement performance.

The new technqiues use thin, flexible printed constructions which can be arranged to measure displacement in up to 6 axes. Key to the high measurement performance is the technique's stability and insensitivity to environmental variation. The printed components require no special seals, protective housings, bearings or precison installation. Further, such devices can be embedded within composite structures.

8052-17, Session 3

A reduced-order disturbance observer applied to inertially stabilized line-of-sight control

J. M. Hilkert, Alpha-Theta Technologies (United States); B. Pautler, Raytheon Network Centric Systems (United States)

One of the key factors that determine how well an inertially stabilized Line-of-Sight control system performs is the ability of the feedback loop to counteract, or reject disturbances such as friction and mass imbalance. These disturbances are usually a function of both the electro-mechanical design and the dynamic operating environment. In a typical control system, this disturbance rejection capability is determined primarily by the loop bandwidth which, in turn, is directly effected by the dynamic characteristics of the gyro, actuator or motor, structural interactions within the system, and noise coupling from the gyro or other sources. A state estimator, configured as a disturbance observer, has been shown by previous reseachers to be an effective method to augment the control system and improve the disturbance rejection performance. This paper discusses a particularly straightforward reduced-order generic observer design which is relatively insensitive to system parameters and is simple enough that it can be implemented with a few lines of digital code or an analog circuit. The effectiveness of the design is investigated with respect to both its performance and its robustness.

8052-18, Session 3

Calibration of VISSTA pointing control system

J. Teuscher, R. Fullmer, R. T. Pack, Utah State Univ. (United States)

The Vehicle Integrated Sensor Suite for Targeting Applications (VISSTA) is a mobile sensor laboratory developed for the U.S. Navy to support the development of Automatic Target Recognition (ATR) technologies. VISSTA simultaneously gathers data from a scanned Eye-safe LADAR with a co-boresighted color Electro-Optical (EO) camera, and a mounted Infrared (IR) camera. Using two 2-axis controlled high speed mirrors, the Pointing Control System controls the optical line-of-sight and the leaving principal ray of the pulsed laser. A commercial pan-tilt platform controls the pointing of the IR sensor. The location of the LADAR system relative to local-level coordinates is determined by a NovAtel SPAN GPS/IMU system with a LN200 IMU, which allows for inertial stabilization.

A hardware test was performed to calibrate the pointing accuracy of VISSTA. The test consisted of fixing reflective targets at various locations on three distinct buildings, and using VISSTA to perform a combined LADAR scan and EO image of the buildings to identify the location (range, azimuth, and elevation) of the reflectors. In parallel, the relative location of the reflectors with respect to VISSTA were measured using a surveying unit. Using the measurements of the surveyed locations and the scanned VISSTA locations, we were able to determine the sensor offsets and calibrate the pointing controls of VISSTA using a linearized perturbation model. This allows for accuracy in relative points, co-boresighting and Geo-location.

8052-19, Session 3

Dynamic performance of a two-axis gimbaled pedestal in keyhole gimbal-lock conditions

J. DeBruin, IJK Controls, LLC (United States)

The common two-axis azimuth-elevation gimbaled pedestal has a full-hemispheric, horizon-to-zenith field of regard. This pedestal has no kinematic difficulties at low elevation angles. In this position, the line-of-sight of the mounted sensor is perpendicular to both the azimuth and elevation gimbal axes, which thus provide two orthogonal degrees of freedom. However, as the line-of-sight approaches zenith, the sensor axis nears alignment with the azimuth axis. The azimuth axis thus loses its ability to move the line-of-sight orthogonally to the sweep of the elevation axis. This condition is known as “gimbal lock” and the position range in which dynamic difficulties occur is called “keyhole”. The keyhole region is a solid cone centered around the zenith axis. The onset of dynamics difficulties is a continuum from horizon to zenith, and as such defining the keyhole region is arbitrary. However, dynamic difficulties become rapidly pronounced somewhere between 70 and 80 degrees, so it is generally agreed that the keyhole region starts in this range. This paper provides a comprehensive analysis of the keyhole region. While performance problems at keyhole are well known (high torque, acceleration, and speed requirements), certain dynamic effects actually reduce in keyhole, such that for some systems the range of worst-case performance is actually outside the keyhole region. Gimbal geometry is introduced and pointing equations derived using vector methodology. Equations for angular velocity and acceleration are then developed, with a focus on the requirements of line-of-sight stabilization for vehicle-mounted systems. Examples and simulation results are provided to illuminate the issue.

8052-20, Session 3

Predicting and preventing reaction torque coupling in gimbal system mounts

G. Ristroph, J. DeBruin, IJK Controls, LLC (United States)

As pointing system performances continue to increase while gimbal and vehicle weights decrease, structural considerations of the gimbal-base interface become more problematic and important.

We begin by presenting the generalized structural transfer function equation in modal superposition form. We emphasize that the reaction torque of an actuator must be included in practice. We present this in a normal form, normalized for inertia. From this theoretical basis, we assume stiff gimbal structures and evaluate the structural coupling due only to mount flexure.

We build finite element models of several example mounts and evaluate the relevant gimbal mount influenced structural transfer functions. We show that in many precision pointing systems the effect of the actuator reaction torques cannot be ignored. We show that structural stiffness is less important than properties of the mount symmetry. In particular, certain types of asymmetries in the system mount (the structure between the reaction torque and the base) allow dangerous coupling even between gimbal axes. The observed coupling may depend on the angles of the gimbals making experimental testing and validation more challenging.

The analysis method is applied to an example system on a soft shock isolation mount. Even a linear elastic model that ignores bearing friction and isolator material non-linearity shows challenges for control.

We discuss the challenge of specifying the structural properties for gimbal system mounting interfaces and emphasize the inadequacy of stiffness as a requirement. In addition to an analytical framework, we present practical insight and guidelines for gimbal designers and system integrators.

8052-21, Session 3

Optomechanically linking the imager’s optical axis to the laser and the gyroscope in finite element models

A. E. Hatheway, Alson E. Hatheway Inc. (United States)

Control systems engineers are good at controlling the axis of a gyroscope but that is not quite the same thing as controlling the lines of sight of the optical instruments. That difference often remains a large (and uneasy) uncertainty until the system is actually built and tested. This paper describes how the author couples the optical lines of sight (imaging and non-imaging) to the control system’s sensors (gyroscopes

and accelerometers) using the optical prescription data and the stiffness, mass and damping matrices of a proposed structure. The mechanical engineer is then able to iterate and optimize the structural design in a finite element modeler/analyzer (Patran/Nastran, for instance) to minimize the errors between the control system's sensors and the optical lines of sight. The engineer then includes the optical lines of sight in the transfer functions and eigenvectors that he passes to the control systems engineer for his design of the control systems. The author illustrates his method with an example from his recent practice.

8052-22, Session 4

Non-mechanical conformal beam steering system with an 80 degree x 80 degree field of regard

S. A. Serati, Boulder Nonlinear Systems, Inc. (United States); J. Kim, M. J. Escuti, North Carolina State Univ. (United States); L. Hosting, Boulder Nonlinear Systems, Inc. (United States)

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 steer a beam over a large field of regard (FOR) in discrete steps. We combined this wide angle steering assembly with a fine angle steering assembly that uses BNS' liquid crystal on silicon optical phased arrays (LCOS OPAs), forming a modular beam control device. We successfully demonstrate the ability to steer over an 80 degree x 80 degree field of regard with 1 mrad resolution using this fully non-mechanical beam steering prototype. This paper describes the prototype assembly and experimental results achieved from this first demonstration unit.

8052-23, Session 4

MWIR wide-area step and stare imager

J. R. Buck, S. A. Serati, R. Serati, H. Masterson, Boulder Nonlinear Systems, Inc. (United States)

Boulder Nonlinear Systems (BNS) is demonstrating a MWIR step and stare imaging system for AFRL that eliminates the need for turrets and multiple cameras to scale the performance of available thermal imagers. The demonstration system non-mechanically switches between fields-of-regard in a Hex-7 pattern to achieve 0.1 milliradian resolution within a 17.5x17.5 degree field-of-regard. The sub-millisecond shutter switching time and polarization independence maximizes the imaging integration time and sensitivity. The system uses a 1024x1024 (19.5 micron square pixels) InSb camera with a 4.5 to 5 micron passband filter. Larger area detectors could be used to obtain larger fields-of-view, or the system could be scaled to a larger pattern of shutter arrays. The system was developed to provide a cost-effective method of providing night-vision and thermal imaging capabilities for persistent, high-resolution surveillance applications with sufficient resolution to track mounted and un-mounted threats. The demo hardware was engineered to enable near-term field and flight testing.

8052-24, Session 4

Optical characterization of MEMS micromirror arrays using digital holographic Shack-Hartmann wavefront sensor: a new technique

I. Anisimov, S. B. Dooley, Air Force Research Lab. (United States)

Micro-mirror Micro Electro-Mechanical Systems (MEMS) devices are widely used in advanced laser beam steering technology and as adaptive optical elements. New generation Micro-Mirror MEMS are fabricated by bulk micromachining of a single Silicon-On-Insulator wafer technique. Optical characterization of these MEMS can be done by direct detection of the reflected beams or by using more advanced wavefront measuring techniques such as phase-shifting interferometer or microlens Shack-Hartmann wavefront sensor. In the case of an interferometer, the geometry of the tested micro-mirror array can be calculated after performing the phase unwrapping procedure which can be quite complex. In the later case of Shack-Hartmann wavefront sensor, careful selection of a high-quality microlens array is required in order to match the capabilities of the wavefront sensor to the measured wavefront produced by the micro-mirrors. The presented Digital Shack-Hartmann technique is a simplified approach for wavefront characterization based on digital processing of interferometer's data. Optical wavefront from the tested micro-mirror array is mixed with the reference wavefront. Then the recorded interference fringe intensity image is Fourier transformed producing digital images of the optical beams in the far filed. Therefore, the digital version of the popular Shack-Hartmann wavefront sensor does not require use of a microlens array and is only limited by the sampling rate of the detector array. However, it does require optical coherent mixing the two wavefronts in order to produce the interference pattern. On the other hand, it may be enhanced by simultaneous phase measurement of the optical wavefront by phase shifting technique.

8052-25, Session 4

Beam shape of coherently-combined optical array

I. W. Smith, Raytheon Co. (United States)

Arrays of optical transmitting and receiving apertures are finding use in a number of applications, including but not limited to laser communications and LADAR. Utility and efficiency of such systems are dependent on the far-field on-axis peak irradiance and also the "power in the bucket", i.e., power in the main lobe of the beam. These are dependent on the illumination pattern of the individual aperture, e.g., truncated-Gaussian. The power in the bucket is even more strongly dependent on the areal fill factor, i.e., the degree to which the emitting apertures (exclusive of the support structure between the apertures) cover the entire array face. Starting from first principles, we derive a rigorous formulation of these measures of array performance and offer a small set of heuristically-motivated but robust design and performance guidelines.

8052-26, Session 4

Embedded FPGA platform for fast steering mirror and optical inertial reference unit applications

S. R. Wasson, F. E. Morgan, D. Eckelkamp-Baker, Applied Technology Associates (United States)

Applied Technology Associates (ATA) is developing a field-programmable gate array (FPGA) based processing platform to transition our state-of-the-art fast-steering mirrors (FSM's) and optical inertial reference units (OIRU's) from the laboratory environment to field operation. This platform offers an abundance of reconfigurable high-speed digital I/O and parallel hardware-based processing resources in a compact size, weight, and power (SWaP) form factor with a path to a radiation-hardened version. The FPGA's high-speed I/O can be used to acquire sensor data and drive actuators with minimal latency while the FPGA's processing resources can efficiently realize signal processing and control algorithms with deterministic timing. These features allow high sampling rates between 20 KHz - 30 KHz. This will result in higher open-loop bandwidths in our FSM's and OIRU's. This will also result in improved disturbance rejection in our FSM's and improved base motion jitter rejection in our OIRU's.

This paper briefly presents the embedded system requirements of ATA's FSM's and OIRU's and the FPGA-based computational architecture derived to meet these requirements. It then describes the FPGA cores

and embedded software that have been developed to efficiently realize interfacing, signal processing, and data collection tasks. Special attention is given to ATA's high-performance floating-point co-processor and innovative design approach that translates signal processing and control algorithms developed in MATLAB®/Simulink® into their equivalent implementation on the co-processor.

8052-27, Session 4

A liquid crystal shutter for unpolarized broadband light

R. Komanduri, K. Lawler, M. J. Escuti, North Carolina State Univ. (United States)

We report on a broadband, diffractive, light shutter with the ability to modulate unpolarized light. This polarizer-free approach employs a conventional twisted-nematic liquid crystal (LC) switch, combined with broadband polymer LC Polarization Gratings (PGs). The thin-film PGs act as diffractive polarizing beam-splitters, while the LC switch operates on both orthogonal polarization states simultaneously. Together they achieve a peak transmittance of > 85% and contrast ratio of > 100:1 for unpolarized light with at least +/- 7 degrees. We characterize the optoelectronic performance, discuss the limitations, and evaluate its use in potential nonmechanical shutter applications (imaging and non-imaging).

8052-28, Session 4

LC polarization gratings: performance review and prospects for visible through longwave infrared applications

M. J. Escuti, J. Kim, M. N. Miskiewicz, K. Lawler, R. Komanduri, North Carolina State Univ. (United States)

Polarization Gratings (PGs) formed using nematic liquid crystals are highly efficient diffraction gratings, which act as thin-film polarizing beam-splitters. These PGs implement a truly linear phase (without 2pi resets) via the Pancharatnam-Berry phase, and offer many unique properties: 100% diffraction into a single order, polarization-selective first-orders, wide grating-period range, and broad spectral/angular response. Over the last few years, we have intensely developed PGs for two application areas where high efficiency, novel polarization sensitivity, and thin-film profile lead to significant advantages: laser beam steering and polarizer-free LC devices. In addition, we studied fundamental and practical aspects of PGs for other VIS/NIR/MIR/LIR devices, including optical-fiber-network attenuators, tunable-optical-filters, imaging-polarimetry, spectral-imaging, and snapshot-imaging-spectropolarimetry. Here, we will broadly summarize PG technology, with a focus on diffraction efficiency, grating period, absorption, and non-ideal leakages in both polymer and switchable PGs. We will also discuss the prospects for PGs to offer significant performance advantages in defense and consumer applications, including primary challenges and opportunities.

While we (et al) have experimentally achieved ~100% efficiency (polymer and switchable), much of the reported work involves relatively small diffraction angles (ie, <= 10deg). Furthermore, the beam steering and display applications where PGs offer breakthrough advantages require larger diffraction angles (ie, up to 45deg). Here, we review how PGs behave at larger diffraction angles and with oblique incidence, where efficiency is reduced and diffracted beam polarizations deviate from circular. We aim to quantify the resulting non-ideal leakages, and directly relate them to the degradation in PG-based beam steering and other devices.

8052-29, Session 4

Demonstration of large-angle nonmechanical laser beam steering based on LC polymer polarization gratings

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Polarization Gratings (PGs) as polarization sensitive diffractive optical elements working in broadband (UV to Mid-IR) with nearly 100% diffraction efficiency in thin material layers have been introduced and utilized in different types of beam steering modules in our previous papers. Here, we describe and demonstrate the design of a nonmechanical beam steering device that covers a large-angle Field-Of-Regard (FOR) with very high total throughput. The design is based on a stack on alternating LC half-wave plates and LC polymer PGs. The half-wave plates are switchable and are used to select the handedness of the circularly polarized input beam. The polymer PGs diffract the input beam to one of the first diffraction orders based on the circular handedness of the beam previously selected. When compared with conventional beam steering methods based on active PGs (ternary and quasi-ternary designs), this technique is experimentally able to steer far larger angles with each steering stage, and also achieves higher diffraction efficiency. We demonstrate a beam steering device achieving ~80° FOR with ~2.5° resolution at 1064 nm wavelength. Design considerations for higher FOR are also discussed.

8052-30, Session 4

An update on electro-evanescent beamsteerers: higher speeds (greater-than 50 kHz), wider 2D fields-of-view (40º x 10º), and larger apertures (1 cm)

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We will provide an update on new devices enabled by liquid crystal (LC) waveguides, with an emphasis on EO beamsteerers. LC-waveguides provide tremendous voltage control over optical phase delays (> 2mm demonstrated), with very low loss (< 0.5 dB/cm) and rapid response time. The electro-evanescent architecture exploits the tremendous electro-optic response of liquid crystals while circumventing their historic limitations; our nematic relaxation speeds can be in the microseconds and our LC scattering losses can be reduced by orders of magnitude from bulk transmissive LC optics. This enables a new class of photonic devices: very wide analog non-mechanical beamsteerers (270o demonstrated), chip-scale widely tunable lasers (50 nm demonstrated), chip-scale Fourier transform spectrometers (< 5 nm resolution demonstrated), widely tunable micro-ring resonators, tunable lenses, ultra-low power (< 5 microWatts) optical switches, true optical time delay devices (12 nsecs demonstrated) for phased array antennas, and many more. We will present new results on wide angle, analog 2-D electro-optic beamsteerers, enabled by voltage tunable waveguide out-couplers. We will also present data on high speed EO scanners (60 kHz scanner demonstrated) and larger aperture scanners (1 cm demonstrated). Data from example laser-communication and laser-ranging experiments that utilize these scanners will also be presented. Finally, a brief update on other, related LC-waveguide devices will also be presented.

Return to Contents

8052-31, Session 4

High-precision scanner control system using online learning

K. Aoki, Y. Yanagita, NEC Corp. (Japan); T. Kurii, NEC TOSHIBA Space Systems, Ltd. (Japan)

We have developed a high-precision whiskbroom scanner control system, which is used on earth observation satellites. This control system keeps high angular precision with ultra smooth rotation. We designed a control system consists of a feedback controller, a feedforward controller and an on-line learning controller.

The feedback controller is composed of a rate loop for rotation-speed control and a position loop for angular control. The position loop inputs an angular signal from a resolver mounted on the motor shaft and calculates a reference rate signal. The rate loop inputs the angular signal and the reference rate signal, and calculates a motor driving torque control signal. In this rate loop, a high pass filter makes a rate signal from the angular signal by approximate differentiation. Under the limit of resolver sampling frequency and derivation using high pass filter, the feedback controller does not enough compress for rotational synchronizing disturbances.

The feedforward controller has a cyclic memory to compress the rotational synchronizing disturbances. The cyclic memory is a reference table which arguments is resolver angle and that memories torque correction values for each resolver angle. The feedforward controller renovates the each torque correction value by adding the angle error of each resolver angle at every rotation. And the feedforward controller corrects the motor driving torque control signal with the torque correction values shifted the order due to the phase delay of motor driver circuit and motor system.

The on-line learning controller has a hysteresis function and a low-pass filter. The hysteresis function suppresses undesired angle-error addition to a cyclic memory. The low-pass filter cuts off high order repeatable disturbances and non-repeatable noises. Optimizing thresholds of hysteresis and a bandwidth of the low-pass filter, this controller sustains long-time robustness against system fluctuation.

As experimental results, these feedback and feedforward controllers compress 1st order rotational synchronizing disturbance caused by eccentric load over 50 dB. A four-hour rotating experiment indicates that the on-line learning controller maintains high pointing accuracy with a standard deviation of 0.003 degree at 80 rpm. This pointing accuracy corresponds with a standard deviation of 73 meters on the surface of the earth from a satellite at an altitude of 700km.

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8053-01, Session 1

A MEMS-based spectral-polarimetric imaging and target tracking architecture for airborne broad-area search

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We describe a compact, multi-sensor design architecture capable of providing both spectral-polarimetric imaging and adaptive matched filter target detection in real time. The sensor suite supports airborne broad area search missions using multiple large format, high speed TDI scanning sensors. The technology approach leverages Micro-Electro-Mechanical System (MEMS) based spectral imaging system and scanning TDI arrays originally developed for space based remote sensing. The MEMS spectrometer system can dynamically select and switch any linear combination of single or multiple VNIR spectral bands. A dual instrument sensor suite based on this technology provides simultaneous spectral-polarimetric imaging and real time, matched filter target tracking with minimal on-board computing requirements. The spectral-polarimetric sensor light path uses the MEMS spectrometer to provide a user programmable spectral bandpass filter as a front end to a scanning TDI polarimetric sensor. The polarimetric image data can be exploited immediately for target signatures and/or post-processed further for extracting detailed material signatures & other features. The real-time matched filter detection light path uses a pulse width modulation capability of the MEMS optical device to synthesize complex, real-time linear combinations of selectable bands. The ability to configure a complex spectral filter with linear combinations of bands enables derived spectral bands such as matched filter and principle components to be collected on demand across a TDI sensor array. Combined with on-board geospatial processing this technology can provide the capability to simultaneously perform broad area imaging and target identification in near real time with a simple thresh-holding operation.

8053-02, Session 1

Techniques for high-performance processing of large image collections into tiled image sets

J. T. Sample, E. Z. Ioup, U.S. Naval Research Lab. (United States)

The problem of transforming large collections of geospatial imagery into uniform tiled images can be approached in several ways. In this paper, we detail two competing approaches: pull-based and push-based.

Pull-based approaches iterate over a desired tile-set and pull imagery from the source files. Push-based approaches iterate over a collection of source images and push imagery to image tiles. Each technique presents different ramifications for computational efficiency, memory usage, and disk utilization. Selection of a technique is driven by computational resources available, the format of the source images, and the storage method for the resulting tiles.

An extensive discussion of multi-threading techniques is presented to demonstrate the computational benefits of each model. Supporting storage models, both in-memory and on disk, are presented for each technique. This includes an analysis of image formats and compression settings for optimal tile creation and storage. An efficient technique for re-projecting geospatial images, when required, is shown in the context of tiled image processing. Techniques and results are related to the Naval Research Laboratory's Tile Server, but are applicable to all tile-based systems. Comparative results are given for each technique over realistic sets of geospatial imagery.

8053-03, Session 1

Indoor localization for GIS using acoustic wireless sensor network

P. U. Desai, N. A. Baine, K. S. Rattan, Wright State Univ. (United States)

Indoor localization with sensing capabilities is the missing link for a Geospatial Information System (GIS) and sensor web, which is a sensor network capable of environmental monitoring and geo-tagging. Wireless sensor networks equipped with acoustic sensors are showing promise as a low cost option for indoor localization with both accuracy and reliability. In previous work, an acoustic wireless network was used for localization using TDoA (time difference of arrival) measurements, which are made using both RF and acoustic signals. Unfortunately, the acoustics require line-of-sight, and, in the absence of such, requires the use of only RF signals using RSSI (signal strength) measurements.

Our previous work used the TDoA measurements to train the RSSI data. In the event of a missing TDoA measurement, an RSSI measurement was used as a substitute. In this paper, a method is proposed that combines the TDoA and RSSI measurements in real-time using a Kalman filter. Outlier rejection algorithms are also used to identify and reject erroneous TDoA measurements.

The sensor motes programmed with the proposed algorithm are also equipped with sensor attachments capable of environmental monitoring. The sensor data is tagged with metadata, including indoor location and a space id. Different rooms within a building are assigned a different space id, which is used to identify the local coordinate system. The indoor positions and space id are then translated into a global coordinates and sent along with sensor data to a GIS where the data can be integrated with information on the worldwide web.

8053-04, Session 1

Reconfigurable real-time distributed processing network

S. F. Page, R. Seely, D. L. Hickman, Waterfall Solutions Ltd. (United Kingdom)

This paper describes a novel real-time image and signal processing network, RONIN, which facilitates the rapid design and deployment of advanced surveillance and situational awareness capability. RONIN is a distributed software architecture consisting of multiple agents or nodes which can be programmed to implement a variety of state of the art computer vision and signal processing algorithms. The nodes operate in an asynchronous fashion and can run on a variety of platforms, thus providing a great deal of scalability and flexibility. Complex algorithmic configuration chains can be assembled using an intuitive graphical interface in a plug and play manner, and a performance profiling tool allows the designer to make efficient use of the network's computing resources. Application programming interfaces exist for both high-level and low-level languages, including C++, Python, and MATLAB. Algorithm wrappers, verification code and unit-tests are automatically generated based on a simple interface through which the designer specifies the new algorithm's operation and interfaces. RONIN has been successfully utilised for a number of applications from event detection to complex multiple-camera real-time 3D object reconstruction. This paper describes the design of the network and presents details of example applications.

Finally, the on-going development of the network is discussed, which is focussed on dynamic network reconfiguration. This allows to the network to automatically adapt itself to node or communications failure by intelligently re-routing network communications and through adaptive resource management.

8053-05, Session 1

MapSnap system to perform vector-to-raster fusion

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As the availability of geospatial data increases, there is a growing need to match these data sets together. However, since these data sets often vary in their origins and spatial accuracy, they frequently do not correspond well to each other, which create multiple problems. To accurately align with imagery, analysts currently either: 1) manually move the vectors, 2) perform a labor-intensive spatial registration of vectors to imagery, 3) move imagery to vectors, or 4) redigitize the vectors from scratch and transfer the attributes. All of these are time-consuming and labor-intensive operations. Automated matching and fusing vector data sets has been a subject of research for years and strides are being made. However, much less has been done with matching or fusing vector and raster data. While there are initial forays into this research area, the approaches are not robust. The objective of this work is to design and build robust software called MapSnap to conflate vector and image data in an automated/semi-automated manner. This paper reports the status of the MapSnap project that includes: (i) the overall algorithmic approach and system architecture, (ii) a tiling approach to deal with large data sets to tune MapSnap parameters, (iii) time comparison of MapSnap with redigitizing the vectors from scratch and transfer the attributes, and (iv) accuracy comparison of MapSnap with manual move of vectors. The paper concludes with the discussion of future work including addressing the general problem of continuous and rapid updating vector data and fusion vector data with other data.

8053-06, Session 1

Spatio-temporal analysis framework

A. Hampapur, X. Liu, S. Mahatma, T. Kumar, IBM Thomas J. Watson Research Ctr. (United States)

Most of the defense and security applications involve dynamic geospatial data that are changing over time. Analyzing large amount of spatio-temporal data and proving actionable insight is of great importance to these applications. For example, if the system identifies same type of vehicle stop in a certain zone over multiple days, which is abnormal compared with the historical behavior, there is a high chance that something is going on in that area, and need to be checked.

In this paper, we propose a spatio-temporal analysis framework that provides a common underlying mechanism and a general visualization layer that can plug and play various spatio-temporal analytics to support different applications. The spatio-temporal analysis framework includes:

1. A set of reusable spatio-temporal analytics for predictive pattern detection. This feature uses historical data to predict abnormal activities, such as potential “threatening / bomb planting” activity. The spatio-temporal analytics include dissolving clusters, outliers and hotspots detection, neighborhood analysis, and network analysis, and etc.

2. A mechanism for spatio-temporal event alerting. This function allows users to specify rules for composite event alerting. For example, Alert- if one target object goes to both area A and B in consecutive days. Once a composite event is identified, an alarm will be triggered.

3. A query specification for spatio-temporal query and visualization. This feature provides query API for users to perform query based on spatial and temporal constraints and visualize the results in maps or charts. This is very powerful tool and can help operators and key decision makers quickly disseminate large quantities of data and make critical quick decisions.

Spatio-temporal analysis framework supports common spatio-temporal analysis needs for many applications. It has significant importance in enabling the defense and security applications.

8053-07, Session 1

Scale-space representation of remote sensing images using an object-oriented approach

A. H. Syed, E. Saber, D. Messinger, Rochester Institute of Technology (United States)

With rapid developments in satellite and sensor technologies, there has been a dramatic increase in the availability of high resolution (HR) remote sensing images (<1m). There is a growing need for automated image analysis techniques which go beyond the traditional pixel based methods (spectral), many of which do not leverage the abundant spatial, contextual, and topological information that is now available in HR images. The HR image brings with it several challenges. It is highly complex with relevant structures occurring at several scales. A single segmentation or image representation may not capture all the information present in the image and thus requiring multi-scale techniques. To deal with complexity and organization of multi-scale information, a consistent framework and image representation, is needed. A hierarchical scale-space representation (HSSR) is proposed in this paper to tackle the aforementioned challenges. The proposed HSSR is object-based image analysis methodology where the tenets of abstraction, encapsulation, modularity and hierarchy are observed. Given an input image, the HSSR is automatically constructed, starting with single pixels (as objects) and ending with the root node indicating the complete image. The HSSR utilizes image tree structure where each node serves as an approximation to an object in the image. Low-level image features, gradient, color and size information are used in the proposed technique to generate multi-scale segmentation maps. These maps can be used in applications such as target/anomaly detection, object tracking, and image region classification. Several HR remote sensing images have been utilized to evaluate the proposed methodology.

8053-08, Session 1

KOLAM: an open, extensible framework for interactive visualization of high-resolution, high-throughput imagery

A. Haridas, J. Fraser, K. Palaniappan, Univ. of Missouri-Columbia (United States); G. S. Seetharaman, Air Force Research Lab. (United States)

Over the past several years, techniques developed in visualization have facilitated multiple data-stream presentation and navigation through huge data sets. These techniques are particularly useful for improving insight into the complex phenomena in satellite, surveillance and geospatial image analysis domains. We present a novel, scalable and extensible framework for high-resolution, high throughput image data visualization with applications in image analysis research. Kolam is a software package for the interactive visualization of massive datasets and 2D imagery of varying resolutions. It is platform and operating system independent, and supports embedded datasets scalable from hundreds of gigabytes to terabytes in size on clusters, workstations, desktops and mobile computers. In addition to rapid roam, zoom and hyper-jump spatial operations, Kolam supports an arbitrary number of simultaneously visible embedded layers, colormap lookup and histogram enhancement, projection of images onto spherical surfaces and elevation

maps. Kolam also provides a robust framework for animation of image sequences, usable via a highly intuitive interface that provides all necessary functionality. Among the current critical defense and security requirements is the need for a visualization tool that allows analysts to easily and productively track different types of objects and perform useful operations on the generated track data. Kolam satisfies this requirement by providing a feature-rich tracking interface enabling simultaneous visualization of multiple tracks, context-sensitive track operations, track archival and retrieval, ground truth generation, track editing and annotation. Kolam can also interface with any tracking algorithm implementation and visualize the results on data in the most widely used image formats.

8053-09, Session 2

Urban event detection for wide field-of-view (WFOV) operations

E. E. Huling, U.S. Air Force (United States)

The US Air Force has the mission to perform reconnaissance, surveillance, and target acquisition (RSTA) from Remotely Piloted Aircraft (RPA) such as Small RPAs, the MQ-1, MQ-9, and RQ-4. The need to rapidly detect, measure, correlate, identify and locate uncued battlefield threats such as small arms fire, mortars, missile launches and Improvised Explosive Devices (IED) detonations has fostered the development of several different types of detection sensors. These include acoustical, electro-optical (EO), Infra-Red (IR), spectrometer, motion imagery and chemical-detect/chemical signature technologies. This paper will focus on airborne Geospatial Intelligence (GEOINT) sensor technologies for event detection supporting Wide Area Persistent Surveillance (WAPS) of urban areas.

Challenges include developing high-speed Wide Field of View (WFOV) GEOINT sensors capable of capturing and processing small transient events such as muzzle flash. In addition to using airborne WAPS system to support forensic analysis, analysts require a capability to detect events real-time. Due to the large amounts of high-resolution motion imagery and slow frame rates, muzzle flashes or IED detonations may go unnoticed until reported by field units or identified later during forensic analysis. Additionally, tools are needed to accurately identify the event and provide accurate geopositioning data for an appropriate military or police response.

This paper will review current operational requirements, discuss the need for WFOV event detection, discuss potential concepts of operation, identify operational and technical challenges, and review potential technological approaches to meet the needs of the battlefield.

8053-10, Session 3

Formatting research and development sensors for data interoperability and fusion with GIS

K. M. Vongsy, Air Force Institute of Technology (United States); E. Cincotta, ITT Corp. Geospatial Systems (United States); T. Jones, ITT Visual Information Solutions (United States)

Airborne Intelligence, Surveillance, and Reconnaissance (ISR) systems are becoming more prevalent and producing an ever increasing volume of data to process, exploit, and disseminate. Successful Processing, Exploitation, and Dissemination (PED) of this data require accurate Geographic correction and file format standardization. The National Imagery Transmission Format (NITF) standard provides a recognizable format handling and a documented and regulated means of metadata provision to the community. Adoption of this NITF standard for geographically corrected imagery facilitates data quality, flexibility, and GIS fusion potential for any R&D sensor and promises the quickest transition to operational status.

In 2009, based on the demonstrated utility of an end-to-end hyperspectral system aboard an MQ-1 Predator system, the Air Force initiated a program of record to develop and procure operational Hyperspectral sensors, the Airborne Cueing and Exploitation System Hyperspectral (ACES HY) program. In support of this effort, the National Air & Space Intelligence Center (NASIC) developed a flexible architecture that includes automated geographic correction and NITF conversion of the ACES HY data to support PED at NASIC, and remote access via NITF metadata queries through a web-based search and discovery tool. NASIC's ACES HY support architecture has pioneered the integration of multiple airborne data sources into a single, coherent, and expandable architecture to support Thermal Infrared (TIR), Spectral, and forensic Ground Moving Target Indicator (GMTI) analysis at NASIC and serves as a model for reapplication to multiple sensors designed against ease of use, access, and fusion with GIS.

8053-11, Session 3

Standards to improve tracking

S. Randall, H. J. Antonisse, Booz Allen Hamilton Inc. (United States)

Automated moving object detection and tracking are becoming cornerstone technologies for the ubiquitous video and wide-area persistent surveillance systems proliferating across the new operational and law-enforcement environment. While classic radar-based surface / ground moving target indicator (S/GMTI) systems provide all-weather detection capabilities, full-motion video (FMV) systems typically found on manned and unmanned surveillance aircraft can exploit recognizable features to support greater continuity of tracking from video moving target indicator (VMTI) information.

Emerging wide-area persistent surveillance platforms promise increasingly long periods of surveillance and increasingly wide areas of coverage with increasingly high-detail imagery over the entire area of interest. However, the very success of the new sensors threatens to overwhelm our ability to understand the implications of the data they provide. A favored response has been to depend on the development of advanced tracking technology to extract the movements and activities in a scene, and so bring data volume under control. Yet despite advances, automated movement detection and tracking capabilities - and ultimately “activity” recognition - are severely limited in comparison to the abilities of a human observer. To address these shortfalls, the authors are nominating for adoption through NGA's Motion Imagery Standards Board a metadata architecture to establish standards-based “interfaces” within the end-to-end detection-tracking-activity exploitation process. This architecture leverages existing standards and provides a mechanism to establish new ones, as appropriate. The architecture fosters interoperability of disparate sources and facilitates plug-and-play insertion and replacement of algorithms and processes, encouraging developers to concentrate on their respective areas of expertise and leading to advances in tracking state of the art.

8053-12, Session 3

Delivery methods for LVSD systems

J. H. Kasner, WiSC Enterprises, LLC. (United States); B. V. Brower, ITT Corp. Geospatial Systems (United States)

In this paper we present formats and delivery methods of Large Volume Streaming Data (LVSD) systems. LVSD systems collect TBs of data per mission with aggregate camera sizes in the 100 Mpixel to several Gpixel range at temporal rates of 2 - 60 Hz. We present options and recommendations for the different stages of LVSD data collection and delivery, to include the raw (multi-camera) data, delivery of processed (stabilized mosaic) data, and delivery of user-defined region of interest windows. Many LVSD systems use JPEG 2000 for the compression of raw and processed data. We explore the use of the JPEG 2000 Interactive Protocol (JPIP) for interactive client/server delivery to thick-clients (desktops and laptops) and MPEG-2 and H.264 to handheld thin-clients (tablets, cell phones). We also explore the use of 3D JPEG

2000 compression, defined in ISO 15444-2, for storage and delivery as well. The delivery of raw, processed, and region of interest data requires different metadata delivery techniques and metadata content. Beyond the format and delivery of data and metadata we discuss the requirements for a client/server protocol that provides data discovery and retrieval. Finally, we look into the future as LVSD systems perform automated processing to produce “information” from the original data. This information may include tracks of moving targets, changes of the background, snap shots of targets, fusion of multiple sensors, and information about “events” that have happened.

8053-13, Session 3

The standard exchange of features in feature-based tracking

H. J. Antonisse, Booz Allen Hamilton Inc. (United States) and Harris Corp. (United States); S. Randall, Booz Allen Hamilton Inc. (United States)

The authors are nominating for adoption through NGA’s Motion Imagery Standards Board a metadata architecture to establish standards-based “interfaces” within the end-to-end detection-tracking-activity exploitation process. This architecture leverages existing standards and provides a mechanism to establish new ones, as appropriate. The architecture fosters interoperability of disparate sources and facilitates plug-and-play insertion and replacement of algorithms and processes, encouraging developers to concentrate on their respective areas of expertise and leading to advances in tracking state of the art. This paper describes a proposed second phase of this plug-and-play approach to tracking. In this phase the open-standards approach to tracking is deepened to include not only standardization of the interfaces of the “sequential” stages of an image-based tracker (image conditioning, motion detection, kinetics-based tracklet extraction, feature-based track development, and track network discovery), but the standardization of the features of a feature-based tracker.

The proposed standard for features defines interfaces into and out of the use feature as they are applied to resolve track extensions as in, e.g., multi-hypothesis tracker (MHT) technology. The proposed standard does not require divulging the nature of the feature itself, but builds an interface to exchanging information about the feature’s efficacy with respect to the tracker problem. The standard model for the application of these features involves an independence assumption that the authors presume will usually be incorrect, and therefore provides one of several large areas for proprietary innovation within the model. The key achievement of the approach is that it offers a way to maintain the confidentiality of feature details so that proprietary features may be interchanged without divulging what the feature actually is. This way proprietary features may be freely mixed and the optimization of features pertinent to particular tracking problems accelerated.

8053-14, Session 4

Target tracking with GIS data using a fusion-based approach

W. D. Reynolds, Jr., E. M. Dixon, J. Sisskind, B. Bradford, ITT Corp. Geospatial Systems (United States)

Military forces and law enforcement agencies are facing new challenges for persistent surveillance as the area of interest shifts towards urban environments. Some of the challenges include tracking vehicles and dismounts within complex road networks, traffic patterns and building structures. Under these conditions, conventional video tracking algorithms suffer from target occlusion, lost tracks and stop-and-start. Furthermore, these algorithms typically depend solely on pixel-based features to detect and locate potential targets, which are computationally intensive and time consuming.

This research paper investigates the fusion of geographic information into video-based target tracking algorithms for persistent surveillance. A geographic information system (GIS) has the capability to store attributes about a target’s surroundings - such as road direction and boundaries, intersections and speed limit - and can be used as a decision-making tool in prediction and analysis. Fusing this prediction capability into conventional video-centric target tracking algorithms provides geographical context to the target feature space, improves occlusion of targets and reduces the search area for tracking. The GIS component specifically improves the performance of target tracking by minimizing the search area a target is likely to be located. We present the results from our simulations to demonstrate the feasibility of the proposed technique with video collected from a prototype persistent surveillance system. Our approach maintains compatibility with existing GIS databases and provides an integrated solution for multi-source target tracking algorithms.

8053-15, Session 4

Spatial analysis of data registration methodologies for fusion applications

P. J. Doucette, H. Theiss, E. M. Mikhail, National Geospatial-Intelligence Agency (United States)

Data registration is the foundational step for fusion applications such as change detection, data conflation, 3D site model construction, or GIS database updating. Image-to-image registration methods have been broadly applied across the photogrammetric, remote sensing and computer vision communities for several decades. However, data registration in the most general sense implies heterogeneous sources, e.g., images, scanned maps, vectorized features, or even textual descriptions. Given the potential for large disparities between input data types, the efficacy of data registration can be limited by inadequate characterization of uncertainty in the data.

For spatial data registration, two challenges to address are: 1) feature matching via correspondence, and 2) determining an appropriate geometric transformation function that accommodates distortions and surface discontinuities inherent in the data. In this paper the objective is to investigate, demonstrate, and make recommendations on how photogrammetric methodology applied to image-to-image registration could be exploited quantitatively in fusion applications. For example, in image-to-image registration, a photogrammetric transformation function is based on knowledge of a sensor model. A DSM or DEM is used to account for the displacements due to a 3D object space. Photogrammetric solutions also propagate the error covariance matrix of physical adjustable parameters (e.g., sensor position and attitude for a pair of images) to provide a statistically rigorous estimation of registration accuracy. Thus, to the extent that image derived information, e.g., feature vector data, scanned maps, etc., can be traced back to their original image source, existing sensor metadata and corresponding uncertainty estimation can be exploited in subsequent data fusion processes. Accurate characterization of spatial uncertainty provides for better decision-making in fusion applications.

8053-16, Session 4

Characterizing the semantic information loss between geospatial sensors and geospatial information systems

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A Geospatial Information System (GIS) collects, integrates, stores, edits, analyzes, shares, and displays geographic information. Naturally, GIS analysts rely on external data coming from disparate sensors to associate the sensor content (e.g. imagery) with relational databases. Inherently, these sensors present differences in their data structures, labelling, and resolution. Given different data structures, information may be lost in the transfer of information, alignment and association of related context, which yields uncertainty in the meaning of the conveyed information. There is a need to characterize and measure the information loss such that the GIS fused product supports actionable knowledge. Utilizing a measure of semantic information loss, fusion process can be improved, predictions of data needs can be determined, and analysts can appropriately understand the GIS product. This paper aims at developing a semantic information loss measure based on information theory to determine the measures of performance for sensor processing uncertainty and syntactic association which lead to measures of effectiveness for semantic alignment.

8053-17, Session 4

Tracking in wide-area persistent motion imagery

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Wide area persistent motion imagery is a newly emerging technology that provides city wide continuous coverage (several square miles) with a temporal sampling of one to two frames per second. Aircraft-based camera systems provide live, high resolution images (16K by 16K pixels) that are collected from multiple cameras on board and georegistered and projected for a single, stabilized view with real-time replay capability. Storing, viewing and analyzing these images for change detection, active surveillance or scene forensics provides unique challenges for computer vision algorithms due to the nature of this data. The challenges include large data size (several terabytes per flight), considerable lens distortions, registration and projection errors across multiple cameras as well as registration errors due to IMU sensor noise, low frame rate, changing viewpoint and strong parallax effects due to flight pattern, and occlusions. Existing approaches for analyzing the objects of interest such as moving vehicles usually require smooth motion and high frame rates to achieve reasonable performance which make them unsuitable for wide area motion imagery. We developed an algorithm that overcomes these challenges by incorporating several approaches such as local stabilization, mean-shift clustering and an adaptive set of descriptors based on speeded-up robust features (SURF). The developed algorithm does not require smooth motion or a background model in order to detect moving objects and provides real-time performance. It can incorporate street map data or LIDAR data into the process where such data is available. The approach is demonstrated on real data obtained from an operational platform.

8053-18, Session 4

Hypercube processing of mixed sensed data entropic associations

P. B. Deignan, Jr., A. Kusmanoff, L-3 Communications Integrated Systems (United States)

A method for calculating unbiased entropic estimates of multivariate associations between mixed data is given. Since there is no assumption of unimodality of the distributions of the categorical and continuous-valued data, measures of central dispersion are not appropriate for the quantification of association. Empirical estimates of entropic associations are provided in respect to the partition entropy of a uniform binning interval and the cardinality of the sensed data. The increased computational demand incurred by the appropriate generalized measure is mitigated by a branch and bound algorithm for information-optimal attribute selection. The methodology is applied against a known data set used in a standard data mining competition that features both sparse categorical and continuous valued descriptors of a target with promising results.

8053-19, Session 4

Multisensor-based image fusion for improvement of small-target detection and tracking

C. Park, Samsung Thales Co., Ltd. (Korea, Republic of)

In this paper, we propose image fusion signal processing for improvement of small target detection and tracking based on an infrared (IR) and visible (VIS) vision systems.

The system certainly needs a registration stage in two images. Because the two images show an each field of view (FOV). The image registration have an extracting procedure for candidate of feature point in two images and a detecting procedure for best point from the extracted candidate of feature points. The proposed method for feature point extraction extracts feature regions by using facet-based filter in an IR image. Matching of feature points performs method which detects maximum value of information by using normalized mutual information (NMI) to detect the feature point in a VIS image on the extracted candidate of feature region in the IR image. The IR and VIS images don't find common characteristics and general correlations. Because of it expresses different intensities of characteristics. A fused image creates information which selects maximum feature point in the IR and the VIS images. The fused image is a gray scale image. The color expression of the fused image expresses a pseudo color image based on hue (H), saturation (S), and intensity (I). In the experiment, the extracted feature points by using facet-based filter from the IR image are the effective feature points.

8053-20, Session 4

The standard exchange of motion indicators by image-based trackers

S. Randall, Booz Allen Hamilton Inc. (United States); H. J. Antonisse, Booz Allen Hamilton Inc. (United States) and Harris Corp. (United States)

The authors are nominating for adoption through NGA's Motion Imagery Standards Board (MISB) and NATO's Standards process a metadata architecture to establish standards-based "interfaces" within the end-to-end detection-tracking-activity exploitation process. The MISB's open-standards approach to tracking is built on the standardization of interfaces of five "sequential" stages of an image-based tracker. These are image conditioning, motion detection, kinetics-based tracklet extraction, feature-based track development, and track network discovery.

Many algorithms and approaches, by many labs, academics, and vendors, comprise the design space for each of these areas and for the ideal tracker. Moreover, what is ideal for a tracker will depend on the kind of tracking is being required. Therefore it will be of significant import to be able to plug-and-play different algorithms and approaches to quickly adapt trackers to the changing purposes to which they are put.

This architecture leverages existing standards and provides a mechanism to establish new ones, as appropriate. The architecture fosters interoperability of disparate sources and facilitates plug-and-play insertion and replacement of algorithms and processes, encouraging developers to concentrate on their respective areas of expertise and leading to advances in tracking state of the art. This paper describes the second of five the components in the MISB's plug-and-play "micro-architecture" for automated, semi-automated, and manual tracking processes. It describes the Video Motion Target Indicator component of the architecture that is currently being standardized by the MISB and NATO.

8053-21, Session 4

Cognitive Modeling to Predict Video Interpretability

D. L. Young, Raytheon Intelligence & Information Systems (United States)

The prediction of video interpretability is challenging because of the large number of variables in both the scene content and how it is processed by the human brain. A study is undertaken to compare cognitive modeling techniques to predict video interpretability.

Representative airborne video clips are rated for interpretability using Video-NIIRS. The clips are analyzed to determine image quality factors such as GSD, RER, and SNR. Motion specific parameters such as camera motion, and target motion are also included in a regression similar to the General Image Quality Equation. The results of the regression is compared to several different cognitive models.

8053-22, Session 4

Geospatial InfoFusion systems and solutions for defense and security applications

R. Wiginton, Intergraph Corp. (United States)

Federal, State, and Local Governments make innovative use of geospatial technologies in order to deliver timely and relevant information used by decisions makers in Defense and Security. Spatial information has expanded from specific, unconnected data silos into spatially integrated multi-agency decision support information systems. The integration of such disparate systems continues to be a key challenge. Increases in data volume from these systems does not come without a cost. An intelligent data management system must be able to handle increasingly larger volumes of data while maintaining currency, relevancy, and accuracy. Systems offering Capturing, Managing, Analyzing, and Integrating using Open Standards, provide greater flexibility for the integration and application of information systems and improve collaboration and confidence of those acting on the information.

This presentation illustrates the application of Intergraph's proven technology by Federal, State, and Local Governments, who use it to protect hundreds of millions of people around the world. Intergraph's spatial information solutions are comprised of open and interoperable technologies, enabling the deployment, management, and dissemination of geospatial data. This framework is comprised of standards-based architectures, geospatial data / supporting metadata and tools connecting Federal agencies, State and Local governments interactively allowing these organizations to use and share geospatial information in efficient and flexible ways. This architecture directly supports specific government mandates requiring sharing of geospatial data among organizations. This architecture also supports the fusion of real-time sensor, imagery / video collections, and observation data which can be spatially referenced to geospatial foundation information such as maps / imagery.

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8054-01, Session 1

Multimaterial optical fibers: fabrication and applications

A. F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Combining a multiplicity of solid materials with disparate electrical and optical properties into a single fiber realized in arbitrary geometries with intimate interfaces produced through the simple and scalable process of thermal drawing enables a large set of unique and unconventional fiber functions produced at kilometer lengths and low costs. I review our progress in this emerging area of multi-material fibers. In particular, I review our efforts towards the fabrication of mid-infrared microstructured, all-chalcogenide glass fibers and fiber tapers. The fabrication process combines elements from multiple procedures: glass processing, thin polymer film processing, preform extrusion, and optical fiber drawing. Our procedure enables us to fabricate chalcogenide glass fibers in a variety of geometries. These fibers have low loss in the mid infrared and are also highly nonlinear.

I also discuss the limits set on the dimensions of the transverse features that may be maintained continuously along the fiber axis set by the thermal and mechanical properties of the materials combined in the fiber. We find that fluid dynamical instabilities, in particular the Plateau-Rayleigh capillary instability, set this limit. Surprisingly, we find that these instabilities that lead to the breakup of structures inside the fiber may be controlled to produce micro- and nano-scale structures covering a large range of scales, materials, and shapes.

8054-02, Session 1

Theoretical study of spur-free dynamic range of a semiconductor resonant cavity linear interferometric intensity modulator

N. Hoghooghi, S. P. Bhooplapur, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Recent development in the field of optical modulators, Hoghooghi et al., shows the possibility of developing a linear modulator which does not require any pre or post-distortion technique. The design of this intensity modulator with a linear transfer function is based on an injection locked resonant cavity with gain. The injection locked resonant cavity has an arcsine phase response function of the detuning of the cavity resonance from the injection seed frequency. Placing the arcsine phase modulator in one arm of a quadrature biased Mach-Zehnder interferometer results in an intensity modulated signal which is directly proportional to the RF drive signal of the modulator. In this paper, simulation results of the performance of this modulator, with a semiconductor laser as the resonant cavity, are presented. Starting from the rate equations of an injection locked semiconductor laser, a stability plot of the injection locked semiconductor laser was obtained. Within the stable locking range without any approximation on the injection power level, effects of the alpha parameter or linewidth enhancement factor of the injection locked semiconductor slave laser, injection ratio, refractive index, and the residual amplitude modulation on the spur-free dynamic range (SFDR) of the modulator are studied. Good agreement between simulation and experimental results are obtained.

8054-03, Session 1

Plasmonic crystals: a new platform to enhance photodetector performance

H. Mohseni, Northwestern Univ. (United States)

Since Ebbesen et al found the extraordinary optical transmission of periodic metal hole arrays in 1998, Surface Plasmonics (SP) has been a rapidly growing field that has greatly impacted many areas. We combine new plasmonic crystals with photon detectors, and show dramatic improvement in the quantum efficiency and detectivity. Also, unlike conventional resonators, we show that certain designs can provide very large optical bandwidth while maintaining the detector performance enhancement.

8054-04, Session 1

Large scale micro-Fabry-Perot optical filter arrays

A. A. Abtahi, Aerospace Missions Corp. (United States); P. B. Griffin, Stanford Univ. (United States); R. J. Morgan, U. Raghuram, Aerospace Missions Corp. (United States); F. Tejada, Sensing Machines (United States); F. S. Vetelino, Aerospace Missions Corp. (United States)

Fabry-Perot filter arrays have been fabricated comprised of six million individual filters with linear pixel dimensions as small as nine microns using standard semiconductor processing techniques. In principle, each and every one of the 3000 x 2000 micro Fabry-Perot filters could be designed to have a different and unique color response. However, to make efficient use of the available semiconductor fabrication techniques, the current 6 megapixel arrays consist of 5x5 subarrays in which each of the 25 micro Fabry-Perot filters in the subarray has a different color response. The 5x5 subarray is replicated to create a 600x400 matrix of 5x5 micro Fabry-Perot filter subarrays; much like RGB “Bayer” arrays except with 25 colors rather than three or four colors. This Fabry-Perot matrix has been integrated with a commercially available panchromatic 6 megapixel CCD focal plane array to create a 25 color hyperspectral camera with 600x400 imaging pixels. The total number of micro Fabry-Perot filters that can be fabricated into an array is limited by the wafer size used in the semiconductor fabrication process. HDTV-scale cameras with 100 different color filters per imaging pixel are possible with the current approach. The configuration of the Fabry-Perot subarrays does not need to be square and can be designed to meet custom requirements. Micro Fabry-Perot filter arrays have been fabricated with peak spectral transmission ranging from the ultraviolet through the visible to the near infrared.

8054-05, Session 2

Multimode 40Gbps CWDM transceivers for optical backplanes

T. J. Eustis, M. Harris, V. Cheung, S. Mahnkopf, D. Louderback, OptiComp Corp. (United States)

A unique multimode VCSEL based 40Gbps CWDM transceiver is presented, designed for the high bandwidth digital signal processing needs of government and military platforms such as unmanned aerial vehicles (UAVs) and satellites. Only with photonic based transceivers can the high speed data rates required in emerging digital signal processing applications be achieved. As the communities pushes to develop optical backplanes, and the continued growth of distributed signal processing and distributed switch architectures, such as those possible with RapidIO, a CWDM solution approach would facilitate larger data rates over a reduced number of optical connections.

8054-06, Session 2

Record performance levels in quantum dot lasers with applications to 1.3 and 1.55 µm wavelengths

D. Deppe, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); S. Freisem, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States) and sdPhotonics LLC (United States); G. Zhao, L. Wang, A. Demir, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Laser diodes have developed through at least three generations of active region structures. The first demonstrations were of homojunctions, which were then surpassed by double heterostructures based on bulk active material, and to the planar quantum well laser diodes that now dominate commercial technology. The change from bulk active material to planar quantum wells came from the advantages of quantum size effects that cause a more favorable electron-hole distribution for efficient recombination. The historical developments have been tracked by the threshold current densities of the different active materials, with each new generation producing lower values. Quantum dot laser diodes are viewed as the next generation offering the greatest quantum confinement effects, and the lowest threshold current density. In this talk we will review the status of quantum dot laser diodes that show record performance at 1.3 µm for GaAs-based laser diodes, and opportunities in 1.55 µm laser diodes. In particular the 1.3 µm quantum dot laser diodes produce record performance in low threshold current density now less than 10 A/cm2, the highest To measured that is nearly unchanged over temperatures from 0 to 80 C, and record low internal loss. The opportunity at 1.55 µm is important for many military applications, and the opportunities and challenges for high temperature operation and low internal loss are discussed, along with questions concerning the influence and importance of Auger recombination in the quantum dot laser diodes.

8054-07, Session 2

Rapidly reconfigurable pulse-shaping using injection-locked VCSELs

S. P. Bhooplapur, N. Hoghooghi, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We demonstrate independent modulation of four optical comb lines at rates of up to 3.125 GHz by injection-locking a VCSEL to each of the comb lines. The comb-lines are separated by 6.25 GHz, as determined by the channel separation of the fiberized, matched-pair of demultiplexer and multiplexer. The currents to the VCSELs are modulated at frequencies between 0.78125 and 3.125 GHz and the resulting optical waveforms are measured using a fast photodetector and a high-bandwidth, real-time oscilloscope. The electronic waveforms have envelopes with periodicities corresponding to the current-modulation frequencies, and the pulse-shapes within one period of the envelope vary. The measurements prove that dynamic reconfiguration of the optical pulse-shape has been achieved at rates approaching the repetition rate of the comb source. This work represents, to our knowledge, the fastest line-by-line pulse-shaping to date.

8054-08, Session 2

New VCSEL technology with scalability for single mode operation and densely integrated arrays

G. Zhao, A. Demir, S. Freisem, Y. Zhang, X. Liu, D. Deppe, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

While oxide-confinement has been the most important technique for lateral mode confinement in vertical-cavity surface-emitting lasers (VCSELs) leading to low threshold, high efficiency and high modulation speed, this technology is now more than fifteen years old and causes roadblocks in further VCSEL development. The internal strain caused by the oxide can seriously degrade device reliability. Its formation by diffusion limits device uniformity and size scaling. The oxide is also a thermal insulator and limits thermal resistance. In this work, a new type of lithographic VCSELs that produces a similar mode- and current-confinement is demonstrated and being developed to overcome the oxide roadblocks. The devices are grown by solid source molecular beam epitaxy, and have lithographically defined sizes that vary from 3 µm to 20 µm, and demonstrate decreased thermal resistance and robust operation under stress testing. The 3 µm device shows a threshold current of 310 µA, the slope efficiency of 0.81 W/A, and the maximum output power is more than 5 mW. High reliability is achieved by removal of internal strain caused by the oxide, stress test shows no degradation for the 3 µm device operating at 85 kA/cm2 for 190 hours, while at this dive level commercial VCSELs fail rapidly. The result is a more robust VCSEL that can be scaled to small sizes and produce very dense arrays. Applications to large area 2-D arrays and low power sensors will be described.

8054-09, Session 3

Coupled optoelectronic oscillator with 1000 finesse intracavity etalon

I. T. Ozdur, J. Davila-Rodriguez, D. Mandridis, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

In this work, an optical frequency stabilized, semiconductor based, 10.285 GHz, coupled opto-electronic oscillator (COEO) is presented. An intracavity ultra-low expansion quartz Fabry-Perot etalon with an expansion coefficient of 30 ppb K-1 is used as the mode-selector and supermode noise suppression. The RF tone showed > 110 dBc/Hz signal-to-noise ratio. Long term Allan deviation stability measurement is also performed and resulted in a stability of ~ 2*10-9 over 1 second. Cavity stabilization is necessary because optical frequency fluctuations may result in a detuning between the etalon transmission peak and optical comb lines, leading to a destabilization of mode-locking. The cavity and hence the optical frequency stabilization is obtained by locking the optical frequency to the ultra-stable etalon via Pound-Drever-Hall technique.

8054-10, Session 3

Injection locked coupled opto-electronic oscillator for optical frequency comb generation

C. G. Williams, D. Mandridis, J. Davila-Rodriguez, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

A CW injection locked Coupled Opto-Electronic Oscillator (COEO) is presented with a 10.24 GHz spaced optical frequency comb output as well as a low noise RF output. A modified Pound-Drever-Hall Scheme is employed to ensure long-term stability of the injection lock, feeding

back into the cavity length to compensate for cavity resonance drifts relative to the injection seed frequency. Error signal comparison to an actively mode-locked injection locked laser is presented. High optical signal-to-noise ratio of ~35 dB is demonstrated with >20 comblines of useable bandwidth. The optical linewidth, in agreement with injection locking theory, reduces to that of the injection seed frequency, <5 kHz. Low amplitude and absolute phase noise are presented from the optical output of the laser system. The integrated pulse-to-pulse energy fluctuation was found to be reduced by up to a factor of two due to optical injection, for varying injection powers.

8054-11, Session 3

A passively mode-locked SOA laser with tunable pulse-repetition frequency based on normal mode splitting of the SOA amplified spontaneous emission spectrum

E. Donkor, Univ. of Connecticut (United States); S. Mukhopadhyay, TranSwitch Corp. (United States)

A novel technique for achieving mode-locking in a continuously tunable Semiconductor Optical Amplifier (SOA) based fiber laser system has been experimentally demonstrated, and results are compared with a theoretical model for the mode-locking mechanism. The laser system comprises an optically coupled cavity formed by a Multi Quantum Well (MQW) SOA, a known length of highly Birefringent fiber (BiFi), and a Faraday rotator mirror (FRM). The coupled cavity formed by the SOA and the BiFi can be tuned for a given set of modes within the Amplified Spontaneous Emission (ASE) spectrum by matching the SOA cavity length and the BiFi length, and then the selected mode buildup is achieved via optical feedback. The high birefringence of the fiber ensures proper separation of the normal and extraordinary polarizations, crucial to achive mode-locking, while the FRM acts as the cavity mirror, and phase conjugator to compensate for the polarization variations. The system is inexpensive, and assembled using off-the-shelf components. We use a very simple and intuitive theoretical model that deterministically selects the mode-locked pulse repetition frequency with robust polarization maintenance, and which is a self-starting process beginning with incoherent SOA ASE. Furthermore, the process is continuously tunable around the resonant operating point by adjustment of various system parameters. Excellent correlation between the theoretical model and experimental observation has been achieved.

8054-12, Session 3

Design of cascaded plasmon resonances for ultrafast nonlinear optical switching

S. Toroghi, P. G. Kik, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Plasmon resonant metallic nanocomposites are of great interest for nanophotonics applications due to their ability to generate strongly enhanced local electric fields. One of the most notable effects associated with such strong local fields is a dramatically enhanced nonlinear optical response, promising the use of these composites as all-optical switching elements. Here we demonstrate numerically that the nonlinear susceptibility enhancement factor can be improved by using cascaded plasmon resonances in two-dimensional arrays of spherical silver nanoparticles embedded in a dielectric host. The influence of cascaded resonances on the linear and nonlinear optical properties of these structures is studied by changing the relative volume of adjacent nanoparticles. Relative particle volumes of 1, 2.3, 4.8, 11 and 30 are considered while maintaining constant metal fill fraction of 1%. For identical particle size, a moderate internal field enhancement of a factor 7 is observed. Increasing the size difference between neighboring particles is shown to lead to the development of additional coupled plasmon modes, as well as field enhancement up to 25×, ~4 times that observed for identically sized particles. This increased enhancement provides clear evidence for cascaded resonances in which the smaller nanoparticle is driven predominantly by the enhanced near-fields around the larger nanoparticle, leading to additive field enhancement. The cascaded field enhancement is shown to generate an enhancement of the nonlinear refractive index and nonlinear optical absorption by two orders of magnitude compared to composites with a single particle size. Implications of our findings for optical switching will be discussed.

8054-13, Session 3

Next generation liquid crystal devices for advance photonic applications

R. A. Ramsey, Meadowlark Optics, Inc. (United States)

Nematic liquid crystal devices have been utilized for decades for phase and amplitude control of light. A limiting factor in the implementation of these devices for real-time system design is speed. Now, a new technology based on sheared polymer stabilized liquid crystals has resulted in new liquid crystal devices with several waves of retardance.

Response times of <100µs with transmissions of over 90% across a broad spectrum have been obtained with retardance uniformities across 3” apertures of better than 20nm.

These newly developed devices will be discussed with emphasis on applications including variable retarders, beam-steering capabilities, wavefront correction, hyperspectral imaging, real-time polarimetry systems and display technologies.

8054-14, Session 4

An etalon stabilized 10 GHz comb source using a slab coupled waveguide amplifier

J. Davila-Rodriguez, I. Ozdur, C. G. Williams, D. Mandridis, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We report on a 10.287 GHz semiconductor-based comb source with ultralow pulse-to-pulse timing-jitter (~2.3 fs integrated from 10 Hz to 100 MHz) at 1550 nm. The laser is harmonically mode-locked and an intra-cavity Fabry-Pérot etalon (FPE) is used to suppress the interleaved supermode sets spaced by the free spectral range of the fiber cavity, generating a comb at the free spectral range of the FPE (~10 GHz).

Fundamental to the ultralow jitter result is the use of a Slab-Coupled Optical Waveguide Amplifier (SCOWA) as the gain medium. SCOWAs have higher saturation power than commercially available semiconductor gain media in the telecom band. The increased optical power at the laser output allows the photodetected RF tone to have very high signal-to-noise ratio, resulting in very low phase noise. A high visibility optical frequency comb spanning ~2 nm (~25 comb-lines) of bandwidth is observed with optical SNR > 60dB.

8054-15, Session 4

Temporal shaping of ultrafast chirped pulses with 27 dB extinction ratio using an arbitrary waveform generator

D. Nguyen, M. U. Piracha, D. Mandridis, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Parabolic pulse generation in the time domain is experimentally demonstrated. Near transform limited pulses with gaussian-shaped optical spectra generated by a mode-locked laser are temporally stretched using dispersion compensating fiber. The temporal intensity profile of the stretched pulses matches the optical spectrum of the

laser, due to frequency-to-time mapping resulting from the linear dispersion introduced by dispersion compensating fiber. An intensity modulator is driven with a carefully designed electrical signal generated by an Arbitrary Waveform Generator, resulting in parabolic pulses. This electrical signal is calculated to incorporate the shape of the input pulses, nonlinear response of the modulator and the desired parabolic pulse shape. A mode-locked laser with a repetition rate of 2.4 MHz and optical bandwidth at full width half maximum of 6 nm was used. The pulses from this mode-locked laser are stretched using a dispersion compensating fiber of 10 km length and dispersion of 1530 ps/nm. The results of pulse shaping using this mode-locked laser source are presented, with residual error of less than 5% and extinction ratio of 27 dB. The results of pulse shaping using a CW laser source are also shown, with residual error of less than 3% and extinction ratio of 30 dB. In the future, this pulse shaping technique will enable the generation of high power pulses using chirped pulse amplification, followed by linear pulse compression.

8054-16, Session 4

Semiconductor-based low-noise 100 MHz chirped pulse laser source based on a theta cavity design with an intra-cavity etalon and long-term stabilization

D. Mandridis, C. G. Williams, I. Ozdur, A. Klee, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

This work discusses the development of a low repetition rate semiconductor based mode-locked laser having reduced noise. Specifically, we present a major upgrade on the 100 MHz harmonically mode-locked Theta (Θ) laser cavity design in the form of the introduction of an intra-cavity fiberized Fabry-Perot etalon. The initial demonstration of the Theta cavity design offered improved energy per pulse and a linearly chirped pulse output compared to conventional cavity designs. Nonetheless, it suffered from pulse-to-pulse timing and pulse energy noise. The noisy operation arises from the harmonic nature of the laser. To mitigate this effect we have inserted a fiberized etalon within the laser cavity.

The intra-cavity etalon stores and inter-mixes the pulses of the harmonically mode-locked laser, as well as enforces lasing on a single optical mode-set from the multiple interleaved sets supported by the mode-locked laser due to its harmonic nature. This leads in the generation of a stable optical frequency comb with 100 MHz spacing and the suppression of the RF super-mode noise spurs, which results in a reduction of the laser noise. Due to fiber length drift in both the fiberized laser cavity and the fiberized etalon, a long-term stabilization scheme is necessary. An intra-cavity Hänsch - Couillaud scheme is employed. The laser outputs chirped pulses with 10 nm of bandwidth.

This work provides an in depth analysis of both the development of the Theta cavity with the intra-cavity etalon and the performance of the developed laser system.

8054-17, Session 4

Long-range high-resolution lidar for velocity and distance measurements

M. U. Piracha, D. Nguyen, I. T. Ozdur, P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

A 20 MHz mode locked laser is used to generate optical pulses that are temporally stretched and frequency chirped by a chirped fiber Bragg grating with a dispersion of 1651 ps/nm. At the receiver, the target echo signal is interfered with a local oscillator signal to realize a coherent detection scheme that results in a beat signal with 30 dB Carrier to Noise ratio after photo detection. A shift of 500 MHz of the RF beat signal is observed for a change in the target distance of 1 mm. Distance measurements with sub-millimeter resolution are demonstrated at a target range of 10.1 km (in fiber). For unambiguous distance measurements, a phase modulator driven by a frequency swept RF drive signal is used to modulate each pulse at a slightly different frequency. At the receiver, when pulses interfere the relative difference in their phase modulation frequencies results in additional side bands on the RF spectrum. The frequency offset between the RF sidebands and the RF main tone is measured to obtain the target distance in terms of the number of pulses to remove range ambiguity, whereas the frequency of the main tone provides sub-millimeter resolution. For high resolution velocity measurements, a moving target is probed and data is acquired over several microseconds using a real time oscilloscope with Fourier analysis to reveal the shift of the RF beat frequency with change in target distance. Velocity measurements of targets moving at over 200 km/h are performed.

8054-18, Session 4

25Gbps 850nm photodiode for emerging 100Gb ethernet applications

D. A. Becker, A. Joshi, S. Datta, J. Rue, Discovery Semiconductors, Inc. (United States)

The IEEE Std 802.3ba-2010 for 40Gb and 100Gb Ethernet was released in July, 2010. This standard will continue to evolve over the next several years. Two of the challenging transmit/receive architectures contained in this standard are the 100GBASE-LR4 (<10km range) and 100GBASE-ER4(<40km range). Although presently envisioned for 1310nm optical wavelengths, both of these 4 lane, 25.78 GBaud formats may be adopted for the newly emerging 850 nm short reach optical backplane market, whose range is below 150m.

Driven by major computer server companies, such as IBM, HP and Oracle, the 850nm Active Optical Cable (AOC) market is presently undergoing an increase of serial rates up to 25Gbaud in order to enhance backplane interconnectivity. With AOCs up to 16 channels, the potential for up to 400 Gbps backhaul composite data rates will soon be possible.

We report a 25Gbps photodiode with a quantum efficiency greater than 0.55 over the 800nm to 1600 nm wavelength range. The InGaAs/InP device was optimized for high quantum efficiency at 850nm. When pigtailed with multimode fiber and integrated with an application-specific RF amplifier, the resultant photoreceiver can provide multiple functionalities for these 100Gb Ethernet markets.

8054-19, Session 5

Coherent optical communications and imaging

G. Li, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

No abstract available

8054-20, Session 6

Free-space optical communication link using spatial optical encryption

S. H. Murshid, W. Howard, Florida Institute of Technology (United States)

Free-space optical links are ideal for short-range (1 km to 3 km) communications. An innovative new technique called Spatial Optical Encryption can be used to secure laser data communications. With this technique, data can be encoded and transmitted spatially through a single fiber, and then transmitted over a free-space optical link. Different sources of data could be simultaneously sent over the same fiber.

This endeavor demonstrates the design and performance issues of such a transmitter and receiver using Spatial Optical Encryption over an environmental link of 100 meters.

8054-21, Session 6

Optical encryption as a function of polarization in optical fiber communications

S. H. Murshid, H. Muralikrishnan, J. Tamilarasan, Florida Institute of Technology (United States); H. J. Caulfield, Diversified Research Corp. (United States)

An optical encryption technique based on polarization property of light is proposed. Many techniques using polarization beam splitters to encrypt the signal have been proposed earlier. They are based on splitting and interference of two light signals, namely message and noise. Only by placing suitable mirrors and a second beam splitter in a suitable position, the two signals are reconstructed at the output.

In this paper we report the fiber optic version of a polarization based encryption technique that also has the potential to double the data carrying capacity of the fiber. Using polarization dependent couplers in the fiber optic cables, we are able to achieve encryption of the light signal. Theoretical analysis and simulated results are also presented.

8054-22, Session 6

A method of hardware support for high-speed data capture at 40 Gbps and beyond

J. S. White, A. W. Pilbeam, Everis, Inc. (United States)

Current high speed networks have reached a throughput capacity in practical implementation of up to OC-768. To date, commercial of the shelf (COTS) hardware cannot meet the requirements for full data capture at these rates. When c In this paper, we first provide an analysis of capabilities of best available hardware. We then propose a method for non-standard configuration of hardware to provide for high speed data capture at 40 Gbps and beyond. This configuration will provide a suitable hardware back-end to enable transport, storage, and processing of the 40+ Gbps full duplex captured data to enable forensics without disposing of any potentially valuable information.

8054-23, Session 7

An analysis of coupling attacks in high-speed fiber optic networks

J. S. White, A. W. Pilbeam, Everis, Inc. (United States)

Much work to date has been done in the identification of physical layer optical network attacks. Our own work has shown the addition of attacks against data integrity through various forms of optical coupling. In this paper, we present an analysis of coupling attacks on a fiber optic link. We then demonstrate on such form of a coupling attack using standard hardware and allowing injection of additional data onto the fiber. This method introduces minimal power loss that is well below most physical layer intrusion detection sensor thresholds. We discuss the severity of this threat from a feasibility and financial standing. We end with a suggestion for mitigating these types of attacks using affordable logical techniques.

8054-24, Session 7

Attenuation and bit error rate for four copropagating spatially multiplexed optical communication channels of exactly same wavelength in step index multimode fibers

S. H. Murshid, A. Chakravarty, Florida Institute of Technology (United States)

Spatial domain multiplexing (SDM) utilizes co-propagation of exactly the same wavelength in optical fibers to increase the bandwidth by integer multiples. Input signals from multiple independent single mode pigtail laser sources are launched at different input angles into a single multimode carrier fiber. The SDM channels follow helical paths and traverse through the carrier fiber without interfering with each other. The optical energy from the different sources is spatially distributed and takes the form of concentric circular donut shaped rings, where each ring corresponds to an independent laser source. At the output end of the fiber these donut shaped independent channels can be separated either with the help of bulk optics or integrated concentric optical detectors.

This presents the experimental setup and results for a four channel SDM system. The attenuation and bit error rate for individual channels of such a system is also presented.

8054-25, Session 7

Nonlinearity compensation for dispersion managed fiber-optic transmission systems

L. Zhu, G. Li, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We apply nonlinearity compensation to dispersion managed fiber-optic systems. The performance of QPSK transmission over transoceanic distances can be significantly improved by nonlinearity compensation at a low computational cost.

8054-26, Poster Session

Mode-locked fiber laser using SU-8 resist incorporating carbon nanotubes

I. Hernandez-Romano, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); D. Mandridis, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); D. A. May-Arrioja, Univ. Autónoma de Tamaulipas (Mexico); J. J. Sanchez-Mondragon, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); P. J. Delfyett, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Recently, Single Wall Carbon Nanotubes (SWCNTs) have attracted attention due to their optical nonlinearity, ultrafast recovery time, and high damage threshold. They can be used to fabricate saturable absorbers which can be inserted in a cavity laser in order to have a passive mode-locked laser. Since these lasers can generate stable short pulses, they can be used in many different optical areas such as spectroscopy, optical communication, and biomedical applications. In this work we present the fabrication of a thin film based on a novel composite material made of SU-8 doped with SWCNTs and its application as a saturable absorber. The SU-8 polymer is a well known and cheap material for microfabrication, and it has high glass transition temperature (210 °C). Since SU8 is photosensitive, its potential use for integrated waveguide devices provides a nice ground for their study. The fabrication process requires few and very simple steps to achieve well dispersed SWCNTs, and the film thickness can be also accurately controlled (100 µm). A passive mode-locked fiber laser in a ring cavity configuration was built and this film was set between to angle connectors. Index matching liquid

was not used because the FC/APC connectors eliminate undesired reflections. The linear transmission of the SU8-2075/SWCNT film at 1550 nm was about 67.5 % (including connector loss). Self-starting passively mode-locked laser operation was observed by means of this film. The generated pulses have a width of 871 fs at a repetition rate of 21.26 MHz and the average power was 0.95 mW.

8054-27, Poster Session

Impairment compensation for unrepeatered fiber transmission with distributed Raman amplification

L. Zhu, E. F. Mateo, G. Li, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We propose and numerically demonstrate impairment compensation via digital backward propagation (DBP) for fiber transmission with distributed Raman amplification. In contrast to EDFA-based systems, signal power evolution in the distributed amplified system has to be obtained prior to DBP by solving the differential equations for Raman amplification. The optimum launching power of an unrepeatered Raman link is significantly increased by nonlinearity compensation.

8054-28, Poster Session

Description of various test scenarios for temporary blinding of pilots by means of bright optical radiation during darkness

H. Reidenbach, Fachhochschule Köln (Germany)

It is well-known that dazzle, flash-blindness and afterimages may be caused by a low power laser beam, particularly under low ambient light conditions. This may have indirect general safety implications resulting from temporary disturbance of vision.

Up to now the knowledge is limited as far as the adverse effects are concerned, but it is mandatory to be aware of the degree and influence on various visual functions, especially under mesopic or even scotopic conditions. Therefore various test scenarios have been designed and bright optical radiation from high-brightness LEDs and laser products applied as blinding light sources in order to simulate the temporary blinding of pilots during a night-flight. As an important realistic test object the primary flight display of a commercial aircraft has been integrated in the respective test setup and various alignments could be adjusted. The pilot's flight deck lighting situation from a full flight simulator A320 has been incorporated in the test scenarios.

The beam diameter of the respective blinding light source was enlarged at least such that both eyes became irradiated simultaneously. The subjects looked either into the light source or fixed onto the flight display during the irradiation. The level of exposure of test subjects has been limited in all cases well below the maximum permissible exposure, i. e. 10 W/m2 and the exposure duration was chosen up to 10 s. All tests have been video recorded in order to measure pupil constriction and other reactions of the subject during irradiation.

As a critical value especially the visual search time (VST), i. e. the time to identify a parameter on the primary flight display during or after a disturbing irradiation, was determined. A total of 24 subjects have been included in the various tests.

An increase of VST between 2.5 s and 14 s under foveal irradiation has been determined. The afterimage duration was between about 0.4 minutes and 3.5 minutes under mesopic conditions. Various pupil diameters and aversion responses of the subjects during the irradiation might be responsible for the relatively large spread of data, but on the other hand a simple mean value would not comply with the spectrum of functional relationships and possible individual physiological and active reactions of the irradiated persons.

The results of these pilot tests have shown the feasibility in principle with the help of a simulated cockpit scenario and will be integrated in an extensive research project.

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8055-01, Session 1

Autonomous learning approach for automatic target recognition processor

T. Chao, T. Lu, Jet Propulsion Lab. (United States)

No abstract available

8055-02, Session 1

Tracking illegally parked vehicles using correlation of multiscale difference of Gaussian filtered patches

B. K. Mitra, W. Hassan, N. Bangalore, P. M. Birch, R. C. D. Young, C. Chatwin, Univ. of Sussex (United Kingdom)

Detection and tracking of illegally parked vehicles are usually considered as crucial steps in the development of a video-surveillance based traffic-management system. The major challenge in this task lies in making the tracking phase illumination-change tolerant. The paper presents a two-stage process to detect vehicles parked illegally and monitor these in subsequent frames. Chromaticity and brightness distortion estimates are used in the first stage to segment the foreground objects from the remainder of the scene. The process then locks onto all stationary `vehicle'-size blobs, parts of which overlap with the regions of interest marked interactively a priori. The second stage of the process is applied subsequently to track all the illegally parked vehicles detected during the first stage. All the locked patches are filtered using a difference-of-Gaussian (DoG) filter operated at three different scales to capture a broad range of information. In succeeding frames patches at the same locations are similarly DoG filtered at the three different scales and the results matched with the corresponding ones initially generated. A combined score based on correlation estimates is used to track and confirm the existence of the illegally parked vehicles. Use of the DoG filter helps in extracting edge based features of the patches thus making the tracking process broadly illumination-invariant. The two-stage approach has been tested on the United Kingdom Home Office iLIDS dataset with encouraging results.

8055-03, Session 1

Remote sensing of cardiopulmonary activity using Doppler radar

J. F. Khan, G. V. Murphy, S. M. A. Bhuiyan, Tuskegee Univ. (United States); M. S. Alam, Univ. of South Alabama (United States)

Remote non-contact monitoring and detection of physiological activity such as human cardiopulmonary activity could be an essential technique for health care applications. It could also be an important application in emergency and security applications where detection and monitoring can be done remotely. Remote sensing approach is required for the applications where it is important to minimize disruption of the object's activity, especially for prolonged monitoring. Doppler radar remote sensing of object's motion has shown promise to these prospects for various applications. Additionally, Doppler radar has the ability to perform at a distance through different barriers such as cloths or walls. Thus the system would be applicable for both health care and security applications. In this paper, we investigated the application of Doppler radar for detecting and monitoring human cardiopulmonary activity such as the heart rate and respiratory rate. Doppler radar sensing has some problems of loosing useful signal power and in distinguishing the desired heart and respiratory signals from other interfering signals. In this paper, we will also focus on overcoming these fundamental problems of useful signal loss using multi-antenna system; and separating signals from multiple objects through frequency and spatial techniques. Additionally, our research will focus on using the Doppler Radar assembly for other possible remote life sensing applications where it is not desirable to interrupt the object during detection.

8055-04, Session 1

ATR using passive 3D photon counting images

A. Mahalanobis, Lockheed Martin Missiles and Fire Control (United States); B. Javidi, Univ. of Connecticut (United States)

No abstract available

8055-05, Session 2

Monolithic liquid crystal waveguide Fourier transform spectrometer for gas species sensing

T. Chao, T. Lu, M. Boesen, D. Keymeulen, Jet Propulsion Lab. (United States); S. R. Davis, G. Farca, Vescent Photonics Inc. (United States)

No abstract available

8055-06, Session 2

Feasibility breadboard demonstration of an imaging Fourier transform spectrometer using solid state time delay

T. Chao, T. Lu, Jet Propulsion Lab. (United States)

No abstract available

8055-07, Session 3

Parameter optimization of the Optimal Trade-off Maximum Average Correlation Height filter (OT-MACH) for FLIR imaging in high clutter environments

A. T. Alkandri, Univ. of Sussex (United Kingdom) and Kuwait Naval Force (Kuwait); A. A. Gardezi, R. C. D. Young, P. M. Birch, C. Chatwin, Univ. of Sussex (United Kingdom)

The OT-MACH filter can be used to detect and discriminate predefined targets from a highly cluttered background. A frequency domain implementation of the Optimal Trade-off Maximum Average Correlation Height (OT-MACH) filter has been optimized to classify target vehicles acquired from a Forward Looking Infra Red (FLIR) sensor. Previously, several models have been used for the estimation the background clutter such as approximation as white noise or the averaged power spectral density of typical clutter scenes. However, the clutter noise does not have a white spectrum and models employing the power spectral density of the background clutter require a predefined threshold. In this paper we present a method of automatically adjusting a white noise power model using background image statistics. Parameter surfaces for the three OT-

MACH variables, a, b and g are calculated in order to determine optimal operating conditions for the view independent recognition of vehicles in highly cluttered FLIR imagery. Tests are conducted on real FLIR imagery to ascertain the filter's performance.

8055-08, Session 3

Enhancement of the speed of space-variant correlation filter implementations by using low-pass pre-filtering for kernel placement and applications to real-time security monitoring

A. A. Gardezi, A. T. Alkandri, P. M. Birch, R. C. D. Young, C. Chatwin, Univ. of Sussex (United Kingdom)

A space domain implementation of the Optimal Trade-off Maximum Average Correlation Height (OT-MACH) filter can not only be designed to be invariant to change in orientation of the target object but also to be spatially variant, i.e. the filter function becoming dependant on local clutter conditions within the image. Sequential location of the kernel in all regions of the image does, however, require excessive computational resources. An optimization technique is discussed in this paper which employs low-pass filtering to highlight the potential region of interests in the image and then restricts the movement of the kernel to these regions to allow target identification. The detection and subsequent identification capability of the two-stage process has been evaluated in highly cluttered backgrounds using both visible and thermal imagery and associated training data sets. A performance matrix comprised of peak-to-correlation energy (PCE) and peak-to-sidelobe ratio (PSR) measurements of the correlation output has been calculated to allow the definition of a recognition criterion. A feasible hardware implementation for potential use in a security application using the proposed two-stage process is also described in the paper.

8055-09, Session 3

Multifeature constellation correlation filters

C. Casey, L. Hassebrook, A. Davidson, E. Crane, Univ. of Kentucky (United States)

Many applications require detection of multiple features which may globally change position with respect to one another, but which remain locally consistent in shape and intensity characteristics. We refer to these feature sets, defined by their characteristic relative positioning, as multi-feature constellations. The process described herein utilizes a multi-level correlation method to detect these constellations.

The method is summarized as follows: the features are first localized via correlation with feature specific composite detector filters. Next, the results of the first level feature detections are combined into a single image and summarily correlated with a constellation-specific detection filter. This second level correlation facilitates distortion-insensitive detection of the overall multi-feature constellation.

Without loss of generality, the method is described and analyzed in the context of 1D signal processing. It is shown that the method offers notable improvement over traditional single-level correlation detection by reducing the sensitivity of the detector to the translation of individual features within a constellation pattern.

8055-10, Session 3

Distortion-invariant color pattern recognition using multiple phase-shifted-reference-based joint transform correlation incorporating synthetic discriminant function

M. N. Islam, Farmingdale State College (United States); M. A. Karim, Old Dominion Univ. (United States)

This paper proposes a new pattern recognition system employing optical joint transform correlation (JTC) technique which offers a great number of advantages over similar digital techniques, including very fast operation, simple architecture and capability of updating the reference image in real time. The proposed JTC technique incorporates a synthetic discriminant function (SDF) of the target image estimated from different training images to make the pattern recognition performance invariant to noise and distortion. It then involves four different phase-shifted versions of the same target SDF reference image, which are individually joint transform correlated with the given input scene. When the correlation signals are combined, it produces a single cross-correlation peak corresponding to each potential target present in the given input scene. The proposed technique also includes a fringe-adjusted filter to generate a delta-like correlation peak with high discrimination between the target and the background noise. The pattern recognition performance is further enhanced by incorporating the color information of the target objects in the proposed technique. The proposed technique is investigated using computer simulation where it shows efficient and successful target detection performance in different complex environments.

8055-11, Session 3

Automatic angle measurement of a 2D object using optical correlator-neural networks hybrid system

N. Manivannan, Brunel Univ. (United Kingdom); M. A. Neil, Imperial College London (United Kingdom)

In this paper a new method is proposed and demonstrated to automatic measurement of a 2D object using a hybrid architecture which consists of of a 4f optical correlator with binary phase only multiplexed matched filters and a single layer neural network. The hybrid set-up can be considered as a two-layer perception neural networks; optical correlator is the first layer and the standard single layer neural network is the second layer. The training scheme used to train the hybrid architecture is a combination of Direct Binary Search algorithm which is used to train the optical correlator and Error Back Propagation algorithm which is used to train the neural network. It is aimed to keep the major information processing performed by optical correlator with a little processing by the neural network stage. This allows the system to be used for real-time applications as optics has inherent ability to process information in full parallel manner at the speed of light. The neural network stage gives an extra dimension of freedom so that complicated tasks like automatic angle measurement can be achieved. Results of both computer simulation and experimental set-up are presented for angle measurement of an English alphabetic character. Experimental set-up consists of a real optical correlator using two spatial light modulators for input and frequency plane representations and a PC-based model single layer network.

8055-30, Session 3

Wide-area surveillance with multiple cameras using distributed compressive imaging

C. Huff, Univ. of Central Florida (United States); R. R. Muise, Lockheed Martin Missiles and Fire Control (United States)

In order to image a large area with a required resolution, a traditional camera would have to scan a smaller field-of-view until the entire area of interest is covered, thus losing persistence. Using a large sensor will result in high bandwidth data streams along with expensive and heavy equipment. One is left with trying to sense (or measure) a large number of pixels with a very limited set of measurements. This issue is precisely what the theory of compressive sensing is trying to resolve. Compressive sensing tries to design a reduced set of measurements which captures the information in the image and then reconstructs the entire image. A single sensor compressive imager for the wide area surveillance problem has been postulated and shown to be effective in detecting moving targets in a wide area. In this paper we look at the compressive imaging problem by assuming we have multiple cameras at our disposal (Distributed Compressive Imaging DCI). We show that we can get significant benefit in image reconstruction from multiple cameras measuring overlapped fields-of-view without any intra-camera communications and under significant transmission bandwidth constraints. We also show analysis and experiments which suggest that we can register these multiple cameras given only the random projective measurements from the compressive sensing theory.

8055-13, Session 4

Optimization of nonlinear kernel PCA feature extraction algorithms for automatic target recognition

S. Winger, Stanford Univ. (United States); T. Chao, T. Lu, Jet Propulsion Lab. (United States)

No abstract available

8055-14, Session 4

Moving object tracking by using a novel real-time 2D image processing method

C. J. Hu, Southern Illinois Univ. Carbondale (United States)

As we reported in many Pattern Recognition Conferences in this country, e.g., the most recent paper was published in Proceedings IS&T/SPIE, vol.7539, pp OU1-OU7, 1-19-2010, we can use the novel LPED (Local polar edge detection) method, to capture the boundary of a temperature-selected object in any digital image, e.g., a JPEG image, in real-time, and form a compact 36-dimension analog vector B to represent the boundary of the object anchored at the center of mass, or CM, of this object. If the object moves, the VB6 program we designed will automatically track the object movement along the trajectory of the CM and measure the distance of movement as well as the angle of orientation change, if the object orientation changes during the movement. The measurement is obtained instantly in “real-time” within one image capturing time interval.

This paper reports the analytical basis of the measurement, in the 36-dimension Euclidean space as we reported in the above quoted paper. It also reports in detail the experimental result on the LPED method we developed. This novel image processing method, with some modifications, can also be adapted for tracking multiple moving-objects in real-time.

8055-15, Session 4

A compressed sensing method with analytical results for lidar feature classification based on height gradient density features

J. D. Allen, Harris Corp. (United States); X. Liu, The Florida State Univ. (United States); M. D. Rahmes, Harris Corp. (United States)

We present an innovative way to autonomously classify LiDAR points from a Digital Surface Model (DSM) into bare earth, building, vegetation, and other categories. One desirable product of LiDAR data is the automatic classification of the points in the scene. Our algorithm automatically classifies scene points using Compressed Sensing Methods. We propose a new method for constructing local features from height-based raster data, which can be used to recognize different objects with distinctive height properties. The features are designed to classify different regions to belong to different objects as predefined in a dictionary. We introduce the compressed sensing technique or sparse representation to deal with the classification issue. Meanwhile, a dictionary is constructed by randomly choosing partial features from the training samples. The benefit of this technology is to reduce manual editing while being cost effective for large scale automated global scene modeling. Quantitative analyses are provided using Receiver Operating Characteristics (ROC) curves to show Probability of Detection and False Alarm of buildings vs. vegetation classification. Histograms are shown with sample size metrics. Our inpainting algorithms then fill the voids where buildings and vegetation were removed, utilizing Computational Fluid Dynamics (CFD) techniques and Partial Differential Equations (PDE) to create an accurate Digital Terrain Model (DTM). Inpainting preserves building height contour consistency and edge sharpness of identified inpainted regions. Qualitative results illustrate other benefits such as Terrain Inpainting’s unique ability to minimize or eliminate undesirable terrain data artifacts

8055-16, Session 5

Optical correlation via dynamic range compression using organic photorefractive materials

B. Haji-saeed, J. Khoury, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States)

In this paper we demonstrate our optical correlation results via organic photorefractive two-beam coupling. Our correlation is based on coupling between the clean reference beam and the joint spectra of the reference image and the target of interest. For the first time in the area of optical correlation, we show outstanding results with complex input data.

8055-17, Session 5

Optical dynamic range compression deconvolution and correlation using organic photorefractive materials

J. Khoury, B. Haji-saeed, C. L. Woods, Air Force Research Lab. (United States)

Imaging in atmospheric turbulence and target recognition in cluttered environment have been a research topic for many years. Currently, there are some well-established techniques for image restoration and recognition. However, if the atmospheric turbulence becomes a severe scattering medium and the surrounding environment is very cluttered, most conventional methods such as inverse filtering and Wiener filtering, won’t be adequate for correcting and recognizing the captured images. In this paper we demonstrate experimentally, nonlinear dynamic range compression techniques for image restoration and correlation via two-beam coupling and four wave mixing in organic photorefractive films.

8055-25, Poster Session

Kernel and stochastic expectation maximization fusion for target detection in hyperspectral imagery

M. I. Elbakary, M. S. Alam, Univ. of South Alabama (United

States)

In this paper, we present a new algorithm for target detection using hyperspectral imagery. The proposed algorithm is inspired by the outstanding performance of nonlinear RX-algorithm and the robustness of the stochastic expectation maximization (SEM) algorithm. The traditional technique of using SEM algorithm for target detection in hyperspectral imagery is associated with dimensionality reduction of the input data using binning or principal components analysis (PCA) algorithm. Although, the data reduction of the input data is enforced to reduce the computational burden on SEM algorithm, but it affects the results of target detection, especially the challenging one, due to not using the entire information of the potential targets. To facilitate detection of the target by using the entire targets information and simultaneously reducing the computational burden on SEM algorithm, we propose a new scheme for data reduction based on using Kernels. Kernel-based input data reduction is a nonlinear filtering technique in which the input data are mapped to the feature space where most of the background data is filtered using an easily selected threshold. Then, Gaussian mixture model is generated for the reduced input-data and SEM algorithm is employed to estimate the model parameters and to classify that input data. Finally, we allocated the target's class and isolated the target pixels. The proposed scheme for fusion the kernel with SEM algorithm has been tested using real life hyperspectral imagery and the results show superior performance compared to alternate algorithms.

8055-26, Poster Session

Spectral pattern recognition of controlled substances in street samples using artificial neural network system

L. Porovkina, V. Aleksejev, S. M. Babichenko, Laser Diagnostic Instruments AS (Estonia)

The NarTest fluorescent technique is aimed at the detection of analyte of interest in street samples by recognition of its specific spectral patterns in 3-dimentional Spectral Fluorescent Signatures (SFS) measured with NTX2000 analyzer without chromatographic or other separation of controlled substances from a mixture with cutting agents. The illicit drugs have their own characteristic SFS features which can be used for detection and identification of narcotics, however typical street sample consists of a mixture with cutting agents: adulterants and diluents. Many of them interfere the spectral shape of SFS. The characteristic fluorescence of controlled substances can be quenched and decreased in intensity, fluorescent pattern can be distorted due to overlapping with the fluorescence of cutting agents or due to re-absorption processes connected with not-fluorescent cutting agents. The expert system based on Artificial Neural Networks (ANNs) has been developed and applied for such pattern recognition in SFS of street samples of illicit drugs.

Taking into account the variability of spectra due to the influence of cutting agents, the ANN was selected as a most promising tool for pattern recognition. The ANN possesses learning ability, and as a result the detection capability of ANNs can be improved by involving newly measured data into repeated training process. It provides extending the range of detectable concentrations of controlled substances in street samples, precluding false-positive and minimizing false-negative results of analysis.

The Nartest ANNs were trained using substantial number of SFSs of neat narcotics, laboratory mixtures with commonly used adulterants and diluents, pure adulterants, the substances that can be seized, and real street samples. The ANNs are constantly updated thus the accuracy and reliability of the method are improved continuously. The result of the analysis with Nartest ANNs is “YES” or “NO” regarding the recognition of controlled substance in a sample. Moreover, the accuracy of NarTest technique is increased by the use of developed confirmatory analysis procedures including chemical treatment with simple reagents and subsequent application of additional ANNs. In such approach several ANNs are used for identification and detection of controlled substances in sample considerably improving the reliability of analysis.

8055-27, Poster Session

Study on the relationship between image features and detection probability based on psychology experiments

W. Lin, Canbao Engineering Design & Research Institute of Beijing (China) and Beijing Institute of Technology (China); Y. Chen, J. Wang, H. Gao, W. Mao, J. Wang, R. Su, Canbao Engineering Design & Research Institute of Beijing (China)

The detection probability is an important index to characterize and estimate target detectability, which provides the basis for target recognition and decision-making. But in practice, it will expend a mass of time and manpower to obtain this detection probability. At the same time, due to the different interpretation of personnel practice knowledge and experience, a great difference will often exist in the datum obtained. By means of studying the relationship between image features and psychosensorial quantity based on psychology experiments, the probability model has been established in which the process is as following: Firstly, four image features have been extracted and quantized which affect directly detection, and using the Bhattacharyaa distance the feature similarity degrees between target region and background region have been defined. Secondly, the relationship between single image feature characteristics and psychosensorial quantity has been established based on psychological principle, and the psychology experiments of target interpretation have been designed which include about five hundred personnel for interpretation and two hundred images. In order to reduce correlation between image features, a lot of artificial synthesis images have been made which include images with single brightness feature difference, images with single chromaticity feature difference, images with single texture feature difference and images with single shape feature difference. By analyzing and fitting a mass of experimental datum, the parameters of the model have been determined. Finally, by applying statistical decision theory and experimental results, the relationship between psychosensorial quantity and target detection probability has been found. With the verification of a great deal of target interpretation in practice, it shows that the target detection probability can be obtained by the model quickly and objectively.

8055-28, Poster Session

The concept models and implementations of multiport neural net associative memory for 2D patterns

V. G. Krasilenko, Vinnitsa Social Economy Institute (Ukraine); A. I. Nikolskyy, Vinnytsia National Technical Univ. (Ukraine); R. A. Yatskovskaya, V. I. Yatskovsky, Vinnitsa State Agrarian Univ. (Ukraine)

The paper considers neural net models and training and recognizing algorithms with base neurobiologic operations: equivalence and non-equivalence The Modified equivalental models (MEMs) of multiport neural net associative memory (MNNAM) are offered with double adaptive -equivalental weighing (DAEW) for recognition of 2D-patterns (images). It is shown, the computing process in MNNAM under using the proposed MEMs, is reduced to two-step and multi-step algorithms and step-by-step matrix-matrix (tenzor-tenzor) procedures. The given results of computer simulations confirmed the perspectiveness of such models. Besides the result was received when MNNAM capacity on base of MEMs exceeded the amount of neurons.

EM of HAM investigation and the results of modeling on the concrete samples showed that such models can successfully function under unipolar coding of multi-gradation and binary gradation images of considerable dimention (1024 neurons) and have considerable capacity (25-400 percent of N and more) and make possible to recognize vectors with considerable percentage of the damaged components (up to 25 percent). Were guided by more high-speed SLM, we shall take quite achievable meanings: 128*128 pixels and twr=0.1ms. For such choice and the whole time of recalculation of a network will make »0.4s. Then transfer of neurons 128*128»16*103 the quantity of interconnection will make 256*106 » 0.25*109, and size equal approximately of 109 connections per one second will estimate the productivity of system. Summing up we see that at identical speeds of recalculation of connections in NN the second architecture with temporary integration has considerably large dimension NN and more simple design.

8055-29, Poster Session

Text encryption via double-random phase encoding

J. Sang, S. Ling, Chongqing Univ. (China); M. S. Alam, Univ. of South Alabama (United States)

Double-random phase-encoding based image hiding method was employed to text. The ASCII codes of the text information were denoted as binary, and transformed to a 2-dimentional array as an image. The elements in the array were valued from 0 to 255, in which the highest 2 bits or the highest 4 bits were stored with the binary bits of the text information, while the lower bits were filled with some binary bits. Then, the double-random phase-encoding method was used to encode the array, and the encoded array was embedded into an extended host image to achieve text information hiding. The experimental results show that the hidden text can be recovered correctly with the ratio of 99.89% and 100% by storing the binary bits of the text information to the highest 4 bits and the highest 2 bits of the transformed array, respectively. The proposed method can improve the security of text information transmission, while the hiding capacity is high.

8055-18, Session 6

Robust human intrusion detection techniques using and hue-saturation histogram

W. Hassan, B. K. Mitra, N. Bangalore, P. M. Birch, R. C. D. Young, C. Chatwin, Univ. of Sussex (United Kingdom)

A robust human intrusion detection technique using hue-saturation histograms is presented in this paper. Initially a region of interest (ROI) manually is identified in the scene viewed by a single fixed CCTV camera.

All objects in the ROI are automatically demarcated from the background using brightness and chromaticity distortion parameters. The segmented objects are then tracked using correlation between hue-saturation based bivariate distributions. The technique has been applied on all the 'Sterile Zone' sequences of the United Kingdom Home Office iLIDS dataset and its performance is evaluated with over a 70% positive results.

8055-19, Session 6

Accurate, fast, and secure biometric recognition system utilizing sensor fusion of same pattern

S. Alsharif, A. M. El-Saba, Univ. of South Alabama (United States)

Fingerprint recognition is one of the first techniques used for automatically identifying people and today it is still one of the most popular and effective biometric techniques. With this increase in fingerprint biometric, issues related to accuracy, security and processing time are major challenges facing the fingerprint recognition systems. Previous work has shown that polarization enhancementencoding of fingerprint patterns increase the accuracy and security of fingerprint systems without burdening the processing time. This is mainly due to the fact that polarization enhancementencoding is inherently a hardware process and does not have detrimental time delay effect of the overall process. Unpolarized images, however, posses a high visual contrast and when fused (without digital enhancement) properly with polarized ones, is shown to increase the recognition accuracy and security of the biometric system without any processing time delay.

8055-20, Session 6

Arabic handwritten optical character recognition using hidden Markov models

M. M. Olama, Oak Ridge National Lab. (United States); M. Aulama, A. Natsheh, G. Abandah, The Univ. of Jordan (Jordan)

The problem of handwritten Arabic optical character recognition (OCR) has not acquired an available satisfactory solution yet. Oak Ridge National Laboratory (ORNL) together with the University of Jordan have developed an Arabic OCR algorithm based on Hidden Markovian Models (HMMs) combined with the Viterbi algorithm that result in an improved and more robust recognition on the sub-word level. Integrating the HMMs represents another step of the overall OCR trends being currently researched in the literature. The proposed approach moves from the character recognition scope to the word scope, giving a more robust character recognition pipeline. Useful statistical information of the Arabic language is initially extracted and then used to estimate the probabilistic parameters of the mathematical HMM. A new custom implementation of the HMMs is developed in this study, where the transition matrix is built based on the collected large corpus, and the emission matrices are built based on the results obtained via the developed tool. The recognition process is triggered using the Viterbi algorithm which employs the most probable sequence of sub-words. The model was implemented to recognize the sub-word unit of Arabic text raising the recognition rate from being linked to the worst recognition rate for any character to the overall structure of the Arabic language. Numerical results are presented to show the viability of the proposed algorithms.

8055-22, Session 7

Error correction in image registration using POCS

P. Duraisamy, Univ. of North Texas (United States); M. S. Alam, Univ. of South Alabama (United States)

Image registration plays a vital role in many real time imaging applications. Registering the images in a precise manner is a challenging problem. In this paper, we focus on accurate image registration using the projection onto convex sets (POCS) techniques which improves the subpixel accuracy in the images leading to better image registration. We also improved the processing speed of POCS by using smart preprocessing steps. The results obtained from the proposed technique matches well with the ground truth which validates the accuracy of this technique. Furthermore, the proposed technique show better performance compared to existing methods

8055-23, Session 7

Sampling balanced system for point target detection

Y. Danziger, Rafael Advanced Defense Systems Ltd. (Israel)

Imaging systems designed for point target detection and 3D reconstruction must be filtered in order to maximize signal-to-noise ratio and minimize position expectation error. An optimal whitening matched filter (WMF) is derived based on expected spatial target distribution and system colored noise. The expected noise is derived as a weighted combination of clutter aliasing, target aliasing, and detector noise. Further optimization of system performance is achieved by modification of the optical point spread function (PSF), so a sampling-balanced operation is achieved where all noise components are comparable. The improved performance of the optimized system is calculated and

compared to the performance of other systems using other known linear post-filters with various optical PSF widths. It is shown that the WMF in a sampling-balanced system is a robust configuration that needs only minor modifications when scenario parameters are varied.

8055-24, Session 7

A novel bag of visual words approach for geospatial object recognition

C. Aytekin, A. A. Alatan, Middle East Technical Univ. (Turkey)

In this work, a novel geospatial object recognition method based on a bag of visual words approach is presented. The traditional codebook approach describes an object with a histogram (distribution) of descriptors over a predefined number of visual words by hard or soft assignment. These visual words are generally formed by clustering descriptors of some extracted keypoints/frames belonging to the object that is to be recognized. In this work, for keypoint extraction and keypoint description SIFT algorithm is used and clustering is achieved by K-means algorithm. Exploiting the fact that spatial images can be taken from a known altitude, scales of keypoint descriptors, which is automatically extracted by SIFT algorithm, are added as an additional descriptor element. Another novel idea presented in this paper is to add a weight for each visual word during the assignment stage. The main idea is to give more importance to the discriminative visual words; the words occurring more in ground truth and less in non-object images in the training set or vice versa. After obtaining the histograms, for both noise reduction and better performance achievement, a principal component analysis is applied. Another advantage of PCA is to reduce the visual-word number utilized; thus, to reduce the computational complexity. In the final stage, an SVM classifier is used for learning and classification of new images. The traditional codebook approach is compared with the proposed method for a set of satellite images and a notable performance increase is achieved.

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8056-01, Session 1

Impulse noise detection and removal using multiple weighted median filters

D. Charalampidis, N. R. Vayuvegula, The Univ. of New Orleans (United States)

Median filters are effective in reducing impulse noise in images. Yet, the performance of median filters is limited under image corruption by significant amounts of noise. High levels of noise require utilization of large median filters, which, however, tend to remove fine image details. In order to solve this problem, techniques have been developed in the literature for identifying noisy pixels and applying generalized forms of the median filter only for those noisy pixels. As a result, noise-free pixels do not get affected by median filtering. Recently, a method in which noisy pixels were identified based on the information extracted from four directional neighborhoods was developed. The technique used four directional weighted median filters to restore noisy pixels. By considering different neighborhoods around each pixel, the finer details of the image, such as thin lines, are preserved, even after filtering is applied. This is achieved by replacing noisy pixels by the median filter output associated to the pixel neighborhood characterized by the least intensity variation, since such neighborhood is more likely to be noise-free. In this work, a new approach that uses additional weighted median filters, not necessarily having directional characteristics, is proposed. The goal of using multiple filters is to consider a larger number of neighborhoods in order to increase the possibility that at least one neighborhood includes relatively similar pixels. This goal is not necessarily achievable by using only directional filters. Experimental results indicate that the proposed technique achieves a higher SNR compared to the previous technique.

8056-02, Session 1

Mean squared error performance of speckle-imaging using the bispectrum in horizontal imaging applications

J. Bos, M. C. Roggemann, Michigan Technological Univ. (United States)

Starting with Labeyrie it was recognized that interferometric techniques could be used to overcome the effects of atmospheric turbulence. Unfortunately, estimation of the power spectrum using Labeyrie's method does not provide an estimate of the object phase necessary for image reconstruction. Borrowing from techniques used in radio astronomy at the time, Lohmann and others recognized that the cross (Knox-Thomson) and triple-correlation or bispectrum (in the spatial frequency domain) could be used to recursively recover the object phase. Equipped with an object amplitude and phase estimate it was then possible to estimate the complex image spectrum and thereby the image. This technique has been successfully in astronomical imaging applications to recover nearly diffraction-limited images of astronomical images using ground-based telescopes.

In this work, the application of speckle imaging using the bispectrum is explored in the context of horizontal imaging applications. A horizontal imaging simulator that includes anisoplanatic and spherical propagation effects was developed by the authors and used to generate three data sets with varied turbulence strength. In turn, these data sets were used to evaluate the performance of a bispectrum-based speckle-imaging algorithm in terms of Mean Squared Error (MSE). Point performance estimates indicate speckle imaging using the bispectrum is able to provide 79, 59, and 51 percent improvements in diffraction-relative MSE for low, moderate and severe turbulence cases when using 70 input frames. However, including 30 input frames provides nearly the same improvement in MSE and significant reductions were observed for a few as 10 input frames. Finally, a cursory examination of the estimator robustness indicates the deviations of only 10 to 14 percent when considering multiple independent data sets.

8056-03, Session 1

Modified bilateral-filter for illumination equalization

S. Brisebois, Rochester Institute of Technology (United States)

Varying illumination conditions through a scene is a common issue for classification, segmentation and recognition applications. Traffic monitoring and driver assistance systems have difficulty with the changing illumination condition between night and day, multiple sources (especially at night) and the presence of shadows. The majority of existing algorithms for color constancy or shadow detection attempting to solve the issue rely on multiple frames (for comparison or to build a background model). There are also hardware solutions explored to provide High-Dynamic Range images, which would permit to better differentiate a dark background (road asphalt) from shadows (only an example). The proposed approach modifies the Bilateral-Filter of C.Tomasi and R. Manduchi to equalize illumination across objects using a single frame. Neighbouring pixels of the same color but of different brightness are assumed to be of the same object/material. The closeness filter remains as in the original paper (a spatial Gaussian) but the similarity filter only compares hue and saturation (Gaussian of the difference in value). A third filter is added to maintain areas of even illumination, give more weight to brighter pixels and less weight to darker pixels. The behaviour of the filter is studied over day and night scenes of varying Dynamic Range with simulated and real images. A variety of filtering schemes are tested: the size of the filter kernels, the standard deviations of each filter and the number of passes. The objective is not to provide a product for visual inspection but rather an alternate image with less illumination related issues for other algorithms to process. The usefulness of the filter is demonstrated by using a k-means classifier and comparing accuracies.

8056-04, Session 1

Optimization approach in local image enhancement

N. Unaldi, S. Demirci, Turkish Air Force Academy (Turkey)

It is well known that human eyes perform much better than cameras when imaging real world scenes, which generally presents high dynamic range that can span more than six orders of magnitude. Human eyes have about 108:1 absolute range from fully adapted dark vision to fully adapted lighting conditions at noon on the equator. They can see about 3 104:1 range of luminance when adapted to a normal working range. This is achieved through a series of adaptive mechanisms for brightness perception. First, the size of pupil is variable to accommodate different levels of radiance from different regions in a scene while the camera aperture is fixed when capturing the scene. When staring at a highly-bright region in the scene, the pupil will shrink to compress the dynamic range so that the eyes can deal with it. Secondly, and more importantly, the major dynamic range compression process is taking place via the lateral processing at the retinal level. Finally, the early visual cortex is also found participating in some of the dynamic range processing.

In this paper, a new spatial domain image enhancement algorithm is proposed, in which high dynamic range of the scene illumination is compressed from the human visual perspective to improve the visual quality and visibility in digital images captured under varying lighting conditions. The enhancement process is taken as an optimization problem in which local image statics, namely the local standard deviation and the local mean in the image are maximized simultaneously using an intensity transform via an "S" shape curve whose curvature parameters are determined iteratively.

The image in hand is first converted into an intensity image which is divided into overlapped sub-regions and in each region the intensities are transformed iteratively so that the brightness and contrast in that region become greater than predefined values which are indicators of high visual quality. The calculated pixel values in the overlapped regions are weighted averaged, in which the weights are determined based on how far the pixels are from the region borders to provide a smooth transition. Finally, the color of the enhanced image is restored by simply multiplying the values of each color channel in the original image with the ratios calculated between the enhanced and original intensity image. Thus, image features such as edges, boundaries and local contrast are enhanced via adaptive local operations by which global dynamic range is compressed while local contrast is increased in a way human visual system (HVS) does.

Preliminary results are encouraging in showing the superiority of the proposed algorithm over the state-of-the-art enhancement techniques in terms of rendition and statistical visual quality measures.

8056-05, Session 2

A novel orientation code for face recognition

Y. Zheng, Alcorn State Univ. (United States)

A novel orientation code is proposed for face recognition applications in this paper. Gabor wavelet transform is a common tool for orientation analysis in a 2D image; whereas Hamming distance is an efficient distance measurement for multiple 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-band orientation codes are then organized into a face pattern byte (FPB) by using order statistics. With the face pattern byte, Hamming distances are calculated and compared to achieve face identification. Experimental results with visible and thermal face database show that the proposed method is very promising in contrast with other methods such as PCA.

8056-06, Session 2

Eye tracking and its application in human computer interfaces

T. Carroll, Univ. of Central Florida (United States); A. J. Rogers, Louisiana Tech Univ. (United States); D. Charalampidis, H. Chen, The Univ. of New Orleans (United States)

Eye tracking involves locating the pupil and recording its movements. By observing the movements of the pupil in real time it is feasible to calculate the gaze of an individual. Knowing the gaze on an individual can have immediate applications in mouse control. This can be beneficial for people with disabilities preventing them from interfacing with a computer through conventional means. Past research has focused on using infrared (IR) light and its characteristic effect on the pupil. Infrared techniques include Bright Pupil and Dark Pupil. Our research team decided against these past techniques due to the potential damage to the eye from infrared radiation. We opted instead to use optical cameras with no additional illumination since there has been insufficient research involving optical cameras. Moreover, past research mostly involves large computational times that rule out real-time performance.

By using a camera located near the eye, we are able to track pupil movements after a novel combination of image processing techniques. Once the pupil is isolated, the centroid can be located and tracked. We present a method to control the mouse using the pupil location relative to the calibration data points for the four corners of the screen. In addition, we present a simple method for blink detection and its possible applications in Human Computer Interfacing (HCI).

We used a Logitech QuickCam Pro 9000 (affixed to a hat).

8056-07, Session 2

Door surveillance using edge map-based Harris corner detector and active contour orientation

N. Bangalore, W. Hassan, B. K. Mitra, P. M. Birch, R. C. D. Young, C. Chatwin, Univ. of Sussex (United Kingdom)

Accurately generating an alarm for a moving door is a precondition for tracking, recognizing and segmenting objects entering or exiting the door. The challenge of generating an alarm when a door event occurs is difficult when dealing with complex doors, moving cameras, objects moving or an obscured entrance of the door, together with the presence of varying illumination conditions such as a door-way light being switched on. In this paper, we propose an effective method of tracking the door motion using edge-map information contained within a localised region at the top of the door. The region is located where the top edge of the door displaces every time the door is opened or closed. The proposed algorithm uses the edge-map information to detect the moving corner in the small windowed area with the help of a Harris corner detector. The moving corner detected in the selected region gives an exact coordinate of the door corner in motion, thus helping in generating an alarm to signify that the door is being opened or closed. Additionally, due to the prior selection of the small region, the proposed method nullifies the adverse effects mentioned above and helps prevent different objects that move in front of the door affecting its efficient tracking. The proposed overall method also generates an alarm to signify whether the door was displaced to provide entry or exit. To do this, an active contour orientation is computed to estimate the direction of motion of objects in the door area when an event occurs. This information is used to distinguish between objects and entities entering or exiting the door. A Hough transform is applied on a specific region in the frame to detect a line, which is used to perform error correction to the selected windows. The detected line coordinates are used to nullify the effects of a moving camera platform, thus improving the robustness of the results. The developed algorithm has been tested on all the Door Zone video sequences contained with the United Kingdom Home Office i-LIDs dataset, with promising results.

8056-08, Session 2

Submap joining smoothing and mapping for camera-based indoor localization and mapping

J. Rydell, J. Bjärkefur, A. Karlsson, C. A. Grönwall, Swedish Defence Research Agency (Sweden)

Positioning of first responders and military personnel is important for increasing the safety in emergency response and military operations. In GPS-denied environments (e.g. indoors), positioning is a difficult problem, and the demands on the positioning system are high: it should be small, light-weight, require little power and provide meter-level accuracy during extended operations. Possible solutions include systems based on one or more of RF, inertial sensors, and cameras.

Camera-based positioning systems often use SLAM (simultaneous localization and mapping) techniques, which means that they create a map of the environment and localize themselves relative to this map. The size of the map, and hence the computational complexity of the localization algorithms, grows with the size of the visited area. This presents a problem when operations are not constrained to very small spaces. A common solution to this problem is to divide the visited region into a number of small submaps which are later combined to form a final map of the region. Thereby relatively simple SLAM algorithms can be used to create the submaps, without sacrificing computational performance.

This paper presents a novel way of merging the submaps into one final map. The way this method merges submaps is similar to how SAM (smoothing and mapping) computes a map directly from landmark

observations. However, while SAM uses all landmark observations along the sensor trajectory, this method instead considers each landmark in a submap as just one observation. This reduces the complexity of the optimization problem significantly.

8056-09, Session 2

Designing the optimal convolution kernel for modeling the motion blur

J. Jelinek, Honeywell Technology (United States)

Motion blur acts on an image like a two dimensional low pass filter, whose spatial frequency characteristic depends both on the trajectory of the relative motion between the scene and the camera and on the velocity vector variation along it. When motion during exposure is permitted, the conventional, static notions of both the image exposure and the scene-to-image mapping become unsuitable and must be revised to accommodate the image formation dynamics. This paper develops an exact image formation model for arbitrary object-camera relative motion with arbitrary velocity profiles. Moreover, for any motion the camera may operate in either continuous or flutter shutter exposure mode. Its result is a convolution kernel, which is optimally designed for both the given motion and sensor array geometry, and hence permits the most accurate computational undoing of the blurring effects for the given camera required in forensic and high security applications. The theory has been implemented and a number of examples are shown in the paper.

8056-10, Session 3

Digital zoom algorithm with context derived basis functions

H. C. Schau, Meridian Systems LLC (United States)

One of the goals of superresultion has been to achieve interpolation in excess of some externally imposed physical constraint. Initially it was the optical diffraction limit while the Nyquist Limit of sampled data systems has also become a more recent issue. Regardless of the setting, the limitations are the same; there generally is not enough available degrees of freedom to perform an interpolation without severe loss of information. While some success has been achieved in superresolution, magnification is generally limited to less than 2. In this paper we present a method where context based basis functions are developed for digital zoom where the magnifications were assumed to be greater that 2. The number of degrees of freedom are still less than the number formally required, because the basis functions are developed for scenes similar to scenes presented for interpolation, they are more efficient than those developed without regard to context.

The technique is presented together with several still images and video examples of digital zoom for a magnification of 5. Results are compared with conventional B-Cubic Spline interpolation. Parallelization of the technique with graphic processors is discussed toward its real time implementation.

8056-11, Session 3

Super-resolution of time-lapse seismic images

S. E. Zarantonello, Algorithmica LLC (United States) and Santa Clara Univ. (United States); B. J. Smithson, Santa Clara Univ. (United States); D. Bevc, 3DGeo Development, Inc. (United States); Y. Quan, J. M. Harris, Stanford Univ. (United States); S. L. Wood, Santa Clara Univ. (United States)

Seismic imaging is a technology for building images of the Earth's subsurface based on the propagation of artificially created seismic waves that penetrate the Earth, reflect at discontinuities, and bounce back to the surface where they are recorded by arrays of sensors. The construction of accurate 3-D images of the subsurface of the Earth is extremely computationally-and-data intensive, requiring dense seismic surveys, data volumes in the order of 10-15 terabytes and 3-D parallel applications running on thousands of processors. This cost is compounded in 4-D seismic imaging (the fourth dimension being time), where a sequence of time-lapse seismic images is required to monitor a time-evolving process below the Earth's surface. In our paper we will assess a low cost imaging procedure for 4-D seismic imaging based on a set of low resolution images derived from spatially sparse but temporarily frequent shot gathers (seismic sources and associated sensors). The low resolution images will then be super-resolved to provide a sequence of time-evolving high resolution ones. Since the low resolution images require a smaller set of shot-gathers, the proposed 4-D procedure presents the advantage of much less data and significantly less processing. The novelty of our approach is the application to seismic imaging of emerging super-resolution technologies for digital imaging and photography. These technologies can potentially enable 4-D seismic at a lower cost and provide greater detail than possible with current methodologies. Major benefits of the proposed technology are in the context of environmental monitoring (geologic sequestration) and the oil and gas industry (real-time optimization of hydrocarbon production).

8056-12, Session 3

On the restoration of the microscanned images captured from unmanned airborne vehicles

A. H. Yousef, Old Dominion Univ. (United States); Z. Rahman, NASA Langley Research Ctr. (United States)

Unmanned Airborne Vehicles (UAVs) during flight capture a set of images that have slightly different looks of the scene. These images often contain a sufficient overlapped area between them and subpixel shifts of random fractions that will allow constructing a high resolution image within the overlapped area. The high resolution image may have a poor visual quality due to the degradations during the acquisition and display processes such as blurring caused by the system optics or aliasing due to the sampling. A technique called the microscanning is an effective method for reducing the aliasing and increasing the spatial resolution in images. By moving the field of view (FOV) on the detector array with predetermined sub-pixel shifts, both the aliasing reduction and resolution improvement are realized as the effective spatial sampling periods will be increased. In this paper we will relate the idea of the microscanning with the UAV captured images. Also based on the continuous-discrete-continuous (CDC) model, a Wiener restoration filter will be used to restore the visually poor quality image to a super resolution (SR) image.

8056-13, Session 3

Continuous quantification of uniqueness and stereoscopic vision

V. Petran, Artificial Perception Technologies Inc. (United States) and Case Western Reserve Univ. (United States); F. L. Merat, Case Western Reserve Univ. (United States)

In this paper we introduce the concept of continuous quantification of uniqueness. Our approach is to construct an algorithm that computes a fuzzy set membership function, that given any inter-object dissimilarity metric and it's variability, measures the probability that an entity of interest will be confused with other irrelevant entities that are deemed similar to it by that metric. Each of these quantifications of an object's uniqueness, is a scalar equal to a normalized sum of areas of intersections of histograms that estimate the variability as a function of changing context, of the output of the dissimilarity metric being used. Values computed using this technique range from 1.0 to 0.0 which in turn correspond to the uniqueness that is assigned to the spike of the Dirac

delta function, and any one output of any constant function respectively. We expect this technique to be useful whenever there is a need to decide which of several equally effective objects to use, for a purpose that requires recognition of the chosen object in a new context that contains objects with which it could be confused, by comparing measurements of object properties that unfortunately do happen to vary as a function of context. We demonstrate use of this uniqueness quantification algorithm by applying it to stereoscopic computer vision, in order to identify which of several sub-problems pertaining to solution of the classic stereoscopic correspondence problem are least likely to be solved incorrectly, and hence most well suited to greatest confidence first approaches.

8056-15, Session 3

Big-data feature screening using Bregman divergence

J. Cheng, Univ. of Hawai'i (United States); M. R. Zargham, Q. Cheng, Southern Illinois Univ. Carbondale (United States)

Modern biomedical data usually have high dimensions and/or massive volumes thanks to fast advancement of sensing and information technologies. These data usually are used to study the underlying biological mechanisms for scientific research or medical diagnosis. For example, disease and normal cells may have differential expressions across various genes, which is particularly useful for cancer diagnosis and prognosis. Typically, modern biomedical data have high dimensional features and/or huge volumes. Even though parallel processing or cloud computing has empowered the computing capability of biomedical research enormously, there is still an intrinsic need to reduce the dimensionality of the data for many pattern recognition and data analytic tasks. The reason is mainly because the state-of-the-art machine learning algorithms or data analytic methods cannot scale well for large data sets. The feature screening for dimensionality reduction has become an enabling technique that facilitates critical pattern recognition tasks. Various methods have been proposed in the literature for reducing the dimensionality of biomedical data. Most traditional methods can only handle large sample data, which are not suitable for handling modern biomedical data (which usually have high dimensions with smaller sample sizes). Many new algorithms have been proposed to handle the high-dimensional case; however, most of these newer methods incur high computational complexity, which seldom scale well for large data sets (which are of either high dimension or huge volume). To handle large data sets, in this paper, we introduce an approach for using Bregman divergence to describe the discriminative power of multivariate features. Not only can our method model the nonlinear relationship existing in the biomedical data, but it produces an discrimination measure whose optimization is particularly efficient. The resulting dimensionality reduction algorithm is very fast and scales well for large data sets. These advantages are expected to be critical for the success of large data machine learning in various modern, data-intensive applications, for example, in cloud computing and social networks. Experimental results show the effectiveness of the proposed scheme.

8056-16, Session 3

Creating bespoke COTS solutions for image processing applications

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It is well known that the operational requirements for military and security systems have changed significantly over the last few years and that constraints on budgets have severely limited the procurement process. Furthermore, the emergent operational requirements are such that systems are often required over much shorter periods of time and must retain significant flexibility to enable rapid upgrades or alternative re-deployments. As a result of this changing environment, the traditional development process of requirement specification leading to a bespoke design solution is no longer appropriate, or even desirable, in many cases.

Over the past few years, Waterfall Solutions Ltd has developed an alternative design approach that utilises commercial-off-the-shelf (COTS) technology and components within a generic software and hardware framework. The primary objective of this Bespoke COTS approach is to deliver high performance imaging capability at low cost in support of military and security applications. Furthermore, the design approach ensures the retention of significant design and interface flexibility, whilst the performance is delivered through advanced processing software which is optimised based on the COTS hardware and specific mission requirements.

In this paper, information on the Bespoke COTS design process is presented and is illustrated using examples of systems that have been built and delivered. The paper also discusses the important area of the design trade-off space (performance, flexibility, quality, and cost) and compares the results to design solutions derived from more conventional design processes.

8056-35, Poster Session

Generalized accelerated hyperspectral, and multiframe algorithm for nondestructive micro-electromechanical systems (MEMS) microscope metrology

W. J. Walecki, F. Szondy, Sunrise Optical LLC (United States)

Measurements of thickness of thin membranes, trenches and other features in Micro Electro-Mechanical Systems (MEMS) devices attracted considerable commercial attention in past, when various techniques including low coherence interferometry, and optical coherence tomography were used for quality control in production environment [1], [2].

In this paper we report a system employing novel generalized, and accelerated Richardson-Lucy algorithm ([3], [4]) for three dimensional mapping of the thin membranes in MEMS pressure sensing devices. System is collecting data at several selected by interference filters wavelengths bands. Several frames representing image of the device allow combining spectral, and spacial information. Our algorithm uses this information together with prior information from the exact thin film model of membranes, and Baysian model for point spread function of the employed microscope to obtain the enhanced spacial resolution image, and the enhanced thickness maps of measured membranes.

While the algorithm corrects for system drift and de-focusing, the speed of the algorithm is compatible with industrial throughput requirement of 30 wafers per hour.

1. United States Patent 7,502,121 by Wojciech J Walecki and Phuc Van.

2. Wojciech J. Walecki, Talal Azfar, Alexander Pravdivstev, Manuel Santos II, Ann Koo, "Combined Low-Coherence Interferometry and Spectrally Resolved Reflectometry for Nondestructive Characterization of Small-diameter High-aspect Ratio Micro-fabricated and Micro-machined Structures and Multilayer Membranes" Proc. SPIE Vol. 6109, p. 156-163, Jan 2006.

3. William H. Richardson, JOSA, Vol. 62, Issue 1, pp. 55-59 (1972)

4. Lucy, L. B., Astronomical Journal 79 (6) pp. 745-754 (1974)

8056-37, Poster Session

The new image segmentation algorithm using adaptive evolutionary programming and fuzzy c-means clustering

F. Liu, Beijing Univ. of Technology (China) and Tsinghua Univ. (China); Q. Dai, Tsinghua Univ. (China)

Image segmentation remains one of the major challenges in image analysis and computer vision. Fuzzy clustering, as a soft segmentation method, has been widely studied and successfully applied in mage clustering and segmentation. The fuzzy c-means (FCM) algorithm is the most popular method used in mage segmentation. However, most clustering algorithms such as the k-means and the FCM clustering algorithms search for the final clusters values based on the predetermined initial centers. Furthermore, the algorithm may be trapped in the local optimum. The FCM clustering algorithms does not consider the space information of pixels and is sensitive to noise. In the paper, Combining Evolutionary programming which is a good global optimization method with FCM algorithm which is a good local optimization method, the new image segmentation algorithm is proposed. The features of the new image segmentation algorithm are: firstly, it needs not predetermined the number of clusters and initial centers. Evolutionary programming will help FCM search for better "initial center" and escape bad centers at local minima. Secondly, the spatial distance and the Euclidean distance are also considered in the FCM clustering in order to guarantee noise insensitiveness and image detail preservation. So this algorithm is more robust to the noises. Thirdly, the adaptive evolutionary programming is proposed. The mutation rule is adaptively changed with learning the useful knowledge in the evolving process. Hence, the convergent speed and computation effect of the adaptive evolutionary programming is improved. Experiment results shows that the new image segmentation algorithm is effective and efficient, providing robustness to noisy images.

8056-38, Poster Session

Review of metropolis Monte Carlo image enhancement

A. M. Amini, Southern Univ. and A&M College (United States)

The Monte Carlo procedure as applied to enhancement problems builds the object by means of grains according to a probability distribution function. This distribution function directs the Monte Carlo Procedure to visit (reconstruct) the brightest regions of the input more often. The enhancement provided by this method does not depend on how wide the impulse response function or the point spread function of the instrument is. Also, The Monte Carlo method does not depend on the shape of the impulse response function and is potentially very fast. In the Metropolis Monte Carlo procedure the blurred output of the instrument is used as a distribution function that guides the Monte Carlo procedure to visit the important regions. A random walk selects a pixel and the Monte Carlo procedure decides whether the selected pixel is accepted or not. If accepted a grain of finite size is placed in or removed from the selected pixel of the input. A convolution of the input and the impulse response function is calculated every time a pixel is selected. At every stage the reconstructed output resulting from the convolution of the input with the impulse response function is compared to the output and the Mean Squared Error is calculated. If the error is reduced the move is accepted otherwise a new pixel is chosen by random walk and the process is repeated. The results indicate that the above procedure works very well for the synthetic data tested and is potentially very fast.

8056-39, Poster Session

A system for airport surveillance: detection of people running, abandoned objects and pointing gestures

S. Foucher, M. Lalonde, L. Gagnon, CRIM (Canada)

The proposed system is focusing on the detection of three events: a person running, a person puts down an object and the pointing gesture. For the detection of a person running, a non-parametric approach was adopted where statistics about tracked object velocities were accumulated over a long period of time using a Gaussian kernel. Outliers were then detected with the help of a kind of t-student test taking into account the local statistics and the number of observations. For the detection of "Object Put" events, we followed a dual background segmentation approach where the difference in response between a short term and a long term background model (Mixture of Gaussians) triggers alerts. False alerts are reduced based on a simple modeling of the camera geometry in order to reject objects that are too large or too small given their positions in the image. The detection of pointing gesture is based on the grouping of significant spatio-temporal corners (Harris) in a 3x3x3 cell called compound features as proposed recently by Andrew Gilbert et al. (2010). A hierarchical codebook is then derived from the training set based on a data mining algorithm looking for frequent items (called transactions). The algorithm was modified in order to deal with the large number of potential transactions (several millions) during the training step. The system was part of the Trecvid 2010 competition, the training dataset consists in 100 hours of video from the Gatwick airport from five different cameras.

8056-18, Session 4

Automatic detection for aircraft emergency landing sites

Y. Shen, Old Dominion Univ. (United States); Z. Rahman, NASA Langley Research Ctr. (United States)

An automatic landing site detection algorithm is proposed for aircraft emergency landing. Emergency landing is an unplanned event in response to emergency situations. If, as is unfortunately usually the case, there is no airstrip or airfield that can be reached by the un-powered aircraft, a crash landing or ditching has to be carried out. Identifying a safe landing site is critical to the survival of passengers and crew. Conventionally, the pilot chooses the landing site visually by looking at the terrain through the cockpit. The success of this vital decision greatly depends on the external environmental factors that can impair human vision, and on the pilot's flight experience that can vary significantly among pilots. Therefore, we propose a robust, reliable and efficient algorithm that is expected to alleviate the negative impact of these factors. We present only the detection mechanism of the proposed algorithm and assume that the image enhancement for increased visibility, and image stitching for a larger field-of-view have already been performed on the images acquired by aircraft-mounted cameras. Specifically, we describe an elastic bound detection method which is designed to position the horizon. The terrain image is divided into non-overlapping blocks which are then clustered according to a "roughness" measure. Adjacent smooth blocks are merged to form potential landing sites whose dimensions are measured with principal component analysis and geometric transformations. If the dimensions of the candidate region exceed the minimum requirement for safe landing, the potential landing site is considered a safe candidate and highlighted by the human machine interface. At the end, the pilot makes the final decision by confirming one of the candidates, also considering other factors such as wind speed and wind direction, etc. Preliminary results show the feasibility of the proposed algorithm.

8056-19, Session 4

Context-based semantic labeling of human-vehicle interactions in persistent surveillance systems

A. H. Shirkhodaie, V. Elangovan, Tennessee State Univ. (United States)

The improved Situational awareness in Persistent Surveillance Systems (PSS) is an ongoing research effort of the Department of Defense. Most PSS generate huge volume of raw data and they heavily rely on human operators to interpret and inference data in order to detect potential threats. Many outdoor apprehensive activities involve vehicles as their primary source of transportation to and from the scene where a plot is executed. Vehicles are employed to bring in and take out ammunitions, supplies, and personnel. Vehicles are also used as a disguise, hide-out, and/or meeting place to execute threat plots. Analysis of the Human-Vehicle Interactions (HVI) helps to identify cohesive patterns

of activities representing potential threats. Identification of such patterns can significantly improve situational awareness in PSS. In our approach, we initially discuss different HVI taxonomy and describe a method for construction of suitable ontology supporting a specific HVI taxonomy. Furthermore, we describe a technique for localization of personnel around a target vehicle and demonstrate an image processing technique for registering HVI activities. By spatiotemporal linking of HVI observable events, we have shown that a track of ontological patterns can be recognized and correspondingly appropriate hypotheses can be generated to explicate threat situations. Moreover, we describe a technique for semantic labeling of real-time HVI imagery data. Lastly, this paper demonstrates efficiency and effectiveness of the proposed technique for identifying HVI activities.

8056-20, Session 4

Image understanding algorithm for segmentation evaluation and region-of-interest identification using Bayesian networks

M. Jaber, E. Saber, Rochester Institute of Technology (United States)

In this paper, an image understanding algorithm for identifying regions of visual interest in RGB color images is introduced. The algorithm uses global and local image features in a Bayesian network-based framework to identify an optimal segmentation map (SM), a probabilistic region ranking map (RRM), and a binary region of interest (ROI) map of a test image. The proposed methodology contains two modules: image segmentation evaluation and ROI identification. The former is a stand-alone system that ranks a set of segmentations of a target image from acceptable to impractical maps. The acceptable SM allows selective access and manipulation of individual image content. It is utilized - in addition to the original image- to estimate the probability of each segment of belonging to the ROI (ROI identification module). These probabilities are represented as a RRM of the target image. The RRM is a saliency map that quantifies the visual significance of a particular image region in relation to other regions. Further processing of the RRM generates a binary ROI map of the test image. The Normalized Probabilistic Rand (NPR) index is used as an objective metric to quantify the performance of the segmentation evaluation module utilizing the Berkeley segmentation dataset. The overall proposed system shows a competitive performance in comparison with the state-of-the-art ROI detection techniques on a set of ~20,000 publicly available color images.

8056-21, Session 4

Fast motion prediction algorithm for multiview video coding

A. Abdelazim, Y. G. Zhang, S. J. Mein, M. R. Varley, Univ. of Central Lancashire (United Kingdom); D. Ait-Boudaoud, Univ. of Portsmouth (United Kingdom)

With the wide expansion of 3D and free viewpoint video applications the H.264 Multiview Video Coding (MVC) standard has been developed as an extension to the H.264 Advanced Video Coding (AVC) standard to enable efficient coding for scenes captured from multiple cameras. Since all cameras capture the same scene from different viewpoints, inter-view statistical dependencies can be expected. Therefore, in addition to the H.264/AVC very refined Motion Estimation and mode decision processes, H.264/MVC exploits inter-view prediction for more efficient coding. However, this further increases overall encoding complexity.

Recently proposed algorithms reduce encoder complexity by locating corresponding objects in neighbouring views by means of a global disparity vector and exploiting the mode distribution correlation between neighbouring views. These algorithms perform well only for certain video sequences and camera configurations; given the inherent scene characteristics are not taken into account.

In this paper, the high correlation between a macroblock and its enclosed partitions is utilised to estimate motion homogeneity, based on the result inter-view prediction is selectively enabled or disabled. Moreover, if the MVC is divided into three layers in terms of motion prediction; the first being the full and sub-pixel motion search, the second being the mode selection process and the third being repetition of the first and second for inter-view prediction, our proposed algorithm significantly reduces the complexity in the three layers. This is accomplished by evaluating several conditional probabilities that relate the macroblock motion characteristics to the mode selection process and the inter-view prediction.

To assess the proposed algorithm, a comprehensive set of experiments were conducted. The results show that the proposed algorithm significantly reduces the motion estimation time whilst maintaining similar Rate Distortion performance, when compared to both the H.264/MVC reference software and recently reported work.

8056-22, Session 5

Improved neural network modeling of inverse lens distortion

J. P. de Villiers, Council for Scientific and Industrial Research (South Africa); F. Nicolls, Univ. of Cape Town (South Africa)

Being able to quickly and accurately determine what pixel in a distorted image is associated with a vector to a real world object has many applications ranging from tracking and target identification in surveillance to computational photography and to image rectification for aesthetics in broadcasting. Many camera calibration procedures are unable to provide this mapping and can instead only provide the more standard lens distortion characterisation, which determines the undistorted image point or vector given a distorted image point. Much work has been published on various methods balancing the memory consumption, computational load and accuracy of inverse distortion methods. Recent methods using complex Brown distortion models for both the forward and reverse distortion model require careful attention to scaling and manipulation of optimisation algorithm parameters. This led to work using neural networks to model the inverse distortion using by-product data of the forward distortion characterisation and obtained favourable results with less expert supervision required of the calibration. This work advances these recent neural distortion correction methods by considering a wider variety of neuron activation functions, architectures and input/output scaling methodologies to obtain improved inverse distortion characterisations. Several wide angle lenses exhibiting are evaluated. The lenses have either extreme classical monotonic ‘barrel’ distortion or significantly decreased, but non-monotonic or unimodal, ‘moustache’ distortion (resulting from optical distortion correction with aspheric elements). The errors are expressed as microns on the imager chip to allow for comparison to recent published results using different imager sizes and resolutions.

8056-23, Session 5

Novel adaptive kernels for image sharpening in the presence of noise

D. C. Bamber, Waterfall Solutions Ltd. (United Kingdom); P. K. Kimber, SELEX Galileo Ltd. (United Kingdom)

Whilst conventional edge enhancement filters are able to enhance the contrast, edge definition and clarity of salient features they can also exaggerate the noise content within the imagery. This study investigated the potential use of adaptive kernels for intelligently sharpening imagery. Waterfall Solutions has developed a series of novel adaptive filters which are able to discern local image content and adapt the nature or mode of the underlying kernel in accordance to user requirements. This paper discusses the use of a series of novel adaptive sharpening filters created by WS. By adapting the scale and shape of the edge sharpening kernel locally the proposed filter is able to ensure that only pertinent edges are enhanced. In order to determine which portions of the image contain pertinent information a local noise content measure is used to generate a saliency map. In region with excessive noise a larger edge enhancement kernel is used such that larger scale edges are enhanced and noise is dampened. The technique has been tested on a series of images with different levels of noise. Results have shown the potential of this technique for distinguishing salient information from noise content and for sharpening pertinent edges. The technique is amenable to GPU-acceleration for real-time operation.

8056-24, Session 5

Information theoretic analysis of canny edge detection in visual communication

B. Jiang, Old Dominion Univ. (United States); Z. Rahman, NASA Langley Research Ctr. (United States)

In general edge detection evaluation, the edge detectors are examined, analyzed, and compared either visually or with a metric for specific an application. This analysis is independent of the characteristics of the image-gathering, transmission and display processes that impact the quality of the acquired image and thus, the edge image. We propose a new information theoretic analysis of edge detection that unites the different components of the visual communication channel and assesses edge detection algorithms in an integrated manner based on Shannon's information theory. The edge detection algorithm is regarded to have high performance only if the information rate from the scene to the edge approaches the maximum possible. Thus, by setting initial conditions of the visual communication system as constant, different edge detection algorithms could be evaluated. This analysis is normally limited to linear shift-invariant filters so in order to examine the Canny edge operator in our proposed system, we need to estimate its "power spectral density" (PSD). Since the Canny operator is non-linear and shift variant, we perform the estimation for a set of different system environment conditions using simulations. In our paper we will first introduce the PSD of the Canny operator for different system parameters. Then, using the estimated PSD, we will assess the Canny operator using information theoretic analysis. The information-theoretic metric is also used to compare the performance of the Canny operator with other edge-detection operators. This also provides a simple tool for selecting appropriate edge-detection algorithms based on system parameters, and for adjusting its parameters to maximize information throughput.

8056-25, Session 5

Local color transfer based on dark-channel dehazing for visible/infrared image fusion

B. Zhang, L. Wang, Beijing Institute of Technology (China)

A local color transfer method based on dark channel dehazing for visible/infrared image fusion is presented. Image fusion combines complemental information from visible and infrared images. Visible image supplies plenty of scene details and infrared image is good at popping out hot or cold targets. However, under a bad weather condition, such as haze or fog, the visible image is degraded greatly and leads to a low contrast and poor color fidelity fused image. Color transfer can improve the color appearance using a bright haze-free reference image, but it usually modifies the pixel values according to the global mean value and standard deviation in each color channel. This paper pays more attention to the dark channel of the reference image and so applies different color transfer schemes to haze area and haze-free area. Results show that it is effective for decreasing the bad effect of the haze and achieving a more visually pleasing color visible/infrared fused image.

8056-26, Session 6

Space-time compressive imaging

V. Treeaporn, A. Ashok, M. A. Neifeld, The Univ. of Arizona (United States)

Feature-specific imaging or compressive imaging involves measuring relatively few linear projections of a scene onto a measurement basis. The number of measurements is typically much less than the inherent dimensionality of the scene and therefore the measurements are compressive. Researchers have exploited the spatial redundancy of natural scenes to design compressive imaging systems using various sparse measurement bases such as Karhunen-Loève (KL) transform, random projections, Discrete Cosine transform and Discrete Wavelet transform and have reported significant improvements in system performance and size, weight, and power (SWaP) compared to conventional non-compressive imaging systems. Here we extend the compressive imaging approach to dynamic spatio-temporal scenes by exploiting the inherent spatio-temporal correlations to make compressive measurements. The performance of space-time feature-specific/compressive imaging systems is analyzed using the KL measurement basis. We find that the addition of temporal redundancy in natural spatio-temporal scenes yields further compression relative to space-only feature specific imaging. For a relative noise strength of 10% of the dynamic range and 12x12 spatial patches, we find a 3% improvement in the reconstruction error while realizing a 16x compression compared to a conventional imager. For the same relative noise strength and desired error, spatio-temporal blocks of size 12x12x64 yield 30x compression, nearly a two-fold improvement over space-only compressive imaging. We also describe candidate architectures for space-time compressive imaging systems.

8056-27, Session 6

Adaptive multiscale resolution enhancement for compressive imaging

A. Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

We present an adaptive method for enahcing the resolution of images formed using compressive sensing techniques. The approach requires a low-resolution sensor to provide a reference image which is then used to reduce the reconstruction error in a higher resolution version of the same scene using compressively sensed data.

8056-29, Session 6

Novel helical point spread functions for 3D imaging

S. Quirin, R. Piestun, Univ. of Colorado at Boulder (United States)

We engineer three-dimensional point spread functions (PSF) to collect the information required for depth recovery and imaging. We investigate computational imaging systems using helical point spread functions for 3-D passive imaging and compare with prevailing methods.

We discuss a class of three-dimensional (3D) imaging systems in which the imaging PSF is modified according to its suitability for ranging. A phase only mask realizes the desired PSF and enables the collection of depth information. Information is collected from images acquired with two complementary PSFs. In order to increase the signal-to-noise ratio (SNR) for a given application we introduce different helical PSF designs.

Return to Contents

8056-30, Session 6

Unconventional optical system design

J. Ford, E. J. Tremblay, Univ. of California, San Diego (United States)

This presentation will describe research being conducted at UCSD's Photonic Systems Integration Lab.

8056-31, Session 6

Image formation challenges in the MOSAIC platform

M. E. Gehm, The Univ. of Arizona (United States); D. J. Brady, Duke Univ. (United States)

The DARPA MOSAIC program applies multiscale lens systems to the acquisition of wide field-of-view, high resolution images. MOSAIC combines a shared objective lens with a large array of microcameras---individual imagers working in parallel to reimage the intermediate image created by the objective. The key advantage of multiscale design is that the individual microcameras need only correct aberrations over their local region rather than the full field-of-view. Local field correction simplifies lens design and enables very high pixel count image acquisition.

Interestingly, very high pixel count images present as many challenges as opportunities. The MOSAIC image is acquired in distributed form over many slightly overlapping fields with diverse focal, exposure and temporal parameters. Estimation of a consensus gigapixel scale image from distributed data using quasi-dynamic registration is a potential challenge, but in considering this challenge one must note that no single display is capable of presenting the full MOSAIC image. This suggests a crucial need for automated anomaly detection to guide viewer attention to relevant portions of the overall scene. Further challenges arise from streaming image and feature estimation for distributed users and displays. Under this operating mode, the MOSAIC camera becomes a distributed computing and communication environment matched to an embedded distributed imager. Power management for this camera is a particularly critical challenge; sustainable operation requires that the power per acquired pixel must be much less than conventional cameras.

This talk describes MOSAIC's image data management and estimation challenges and discuss progress to date.

8056-32, Session 7

On grey levels in random CAPTCHA generation

M. A. Kouritzin, F. Newton, S. Sadeghi, Univ. of Alberta (Canada)

A CAPTCHA is an automatically generated test designed to distinguish between humans and computer programs; specifically, they are designed to be easy for humans to pass but difficult for computer programs in order to prevent the abuse of resources by automated bots. They are commonly seen guarding webmail registration forms, online auction sites, and preventing brute force attacks on passwords.

In the following, we address the question: how does adding grey levels to random CAPTCHA generation affect the utility of the CAPTCHA? We treat the problem of generating the random CAPTCHA as one of random field generation: an initial state of background noise is evolved over time using Gibbs sampling and an efficient algorithm for generating correlated random variables. This approach has been found to yield highly readable yet difficult to crack CAPTCHAs in (as yet unpublished) work. We detail how the requisite parameters for introducing grey levels are estimated and how we generate the random CAPTCHA. The resulting CAPTCHA will be evaluated in terms of human readability as well as its resistance to automated attacks in the forms of character segmentation and optical character recognition.

8056-33, Session 7

A simplified rate control algorithm for H.264/SVC

Y. G. Zhang, A. Abdelazim, S. J. Mein, M. R. Varley, Univ. of Central Lancashire (United Kingdom); D. Ait-Boudaoud, Univ. of Portsmouth (United Kingdom)

The objective of scalable video coding is to enable the generation of a unique bitstream that can adapt to various bit-rates, transmission channels and display capabilities. The scalability is categorised in terms of temporal, spatial, and quality. Effective Rate Control (RC) has important ramifications for coding efficiency, and also channel bandwidth and buffer constraints in real-time communication.

The main target of RC is to reduce the disparity between the actual and target bit-rates. In order to meet the target bit-rate, a predicted Mean of Absolute Difference (MAD) between frames is used in a rate-quantisation model to obtain the Quantisation Parameter (QP) for encoding the current frame.

The encoding process exploits the interdependencies between video frames; therefore the MAD does not change abruptly unless the scene changes significantly. After the scene change, the MAD will maintain a stable slow increase or decrease. Based on this observation we developed a simplified RC algorithm. The scheme is divided in two steps; firstly, we predict scene changes, secondly, in order to suppress the visual quality, we limit the change in QP value between two frames to an adaptive range. Furthermore, the algorithm is deployed for spatial, temporal and coarse-grain scalabilities. This limits the need to use the rate-quantisation model to those situations where the scene changes significantly in the base layer.

To assess the proposed algorithm, comprehensive experiments were conducted. The experimental results show that the proposed algorithm significantly reduces encoding time whilst maintaining similar rate distortion performance, compared to both the H.264/SVC reference software and recently reported work.

8056-34, Session 7

A joint perceptual encryption and watermarking scheme (JPEW) for DCT-based codecs

M. I. Khan, V. Jeoti, A. S. Malik, Univ. Teknologi Petronas (Malaysia)

A Joint Perceptual Encryption and Blind Watermarking technique have been proposed. The technique has been incorporated in the JPEG compression standard.Perceptual Encryption is required in many of the multimedia content preview application and Watermarking is used to ensure the integrity of the multimedia content.In the proposed scheme both operations can be carried out simultaneously on multimedia content.In the proposed watermarking technique,the watermark embedding is carried out using DC component.The results have shown that the proposed watermarking technique is imperceptible. Similarly the proposed perceptual encryption scheme is designed using newly emerged Objective Image Quality metrics i.e. SSIM, MS-SSIM, VIF and VIFP etc. and it is carried out using AC Coefficients that are selected based on the statistical analysis.The proposed joint scheme is found to be secure, simple in implementation and reduces the overhead of sequential computation of both operations in real-time.

Conference 8057: Quantum Information and Computation IX

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8057-01, Session 1

Quantum braids and their applications

S. J. Lomonaco, Jr., Univ. of Maryland, Baltimore County (United States); L. H. Kauffman, Univ. of Illinois at Chicago (United States)

We will discuss two different approaches to the theory of quantum braids, one geometric, the other algebraic. We will then focus on applications.

8057-02, Session 2

Bright photon pair source with high spectral and spatial purity

W. P. Grice, R. S. Bennink, P. G. Evans, T. S. Humble, Oak Ridge National Lab. (United States); J. Schaake, The Univ. of Tennessee (United States)

Spontaneous parametric down-conversion (SPDC) is a reliable and robust source of photon pairs for quantum information applications. For applications that involve operations such as entanglement swapping or single-photon heralding, the two-photon states are required to be factorable (or uncorrelated) in their spectral and spatial degrees of freedom. We report the design and experimental characterization of an SPDC source that has been optimized for high spectral and spatial purity. The source is pumped by the 776 nm output of a mode-locked Ti:Sapphire laser and consists of a periodically-poled Potassium Titanyl Phosphate (PPKTP) crystal phase-matched for collinear type-II SPDC. The dispersive properties of PPKTP at these wavelengths is such that it is possible to minimize the spectral entanglement by matching the widths of the pump to the spectral phase-matching function. The spatial entanglement is minimized through careful control of the pump focus, yielding nearly single-mode emission. An advantage of this approach is that the emission rate into the collection modes is very high, resulting in a very bright SPDC source. We also report a scheme that employs the output of collinear sources such as these to produce polarization-entangled photon pairs. The scheme, which requires only simple polarization elements, can be scaled to N-photon GHZ states.

8057-03, Session 2

Entangled photons produced by interactions with quantum wells and quantum dots

M. N. Leuenberger, M. V. Erementchouk, Univ. of Central Florida (United States)

In today's highly connected world, it is essential to keep sensitive information safe from getting into the wrong hands.

Quantum cryptography has already become a viable solution to produce quantum keys for sharing secret information between several parties. Current entangled-photon sources based on nonlinear crystals have a very low yield of producing entangled photons.

We have developed theoretical schemes based on the interaction of photons with excitons in quantum wells and on the interaction of photons with a single quantum dot inside a cavity that promise to produce entangled photons much more efficiently.

We make use of a quantum-field theoretical approach to describe the dynamics of the many-photon entanglement.

Our approach is particularly useful when describing the entanglement among a large number of indistinguishable photons. It allows us to find simple analytical approximations that show the nonperturbative time evolution of the entanglement of many-photon systems.

8057-04, Session 2

Multiple-entangled photon spontaneous parametric down-conversion source

M. L. Fanto, R. K. Erdmann, P. M. Alsing, Air Force Research Lab. (United States); E. J. Galvez, Colgate Univ. (United States); C. Peters, Air Force Research Lab. (United States)

Spontaneous parametric down-conversion yields photons for Quantum-Optical-logic Gate development, with the highest mode quality of any sources presently available. Entangled photon pairs are emitted in the passage of high energy pump photons through a nonlinear crystal; multi-partite states with four or more entangled photons are typically generated in several crystals or multiple passes through a single crystal. In this work, we discuss a novel source design that permits generation of up to six pairs of entangled photons from a single pass of the pump beam through a crystal assembly. The experimental demonstrations reported are at 810 nm so as to utilize high quantum efficiency Si-APD detectors, but the design can be readily implemented in other wavelength regimes including the telecom bands near 1550 nm. An immediate application of this source enables particular multi-qubit cluster states to be generated in a highly compact unidirectional configuration. This can significantly simplify the interferometric stability, as well as feed-forward methods required in photon based quantum logic circuitry.

8057-05, Session 2

Proposals to produce entangled states of spatial modes of light

E. J. Galvez, Colgate Univ. (United States)

Two methods to prepare photon pairs in entangled states of spatial modes are presented. These methods improve upon current methods, in which there is no flexibility on the selection of the modes that one wishes to be entangled. The methods proposed here would allow the preparation of entangled states in any desired pair of modes. Both proposals use spontaneous parametric down conversion for the generation of collinear photon pairs. In method I collinear photons are sent to a Mach-Zehnder interferometer that has mode-generating elements in each of its two arms. The light leaving the interferometer is in a product state of the two modes. However, by manipulating the interferometer we can discard a subset of the paths that contribute the final state of the light and thus produce an entangled state of the path-labeling modes. In method II photon pairs are prepared in polarization-entangled state. The pairs are sent to a polarization interferometer with which we can perform polarization to mode entanglement swapping. In both methods the entangled states are retrieved in post-selection. We are currently working on laboratory demonstrations of these proposals.

8057-06, Session 2

Experimental consideration of local realism with entangled photon pairs

R. K. Erdmann, M. L. Fanto, P. M. Alsing, C. Peters, Air Force Research Lab. (United States); E. J. Galvez, Colgate Univ. (United States); W. A. Miller, Florida Atlantic Univ. (United States)

Return to Contents

Bell's theorem and inequalities that stem from it address the conflict of quantum mechanics with certain understandings of local realism, for the first time in an experimental context. So-called hidden variable approaches to resolving the associated EPR paradox were shown to be at variance with observations of entangled states, with photon pairs providing the most convenient realization. We examine here the extent to which such 'hidden variables' can be experimentally represented by the ensemble of the two-photon product states that exhibit local realism. This motivates conceptually straightforward experiments that manifest perfect correlation for entangled states and dramatically reduced correlation for any two-photon states that exhibit local realism. This is compared with the more limited contrast in correlation observed in most Bell-type violations, though the observations made are consistent with the latter. Quantum mechanics describes both the entangled state behavior as well as that of the product states, which are treated as a special case in the same experimental configuration. As expected, no local realistic states are able to simulate the entangled photon pair results. The experimental methods are then considered as a tool for characterizing two-photon entanglement (fidelity) in the presence of controlled decoherence. Implications for quantum steering in terms of two-qubit Werner states are also assessed. The term was originally used by Schrodinger to depict the non-local influence on a (remote) quantum state enabled by quantum entanglement. This is distinct from any ability to relay information or, as has been demonstrated more recently to violate a Bell-type inequality.

8057-07, Session 3

Generation and detection of quantum entangled states and quantum imaging

J. F. Smith III, U.S. Naval Research Lab. (United States)

A factorization scheme will be introduced that permits any N00N, linear combination of N00N, M&M, linear combination of M&M, or more exotic entangled states to be generated and detected. Methods of using such procedures to produce and detect photons entangled in more than one mode will be discussed. Internal loss within the entanglement generator and external loss due to atmosphere, detectors and targets are modeled. A method using these approaches for quantum entanglement based imaging is provided that gives N times classical resolution, where N is the number photons entangled. The wave function, normalization, density matrix, reduced density matrix and expectation of powers of the detection operator, visibility, and phase error are provided. Explicit entanglement generator and detector designs are provided in terms of linear and nonlinear photonics devices. The fundamental role of post-selection measurement for generating entanglement is included. Different detector configurations and their merit are discussed as well as configurations for implementing optimal detection operators. Methods of extending these results to non-optical frequencies are discussed. Various approaches to quantum ghost imaging (QGI) will be considered. Loss mechanisms associated with atmospheric and other types of propagation, scattering from the object to be imaged and detector loss will be examined. Other types of quantum imaging will be discussed. Closed form as well as other mathematical and numerical results will be provided.

8057-08, Session 3

Resolution enhancement of imaging systems by quantum phase amplification

Y. Yin, D. French, I. Jovanovic, The Pennsylvania State Univ. (United States)

Remote sensing of spatial information exhibits resolution requirements and technology challenges that in many aspects resemble those found in the field of astronomy. The classical limit on the resolution of optical imaging systems is determined by wavelength and the optical system aperture size. A well-known approach to resolution improvement is the use of synthetic aperture imaging, which relies on phase locking of numerous independent apertures into a system which achieves the classical resolution limit which can approach that of a monolithic aperture of the same spatial extent. A novel quantum phase amplification (QPA) technique is proposed here to enhance the spatial resolution of passive imaging systems beyond the classical limit, without the commensurate increase in the aperture size. The key component of this approach is the production of phase-amplified light, a squeezed state of the electromagnetic field which can be generated in a phase-sensitive optical parametric amplifier (PSOPA). We have established the theoretical basis for quantum imaging using QPA. Additionally, practical implementations of the phase amplifier operating in the temporal domain have been proposed, particularly by the use of phase-sensitive three-wave mixing process. We have theoretically derived the conditions for the operation of the ubiquitous PSOPA realized by using standard laser technology, in which nonclassical, sub-Rayleigh imaging can be observed and explored to perform the super-resolution enhancement of remotely sensed data. This quantum imaging approach has a potential to overcome the Cramer-Rao bound to deliver quantum sensors capable of reaching a more favorable, linear scaling of signal-to-noise ratio (SNR) with signal energy.

8057-09, Session 3

All-optical flip-flop memory for quantum computing

E. Donkor, Univ. of Connecticut (United States)

We present experimental demonstration of an all-optical flip-flop based on mode competition in a polarization-coupled two-energy system. The two energy systems are comprised of a semiconductor optical amplifier and a supercontinuum generator. Adjusting the polarization state of the nonlinear coupling between the two energy systems allows for a stable cycling between the four states of a flip-flop namely:

(off, off); (off, on); (on, off); (on, on). So that, in this case, representing qubits by orthogonal polarization states allows for qubit logic operations to be performed with the results of such operation stored directly in memory.

8057-10, Session 3

Entangled photon holes and nonclassical interferomtery

J. Liang, J. D. Franson, T. B. Pittman, Univ. of Maryland, Baltimore County (United States)

The generation of entangled photon holes may be realized through several different ways, for examples, two-photon absorption, quantum interference, four-wave mixing, etc. It has been proposed that entangled photon holes may have potential applications in quantum communication and quantum information systems. Similar to entangled photons, the entangled features of photon holes can be characterized by using two separated unbalanced Mach-Zehnder interferometers to perform Bell's inequality test on the coincidence counts of the photon background. The violation of Bell's inequality will reveal the nonclassical properties of entangled photon holes. In such experiments, it is important to obtain high-accuracy phase-stabilization of the two interferometers, which requires active-feedback control over the relative path-length difference of the interferometers. Here, we will discuss the details of experiments related to entangled photon holes and phase-stabilized nonclassical interferometry.

8057-12, Session 4

Analytical calculation of the dynamics of Shor state verification in the presence of non-equiprobable errors

G. N. Gilbert, Y. S. Weinstein, 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.

8057-13, Session 4

Unitary quantum lattice gas representation of 2D quantum turbulence

B. Zhang, G. Vahala, The College of William & Mary (United States); L. L. Vahala, Old Dominion Univ. (United States); J. Yepez, Air Force Research Lab. (United States)

There is much interest in understanding the connection between classical turbulence and quantum turbulence. The simplest form of quantum turbulence arises from the evolution of the T = 0 BEC wave function which satisfies the Hamiltonian Gross-Pitaevskii (GP) equation. In contrast to classical turbulence where the vortices are continuous and of variable strengths, the quantum vortex is a topological singularity, quantized with a fixed circulation and can undergo vortex-vortex reconnection in the absence of dissipation.

In classical turbulence there is a direct energy cascade in 3D but an inverse energy cascade-direct enstrophy cascade in 2D. 3D quantum turbulence [1] exhibits 3 cascade regions in the kinetic energy spectrum. In our quantum lattice gas algorithm, we choose two qubits per lattice site. To recover the T = 0 GP equation for the wavefunction, we need only to operate on two of these states by an interleaved sequence of unitary collide-stream operators. In diffusion ordering, moments of the evolution equations for the two states recovers the GP equation for 2D simulations of quantum turbulence are performed in an inhomogeneous Gaussian BEC with embedded vortices both with and without an external potential as well as for initial random phase wave function. The incompressible kinetic energy invariably exhibits a spectrum as in 3D quantum turbulence. Higher resolution runs will be reported to ascertain the small k spectrum and whether the kinetic energy follows the Kolmogorov cascade.

[1] J. Yepez, G. Vahala, L. Vahala and M. Soe, Phys. Rev. Lett. 103, 084501 (2009); 104, 129402 (2010)

8057-15, Session 4

Using the Mathematica package Qucalc to simulate quantum algorithms and games

D. A. Bolívar, Univ. EAFIT (Colombia)

Nowadays, some computer investigations are focused on the development of new quantum systems. For quantum computing the development of mathematics and physics together is important, recently emerged as computer algebra software MAPLE® or MATHEMATICA® used to implement simulations of quantum systems. The main objective of this paper is to perform simulations of games and quantum algorithms using the MATHEMATICA® package Qucalc. In this paper is implemented the Glover algorithm, which is useful to make programmed researching as the game of a needle in a haystack. The simulations are very interesting because those allow to confirm the theoretical models.

8057-27, Session 4

Quantum computing in a piece of glass

W. A. Miller, Florida Atlantic Univ. (United States); P. M. Alsing, J. R. McDonald, Air Force Research Lab. (United States); C. C. Tison, Florida Atlantic Univ. (United States)

Quantum gates and simple quantum algorithms can be efficiently simulated by the diffraction phenomena of a photon within a multiplexed holographic element. The quantum eigenstates we use are the photon's linear momentum (LM) as measured by the number of waves of tilt across the aperture. Two properties of quantum computing within the circuit model make this approach attractive. First, any conditional measurement can be commuted in time with any unitary quantum gate - the timeless nature of quantum computing. Second, photon entanglement can be encoded as a superposition state of a single photon in a higher-dimensional state spaces afforded by LM. Our theoretical and numerical results indicate that OptiGrate's photo-thermal refractive (PTR) glass is an enabling technology. We will review our previous design of a quantum projection operator and validate this approach on a representative quantum gate using coupled-mode theory and paraxial simulations, all with parameters consistent with PTR glass. We discuss the strengths (high efficiencies, robustness to environment) and limitations (scalability, crosstalk) of this technology. While not scalable, the utility and robustness of such optical elements for broader quantum information processing applications can be substantial.

We acknowledge support for this research under a grant from AFRL/RI.

8057-16, Session 5

Causal connectivity

H. E. Brandt, U.S. Army Research Lab. (United States)

Canonical quantum field theory in Minkowski spacetime suffers from the divergences occurring at very small distances and/or very high energy. This long standing issue is also manifested in the singular delta function appearing in the microcausality relation involving the commutator of the quantum field at two points separated in spacetime. It has been argued that an implication of a physical upper bound on allowed proper acceleration relative to the vacuum is that the canonical microcausality relation is modified to include dependence of the field on the four-velocity of the device measuring the field, so that the delta function is replaced by a function concentrated near the Planck scale of spatial separation between the two devices measuring the field, or at much larger separation when the relative speed of the two measuring devices is near the canonical speed of light. A consequence is that the causal boundary, canonically defined by the light cone, is warped at these scales so that the timelike region extends into the canonical spacelike region. The condition for this warping to occur maximally is when the spatial component of the relative four-velocity of the two measuring devices is near-orthogonal to their spatial separation, and for spatial separations near the Planck scale. When the relative speed of the measuring devices is very large, the range of the causal connectivity may extend well beyond the Planck scale, but if the wavelength is much less than the range, the field is extremely reduced. It is also significant to note that the modified quantum field is Lorentz invariant, and causal connectivity backward in time remains impossible.

8057-17, Session 5

Wonderful world of weak values

J. C. Howell, C. J. Broadbent, A. N. Jordan, D. J. Starling, B. Dixon, Univ. of Rochester (United States)

Weak values were originally introduced by Aharanov, Albert and Vaidman for understanding the arrow of time in quantum mechanics. Weak values have recently proved useful in amplifying very small effects. I will introduce the ideas of weak values and discuss some of our recent experimental results in which we were able to observe a deflection of a laser beam of less than 1 picoradian (equivalent to measuring a deflection of the width of a hair at the distance of the moon). Perhaps more interestingly, the noise properties are simply remarkable in leading to a suppression of technical noise and a tremendous amplification of the signal to noise ratio for standard beam deflection techniques.

8057-18, Session 5

A statistical and comparative study of quantum walks under weak measurements and weak values regimes

D. Ghoshal, George Mason Univ. (United States); M. O. Lanzagorta, ITT Advanced Engineering & Sciences (United States); S. E. Venegas-Andraca, Tecnologico de Monterrey (Mexico)

Quantum walks have been studied under several regimes. Motivated by experimental results on quantum weak measurements and weak values as well as by the need to develop new insights for quantum algorithm development, we are extending our knowledge by studying the behavior of quantum walks under the regime of quantum weak measurements and weak values of pre- and postselected measurements (QWWM hereinafter). In particular, we investigate the limiting position probability distribution and several statistical measures (such as standard deviation) of a QWWM on an infinite line, and compare such results with corresponding classical and quantum walks position probability distributions and statistical measures, stressing the differences provided by weak measurements and weak values with respect to results computed by using canonical observables.

We start by producing a concise introduction to quantum weak values and quantum weak measurements. We then introduce definitions as well as both analytical and numerical results for a QWWM under Hadamard evolution and extend our analysis to quantum evolution ruled by general unitary operators. Moreover, we propose a definition and focus on the properties of mixing time of QWWM on an infinite line, followed by a comparison of known corresponding results for classical and quantum walks mixing times. We finish this paper by presenting a plausible experimental implementation of a QWWM.

8057-19, Session 5

Quantum spread spectrum communication

T. S. Humble, Oak Ridge National Lab. (United States)

Spread spectrum techniques are widespread use in classical contexts, including sensing and communication, for establishing low probability of intercept, resistance to narrowband jamming, and multiuser access protocols. In the classical setting, spread spectrum is based on the process that the spectrum of the signal is spread much larger than the minimum bandwidth required for representing the encoded information. In this contribution, we apply similar ideas to the transmission and detection of quantum information encoded into photonic states, especially for the purposes of defining multiuser access control (MAC) protocols and avoidance of narrowband interferers.

We investigate applications of spread spectrum modulation to the transmission of quantum information encoded into single-photon states. We draw upon our previously developed methods for coherently dilating the spectral probability amplitude of a single photon. These techniques can be based on direct modulation of the single-photon amplitude, modulation via pumped single-photon up-conversion, or modulation via spread spectral teleportation. The present work develops those modulations schemes into particular communication protocols and quantifies their communication capacities.

After developing forms of quantum spread spectrum based on direct-sequence and frequency-hopping modulation of the single-photon spectral probability amplitude, we discuss the gain from these protocols. We quantify the channel capacities and process gains in terms of the spread bandwidth and we investigate the behavior of these protocols in the face of frequency-selective fading models, e.g., narrowband absorbers in the transmission medium. We conclude by discussing the potential for quantum spread spectrum to underlie a MAC protocol for multi-user free-space QKD.

8057-20, Session 5

Nash equilibrium in quantum superpositions

F. S. Khan, Khalifa Univ. of Science, Technology and Research (United Arab Emirates)

The prevailing theory of quantum games takes the approach of “quantizing the game” with the goal of locating potentially enhanced game theoretic results. Essentially, this is achieved by identifying the outcomes of a game with an orthogonal basis of the state space of a quantum system and defining a notion of quantum strategies. A function is defined next that takes quantum strategies to quantum superpositions. Following this by measurement produces a probability distribution over the games’ outcomes and expected payoffs to the players are computed which are often not only better than those in the original game but also constitute Nash equilibrium in quantum strategies.

Taking the converse of this prevailing approach of mixing quantum mechanics and game theory produces what may be called “gaming the quantum” approach. This approach is used here to identify an orthogonal basis of a quantum system with the outcomes of some non-cooperative game, with some of the outcomes identified as the desired outcomes of the players. Each player is tasked with forming a quantum superposition of the basis which is closest to his desired outcome so that measurement projects onto the desired outcome with greatest probability. This essentially identifies the game theoretic notion of players’ “rationality” with the measurement principle. The main result here is that the preceding identifications naturally lead to the notion of Nash equilibrium in quantum superpositions, giving a quantum mechanical setting for this notion. Because Nash equilibrium is an optimal solution concept given constraints, this setting for it can potentially lead to optimal solutions of problems in quantum mechanics.

8057-11, Session 6

Grover’s search algorithm with an entangled database state

P. M. Alsing, N. McDonald, Air Force Research Lab. (United States)

Grover’s oracle based unstructured search algorithm is often stated as “given a phone number in a directory, find the associated name.” More formally, the problem can be stated as “given as input a unitary black box Uf for computing an unknown function f: {0,1}^n -> {0,1}, find x=x0 an element of {0,1}^n such that f(x0)=1, (and zero otherwise). The crucial role of the externally supplied oracle (whose inner workings are unknown to the user) is to change the sign of the solution |x0>, while leaving all other states unaltered. Thus, Uf depends on the desired solution x0. This paper examines an amplitude amplification algorithm in which the user encodes the directory (e.g. names and telephone numbers) into an entangled database state, which at a later time can be queried on one supplied component entry (e.g. a given phone number t0) to find the other associated unknown component (e.g. name x0). For N=2^n names |x> with N associated phone numbers |t>, performing amplitude amplification on a subspace of size N of the total space of size N^2 produces the desired state |x0>|t0> in sqrt(N) steps. We show how this procedure can be generalized to databases with more than two correlated lists (e.g. |x>|t>|s>...). We also discuss how and why sequential (though not concurrent parallel) searches can be performed on multiple database states.

8057-21, Session 6

Implementing an optical CNOT using spatial parity qubits

K. H. Kagalwala, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); G. Di Giuseppe, Univ. degli Studi di Camerino (Italy); A. F. Abouraddy, B. E. A. Saleh, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The construction of quantum optical gates, such as the CNOT gate, is essential for quantum information processing and quantum computation. We demonstrate a new and simple implementation for an optical CNOT gate that relies on manipulating the spatial distribution of a single-photon beam. Both control and target qubits are encoded in the same photon. The control qubit is the photon polarization. The target qubit is the one-dimensional spatial parity of the single photon. We describe an experimental arrangement that allows us to prepare an arbitrary single-photon state in the polarization and spatial-parity Hilbert space. The CNOT gate is implemented using a polarization-sensitive spatial light modulator (SLM). The SLM modifies the phase of one polarization component of the single-photon wave front. For a general state of polarization, this results in entangling spatial parity and polarization qubits. The resulting single-photon states are analyzed using a modified Mach-Zehnder interferometer. The gate operation is characterized using quantum process tomography. Using this approach, one may operate a CNOT gate that implements a general rotation of the target qubit. This new optical CNOT gate design is simple and does not require interferometric stability. Furthermore, it paves the way to designing multi-qubit CNOT gate designs based on utlilizing the higher dimensionality of the Hilbert space for the spatial degree of freedom.

8057-22, Session 6

Quantum cellular automata without quiescent states

H. A. Blair, R. J. Irwin, Syracuse Univ. (United States)

A deterministic (classical) cellular automaton (CA) is a dynamical system that regards the nodes of a homogeneous network as an ensemble of variables whose values, or states, co-evolve according to a single state update function synchronously applicable to every node. The update of a node to a new state is dependent on the state of small neighborhoods of the node independently of the node's location in the network. At any given time the global state of a classical CA, i.e. the states of all of the nodes, is definite. In contrast, the global state of a deterministic quantum cellular automaton (QCA) is a superposition of definite states represented by a unit vector in a complex vector space and evolves by iterations of a unitary operator. A quiescent state of a CA, classical or quantum, is a state which, if shared by every point in a small neighborhood of a given node, requires the given node to remain in the quiescent state. QCAs with quiescent states, originally defined and investigated by Watrous, 95 are sufficient for most computational purposes and the quantum state space is simpler than for QCAs without quiescent states. Nevertheless, QCAs without quiescent states allows probabilistic logic approaches to combinatorial search, decidability and formal verification that draws from the well-developed yet still developing computability and complexity theory on trees. We show how to construct non-quiescent QCA's using shift-invariant measures on Cantor space and set up a formal probabilistic specification logic based on the construction.

8057-23, Session 6

Rhythms essential to logical communication

J. M. Myers, Harvard Univ. (United States); F. H. Madjid, Consultant (United States)

Any endeavor in physics involves mathematical symbols along with some link of these symbols to expected or actual records of devices on a workbench. Several years ago, we proved that linking symbols on a blackboard expressing quantum states to records of behavior on a workbench requires reaching outside of logic to make a guess. Here we develop the theme of extra-logical operations essential to physics, and in particular to the establishment of rhythms necessary to communication.

Experiments in physics require establishing communication that is at once symbolic (blackboard) and physical (workbench): the experimenter must arrange for some effect to be tossed like a ball at whatever is investigated, and to see what comes back as a response. To count as physics, the experimenter has to say in symbols, including words, what was done at the workbench and what happened.

Now we ask: What are the physical circumstances necessary to the communication of logical symbols? We make the assumption that the communication of logical symbols requires a kind of ball tossing, or in engineering parlance synchronous communication, characterized by a certain rhythm shared by communicating parties.

In the following sections we spell out the rhythms inherent in logical communication and report on the first step of an inquiry into the impact of both quantum mechanics and of spacetime curvature on the possibilities for these rhythms spanning networks of communicating parties. It will be shown that there can be no universal pattern, rather ball tossing is local to an endeavor.

8057-24, Session 6

Quantum computing with induced dipole-dipole forbidden transitions

E. Donkor, Univ. of Connecticut (United States)

Forbidden transitions often have moderate energy separations and long lifetimes. They can be induced in elements by external force including laser absorption, magnetic effect, crystal forces and collision with energetic particles. In this paper we discuss the prospects of quantum information processing involving forbidden transitions in the inner shell of the rare-earth elements. We shall derive the selection rule for such transitions and discuss the prospects for quantum information procession with induced dipole-dipole forbidden transitions emphasizing the long decoherence time, degree of entanglement, lossless interconnectivity characteristics of these transitions.

8057-25, Session 6

A theoretical model of multi-agent quantum computing

F. M. Mihelic, Light Consulting (United States)

Man-made quantum computing should be modeled after the multi-agent system of quantum logic that naturally occurs in biological systems. Schrödinger had predicted that quantum leaps of electrons between energy states of covalent bonds within the “aperiodic crystal” that carries the genetic information within the nucleus of the cell, would provide what could be considered as a synchronization backbone of quantum logic and coherence, and thus form the essence of biological “life”. The quantum gate that forms the basis of such a quantum logic system is a theoretical Szilard engine function of nucleic acids that converts the energy associated with the Shannon entropy of molecules encountered by the nucleic acid, into the useful work of geometric conformational change of the nucleic acid molecule. This theoretical nucleic acid Szilard engine (NASE) is logically and thermodynamically reversible in this special case because its mechanism is literally constructed out of the (nucleic acid) information necessary for its function, thereby addressing the concern that Bennett raised about how a Szilard engine cannot function reversibly because of the thermodynamic consequences of erasing the information that would build up inside it. The reversibility of the system is further ensured via retention of information in the geometric conformational change of the nucleic acid molecule, and entangled photons emitted as a result of the symmetry breaking Szilard engine function can affect other nucleic acids within and between cells. Computing systems based on this theoretical multi-agent model will provide a practical quantum logic mechanism with stable coherence at room temperature.

Return to Contents

8057-26, Session 6

Encoding qubits into the spatial distribution of single photons and entangled photon pairs

A. F. Abouraddy, B. E. A. Saleh, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

While the discrete two-dimensional Hilbert space of the polarization of a single photon has received the most attention as an implementation of an optical qubit, the spatial degree of freedom has recently started to play a role as an alternative for encoding quantum information. The infinite-dimension of the continuous spatial parameter of a single-photon wave front presents an opportunity and a challenge: an opportunity for encoding a large amount of information (quantified in qubits), and a challenge in designing feasible optical systems that manipulate this large Hilbert space. We describe an approach to encoding qubits in the spatial parity of s single-photon state. We show that the state of parity may be rotated in its Hilbert space using simple wave plates and analyzed using a modified Mach-Zehnder interferometer. Furthermore, we encode two qubits in an entangled photon pair in an EPR state. Using this scheme, we are able to demonstrate for the first time a violation of Bell's inequality, and hence a demonstration of quantum nonlocality, using the spatial degree of freedom of the photon pair as envisioned in the original EPR proposal. Extensions of this scheme that allow for encoding more than one qubit per photon are described. This approach connects the two realms of discrete quantum information processing that relies on qubits and that of quantum sensing and imaging which has traditionally relied on continuous variables.

8057-28, Session 7

Random gauge theory

J. E. Gray, Naval Surface Warfare Ctr. Dahlgren Div. (United States)

A gauge transformation can often be associated with the evolutionary path of a quantum mechanical object. This is not observable directly, a difference can be such as when quantum mechanical object can take distinct paths, and then recombined to demonstrate a phase difference such as in the A-B effect. This has been interpreted as a geometric phase in a number of papers by Aharonov and various collaborators. Aharonov's career can be viewed as largely devoted to elucidating what phase means in quantum mechanics. The wavefunction is invariant under U(1) gauge transformations, so the wavefunction can be written with a relative phase function:

Ψ(x,t)→e^{iΛ}Ψ(x,t),

where Λ is a constant. This can be interpreted as associating a memory with a path. In general, the phase can depend upon the topological features of the phase such as associated with the Aharonov-Bohm effect. There is no reason, however to limit Λ, it can be an arbitrary function Λ(x) or it could also be considered a random variable with an underlying PDF. Under some circumstances this "randomization" of Λ could be used to explicitly bring in randomness associated with a path with an underlying PDF. Thus, it is possible to define a "random gauge" in quantum mechanics. Random path-dependent effects become a stochastic memory associated with the quantum mechanical system. We explore this is some detail and suggest an experiment to test the effects of randomness on path dependent phase difference effects.

8057-29, Session 7

Quantizing knots, groups and graphs

L. H. Kauffman, Univ. of Illinois at Chicago (United States); S. J. Lomonaco, Jr., Univ. of Maryland, Baltimore County (United States)

We show how to associate a Hilbert space to a category of combinatorial objects such as diagrams or piecewise linear embeddings representing knots, presentations of a group such as the braid group, or graphs of a certain type. The combinatorial objects are given extra structure so that transformations on them (such as Reidemeister moves on knots, or specific types of equivalence of group presentations, or isomorphisms of graphs) can be seen as unitary transformations of the Hilbert space. Once such constructions have been accomplished, then we say that the corresponding category of combinatorial objects has been quantized. Quantization in this sense makes properties of these categories available to analysis in the context of quantum information theory and brings to light the possibility for new quantum algorithms.

We will give detailed examples of these quantizations via quantum knots, quantum braids, quantized group presentations including the symmetric group and quantized versions of graphs and graph isomorphims. We will also discuss how this method leads to a Hilbert space that carries the chain complex (over the complex numbers) for Khovanov homology and how this structure is related to quantum algorithms for computing the Jones polynomial.

8057-30, Session 7

Possible quantum algorithms for generalized turaev-viro invariants of 3-manifolds

J. F. Ospina, Univ. EAFIT (Colombia)

An emergent trend in quantum computation is the topological quantum computation (TQC). Briefly, TQC results from the application of quantum computation with the aim to solve the problems of quantum topology such as topological invariants for knots and links (Jones polynomials, HOMFLY polynomials, Khovanov polynomials); topological invariants for graphs (Tutte polynomial and Bollobás-Riordan polynomial); topological invariants for 3-manifolds (Reshetiskin-Turaev, Turaev-Viro and Turaer-Viro-Ocneanu invariants) and topological invariants for 4-manifolds(Crane-Yetter invariants). In a few words, TQC is concerned with the formulation of quantum algorithms for the computation of these topological invariants in quantum topology. Given that one of the fundamental achievements of quantum topology was the discovery of strong connections between monoidal categories and 3-dimensional manifolds, in TQC is possible and necessary to exploit such connections with the purpose to formulate universal quantum algorithms for topological invariants of 3-manifolds. In the present work we make an exploration of such possibilities. Specifically we search for universal quantum algorithms for generalized Turaev-Viro invariants of 3-manifolds such as the Turaev-Viro-Ocneanu invariants, the Kashaev-Baseilhac-Benedetti invariants of 3-manifolds with links and the Geer-Kashaev-Turaev invariants of 3-manifolds with a link and a principal bundle. Similarly, we search for universal quantum algorithms for the Crane-Yetter invariants of 4-manifolds and theirs generalizations. We also look for physical systems (three dimensional topological insulators and three-dimensional and four-dimensional quantum gravity) over which implement the resulting universal topological quantum algorithms. Finally we discuss about the possibility to formulate our universal topological quantum algorithm in terms of a simple program in topological quantum lambda-calculus and its possible simulations using computer algebra software.

8057-31, Session 7

A combinatorial approach to the optical random walk

S. E. Spence, Naval Surface Warfare Ctr. Dahlgren Div. (United States)

A random walk is a useful model for a variety of classical random processes and it has recently come into vogue in quantum mechanics, particular in the area of quantum algorithms. A random walk which is implemented optically can be used as both a semi-classical and quantum mechanical instance of a random walk. Thus, it provides a useful model to study both quantum and mesocale models of interest. In this paper,

the optical random walk is examined as a combinatoral problem. A walk is given a graphical representation utilizing two-dimensional lattice points which is then related to bipartite expressions. The walk can be treated with three-dimensional lattice points with tripartite expressions, so this process can be extended to an arbitrary dimension n. Overall, a non-rigorous description of the approach is given that will solve for general combinatoral relations in two or more dimensions. Further, the approach points toward a solution to an interferometric random walk, which can be converted to a quantum random walk. This provides a roadmap to deal with higher dimensional cases.

8057-32, Session 7

Two-spectral Yang-Baxter operators in topological quantum computation

W. F. Sánchez, Univ. EAFIT (Colombia)

One of the current trends in quantum computing is the application of algebraic topological methods in the design of new algorithms and quantum computers, giving rise to topological quantum computing. One of the tools used in it is the Yang-Baxter equation whose solutions are interpreted as universal quantum gates. Lately, more general Yang-Baxter equations have been investigated, making progress as two-spectral equations and Yang-Baxter systems. This paper intends to apply these new findings to the field of topological quantum computation, more specifically, the proposition of the two-spectral Yang-Baxter operators as universal quantum gates for 2 qubits and 2 qutrits systems, obtaining 4x4 and 9x9 matrices respectively, and further elaboration of the corresponding Hamiltonian by the use of computer algebra software Mathematica® and its Qucalc package. In addition, possible physical systems to which the Yang-Baxter operators obtained can be applied are considered. In the present work it is demonstrated the utility of the Yang-Baxter equation to generate universal quantum gates and the power of computer algebra to design them; it is expected that these mathematical studies contribute to the further development of quantum computers

8057-33, Session 7

New gauge field from extension of space time parallel transport of vector spaces to underlying scalar fields

P. Benioff, Argonne National Lab. (United States)

Gauge theories can be described by assigning a vector space Vx to each space time point x. The freedom to choose bases in these spaces introduces unitary operators as parallel transformations between the vector spaces. The Lie algebra of these operators introduces gauge bosons into the Lagrangians for these theories. Here these ideas are extended to the underlying complex number field as scalars. A Hilbert space, Hx, as an example of Vx , and a complex number field, Cx, are associated with each point x. The basis choice freedom is expanded here to include the freedom to choose complex number fields. This expansion is based on the discovery that there exist representations of scalar fields that differ by arbitrary scale factors. This results in the presence of a real gauge field A(x). Inclusion of this field into the covariant derivatives in Lagrangians results in A(x) appearing as a gauge boson, for which mass is optional. The great accuracy of QED suggests that the coupling constant of A(x) to matter fields is very small compared to the fine structure constant. Other properties of A(x) are not known at present.

Return to Contents

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8058-02, Session 2

Adaptive supermother wavelet for compressive sensing

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Supermother theorem states that a finite linear combination of admissible mother wavelets remains admissible (Szu, 1994). It provides one with a tight frame for LMS approximation of the transient signal waveform. Therefore, fewer number of supermother daughter wavelets in shifts and scales can represent the real world transient dynamics. We conclude that the supermothers wavelets can always produce piece-wise-ly sparse subapce approximations. This is the spirit of compressive sensing.

8058-03, Session 2

Classification of transient signals using sparse representations over adaptive dictionaries

D. I. Moody, Los Alamos National Lab. (United States) and Univ. of Maryland, College Park (United States); S. P. Brumby, K. L. Myers, N. H. Pawley, Los Alamos National Lab. (United States)

Automatic classification of broadband transient radio frequency (RF) signals is of particular interest in nonproliferation monitoring, IED detection, and persistent surveillance. Because such transients are often non-stationary, are acquired in noisy, cluttered environments, and are characterized by complex or unknown analytical models, feature extraction and classification can be difficult. We propose a fast, adaptive classification approach based on non-analytical dictionaries learned from data. Conventional representations using fixed orthogonal dictionaries, e.g., Short Time Fourier and Wavelet Transforms, are suboptimal for classification of transients, as they are not designed to match the individual properties of the target signal. They do not usually lead to sparse decompositions, and require separate feature selection algorithms, creating additional computational overhead. Pursuit-type decompositions over analytical (i.e., fixed), redundant dictionaries yield sparse representations by design, and work well for target signals in the same function class as the dictionary atoms. The pursuit search however has a high computational cost, and the method can perform poorly in the presence of realistic noise and clutter. Our approach builds on the image analysis work of Mairal et al. (2008) to learn a discriminative dictionary for RF transients directly from data without relying on analytical constraints or a priori knowledge. We then use a pursuit search over this dictionary to generate sparse classification features. By using judiciously chosen training data, our learned dictionary is robust to unexpected changes in background content and noise levels. The target classification decision is obtained in almost real-time via a parallel, vectorized implementation.

8058-04, Session 2

Fractional wavelet transform using an unbalanced lifting structure

K. Kose, E. A. Cetin, Bilkent Univ. (Turkey)

In this article, we will introduce the concept of fractional wavelet transform. Using a two-channel unbalanced lifting structure it is possible to decompose a given discrete-time signal x[n] sampled with period T into two subsignals x1[n] and x2[n] whose sampling periods are pT and qT, respectively. Fractions p and q are rational numbers satisfying the condition: 1/p + 1/q =1. The low-band subsignal x1[n] comes from [0,pi/p] band and the high-band wavelet signal x2[n] comes from (pi/p, pi] band of the original signal x[n]. Filters used in the Lifting structure are designed using the Lagrange interpolation formula. The filter design approach is an extension of our earlier work, which was referenced in the lifting wavelet transform paper by Sweldens and Daubechies. It is straightforward to extend the proposed fractional wavelet transform to two or higher dimensions in a separable manner.

8058-05, Session 2

Anomaly recovery from compressive sensed spectral image sequences via low-rank matrix minimization

A. Ramirez, H. Arguello, G. Arce, Univ. of Delaware (United States)

This work describes a methodology for the recovery of anomalies and their spectral signatures from compressively sensed multi-spectral video using Principal Component Pursuit (PCP). In video surveillance, approaches based on PCP allow the anomaly detection in a cluttered background by modeling a sequence of video frames as a large data matrix composed by a low-rank matrix plus a sparse matrix. The low-rank matrix corresponds to the stationary background and the sparse matrix captures the moving objects in the foreground. The compressive spectral video frames are attained by the use of a Coded Aperture Snapshot Spectral Imaging (CASSI) system. The CASSI system allows the compressive measurement of spectrally rich video content by simply capturing a sequence of 2-D coded aperture video frames. This paper describes improved procedures for the reconstruction of the video anomalies and their spectra based on the 2-D, aperture-coded, isolated anomalies.

8058-06, Session 3

Optimally sparse shearlet approximations of 3D data

D. Labate, Univ. of Houston (United States); K. Guo, Missouri State Univ. (United States)

Sparse representations of multidimensional data have gained more and more prominence in recent years as a variety of applied problems require to process massive and multi-dimensional data sets in a timely and effective manner. This is especially important in applications such as remote sensing, satellite imagery, scientific simulations and electronic surveillance.

Directional multiscale systems such as shearlets are especially designed to deal with anisotropic features and have been shown to be optimally efficient in representing images with edges. We show that the shearlet approach is essentially optimal in representing a large class of 3D containing discontinuities along surfaces. This is the first (nonadaptrve) approach to achieve provably optimal sparsity properties in the 3D setting.

8058-07, Session 3

Three-dimensional shearlet edge analysis

D. A. Schug, Univ. of Maryland, College Park (United States); G. R. Easley, System Planning Corp. (United States); D. P. O'Leary, Univ. of Maryland, College Park (United States)

Volumetric data acquisition and increasingly massive data storage have increased the need to develop better analysis tools for three-dimensional data sets. These volumetric data sets can provide information beyond that contained in standard two-dimensional images.

Common strategies to deal with such data sets have been based on sequential use of two-dimensional analysis tools. In this work, we propose using an extension of the wavelet transform known as the shearlet transform for the purpose of edge analysis and detection in three-dimensions. This method takes advantage of the shearlet transform's improved capability to identify edges compared to wavelet-based approaches.

8058-09, Session 3

Denoising medical imagery using a novel framework

S. P. Kozaitis, J. Mehta, S. Ponkia, Florida Institute of Technology (United States)

A successful denoising approach should work under a variety of conditions. To denoise various types of medical imagery, we proposed a framework that allows for spatially-varying and data-dependent noise. Several intermediate denoised images were produced by applying different parameter values to an image. Then, the final denoised image was determined by clustering pixel values of the intermediate images. We presented results using non-local means and BM3D approaches for denoising. We considered low-dose x-ray CT imagery where lowering the dose of x-rays results in an increase in quantum noise. In addition, results were obtained for ultrasound and MRI magnitude imagery. In all cases, we obtained improved results when compared to using a single value of estimate for the noise variance. We found that a small number of intermediate denoising images were sufficient to improve results, therefore keeping the computational burden reasonable.

8058-10, Session 3

Application of wavelet transforms in de-noising optical emission transient signals generated from microsamples introduced into microplasmas and comparison with Fourier-transform and Hartley-transform signal processing noise-filtering methods

V. Karanassios, D. Hunter, Univ. of Waterloo (Canada)

For the last several years we have been developing and characterizing atmospheric-pressure, self-igniting, battery-operated microplasmas that can be used on-site (i.e., in the field), for example, for environmental monitoring. In environmental monitoring, analytes must be frequently determined near the detection limit. But as concentration decreases, so does signal intensity, thus degrading signal-to-noise ratio (SNR). In our laboratories, we are working toward improving signal intensity (e.g., by using specialized micro- and nano-sample introduction systems) and by using signal processing methods to reduce noise (by filtering). In this presentation, use of wavelet transforms to de-noise optical-emission transient-signals generated by introducing micro- and nano-amounts of sample into microplasmas [1-3] will be described in detail. De-nosing results and SNR obtained using wavelet transforms will be compared with noise-filtering and SNR results obtained using the same transient signals and more traditional signal processing methods, such as, Fourier-transforms and Hartley-transforms.

1. S. Weagant, A. T. Smith and V. Karanassios, "Mobile micro- and nano-instruments: Fast, cheap and under wireless control", ECS Transactions, 28(14), 1-6 (2010) [Invited]

2. S. Weagent and V. Karanassios, Helium-hydrogen microplasma device (MPD) on postage-stamp-size plastic-quartz chips, Analytical and Bio Analytical Chemistry, 395, 577-589 (2009).

3. V. Karanassios, K. Johnson and A. T. Smith, Micromachined, planar-geometry, atmospheric-pressure, battery-operated microplasma devices (MPDs) on chips for microsamples of liquids, gases or solids by optical emission spectrometry, Analytical and Bioanalytical Chemistry, 388, 1595-1604 (2007).

8058-12, Session 5

Imposing constraints on extracting filters to extract specific sources from convolutive mixtures

J. Yoo, C. H. Choi, S. Lee, KAIST (Korea, Republic of)

Although blind source extraction (BSE) is advantageous over blind signal separation in many practical applications, it is difficult to choose the extracted source from many sources in the mixtures. Many semi-blind signal separation algorithms utilize a priori information on the sources of interests, but it is usually difficult to impose 'right' constraints in real-world applications. We present another class of algorithms to extract specific sources of interests by imposing constraints on the convolutive mixing filters. The directional-constrained independent component analysis (dcICA) utilizes the direction-of-arrival of sources, which has been successfully imposed on the extracting filters. The closeness-constrained ICA (ccICA) utilizes high direct-to-reverberation ratio (DRR) of the mixing filters for close source-to-microphone distance, and the constraints are successfully transformed for the extracting filters. For the extraction of moving sources the motion-constrained ICA (mcICA) algorithm had been developed. Performance of the algorithms are tested on many simulated and real mixing environments, and clearly shows usefulness of the developed constrained ICA algorithms.

8058-13, Session 5

Robust speech recognition using missing feature theory and target speech enhancement based on degenerate unmixing and estimation technique

M. Kim, J. Kim, H. Park, Sogang Univ. (Korea, Republic of)

A method for target speech enhancement based on degenerate unmixing and estimating technique (DUET) has been described. To avoid the requirements of the DUET which need to know the number of sources in advance and to estimate the attenuation and delay parameters for all sources, the method assumes that extraction of only one target signal is required, which is often plausible in real-world applications such as speech enhancement. The method can efficiently recover the target speech with fast convergence by estimating the parameters for the target source only. In addition, it does not need to know the number of sources in advance.

In order to accomplish robust speech recognition, we propose an algorithm which employs the cluster-based missing feature reconstruction technique based on log-spectral features of enhanced speech in the process of extracting mel-frequency cepstral coefficients (MFCCs). The algorithm estimates missing time-frequency regions by computing the signal-to-noise ratios (SNRs) from the log-spectral features of the enhanced speech and observed noisy speech and by finding time-frequency segments which have the SNRs smaller than a threshold. The missing time-frequency regions are filled by using bounded estimation based on the log-spectral features that are considered to be reliable and on the knowledge of the log-spectral feature cluster to which the incoming target speech is assumed to belong. Then, the log-spectral features are transformed into cepstral features in the usual fashion of extracting MFCCs. Experimental results show that the proposed algorithm significantly improves recognition performance in noisy environments.

8058-14, Session 5

Bioimaging and biospectra analysis by means of ICA: experimental results

Q. Zhao, J. Langley, J. Lee, J. Abell, Y. Zhao, The Univ. of Georgia (United States)

Analysis of bioimaging and biospectra data has received increasingly more attention in recent years. In this paper, our research will be presented with experimental results of two recent works using independent component analysis approaches. The first work is on differentiation of superparamagnetic iron oxide (SPIO) nanoparticles, used as contrast agents in magnetic resonance imaging (MRI). The second work is on virus detection by surface-enhanced Raman scattering (SERS).

The SPIO nanoparticles have been applied extensively as contrast agent in MRI for tracking of stem cells, targeted detection of cancer, due to its biocompatible and biodegradable features. For differentiation of SPIO from the background signal (e.g. interface between air and tissues), the signal voids from multiple sources makes the task very difficult. To solve this problem, we assume that the number of sensors corresponds to the number of acquisitions with different combinations of MR parameters, i.e., longitudinal and transverse relaxation times. For the virus detection, the SERS approach has drawn more interest because of its high sensitivity. In our work, SERS spectra were acquired using various viruses in complex medium. Laser beams of two different wavelengths were employed for data acquisition. In both the MRI and SERS data, signal source separation (SPIO or virus from background signal) was performed on a pixel by pixel basis. The ICA was performed by two approaches. One is the thermodynamic approach (minimum free energy) proposed by Szu et al. Another one is spatial analysis using the fast ICA method. Experimental results of the two recent works will be presented and discussed.

(Supported by US Army Grant #80173)

8058-15, Session 5

Stability analysis of minimum free energy equilibrium prediction

B. Kaur, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Recently, Dr. Szu has developed an early cancer detection algorithm based on dual spectral passive images [Szu, 2006]. This algorithm is based on minimum free energy constrains over the blind demixing matrix formulism between unknown percentage of malign and benign tumor sources. We will analyze the stability of such a solution under the arbitrary room illumination and environmental conditions.

Reference:

Szu, Harold, Miao, L., and Qi, H. “Unsupervised Learning with Minimum Free Energy,” In: “ICA, Wavelet Conference,” SPIE 2006 Orlando.

8058-16, Session 6

Understanding human implict intention from physiological and behavioral data

S. Lee, S. Dong, D. Kim, KAIST (Korea, Republic of)

The main contribution of this research is to provide theoretical basis for the recognition of human implicit intention. Although human implicit intention itself is an interesting topic in cognitive neuroscience and its application to intelligent human-oriented user interface may open a new horizon, as far as we know, there has not been rigorous research on scientific or engineering community. It will also help to understand interaction mechanism between explicit and implicit intentions in human mind. The implicit intention model may also be utilized to explore new high-level cognitive functions in academic community.

8058-18, Session 6

Estimation of the magnetic flux induced by human motion

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States); J. Willey, U.S. Naval Research Lab. (United States)

No abstract available

8058-19, Session 6

Generative and discriminant feature extraction with supervised learning

C. S. Dhir, S. Lee, KAIST (Korea, Republic of)

Standard unsupervised feature extraction methods such as Principal Component Analysis (PCA) and Independent Component Analysis (ICA) provide representative features and latent variables which minimizes the data reconstruction error. These generative features may be common to all data, and may not be optimal for classification tasks. A supervised linear feature extraction method, namely, discriminate ICA (dICA), had recently been proposed which jointly maximizes Fisher linear discriminant and Negentropy of the extracted features. Motivated by independence among features and modified Fisher linear discriminant, the new algorithm extracts features with both generative and discriminant powers. Then, the features are further fine-tuned by supervised learning such as error backpropagation from the classifiers. Experimental results show excellent recognition performance with these features.

8058-20, Session 6

Development of artificial neural networks for spectral interference correction in optical emission spectrometry

Z. Li, V. Karanassios, Univ. of Waterloo (Canada)

Miniaturization of analytical instrumentation is receiving increased attention at conferences and the current scientific literature. Although small-size, miniaturized instruments offer increased promise for portability and use on-site, due to their small-size they also have the potential to suffer from increased spectral interference effects.

In this presentation, development of algorithms for spectral interference correction will be outlined. In particular, multi-layer feed-forward back-propagation network and one-layer adaptive network will de discussed and neural network training and testing will be described. Also, building up of a network’s architecture (e.g., layer connection, transfer function in each layer, number of layers and number of neurons in each layer and selection of neural network parameters will be described in some detail.

Furthermore, evaluation of several network architectures using training performance, training time and training epochs as key criteria will be discussed.

8058-21, Session 6

A new approach for neural network training and evaluation

X. Chen, E. L. Walker, Southern Univ. and A&M College (United States)

Neural Networks are widely used in pattern recognition for sensing systems and other areas. In this paper, we propose to improve the performance of neural networks by introducing new criterion used to train the neural networks and efficient estimation methods for estimation of the generalization error of the associated networks.

Our computational experiences and mathematical analysis indicate that the frequently used Euclid distance is not a good measure of the network performance. It is our contention that it will be a much superior criterion to maximize the proportion of training instances that are correctly recognized. By introducing a probabilistic function, we can transform the proportion into a smooth function, which is amenable for optimization using the powerful gradient descent algorithms. Moreover, we discovered that the existing methods for estimating the generalization error of a neural network is overly conservative. We propose multistage estimation methods which requires much few samples for performance evaluation.

8058-22, Session 6

Generalized statistics framework for lagrange constraint neural networks

R. C. Venkatesan, Systems Research Corp. (India); A. Sharma, SecureALL Corp. (United States)

The genrealized nonextensive statistics of Tsallis has achieved much prominence in defining complex systems characterized by correlations, fluctuations, and long-range interactions. The theory of Lagrange Constraint Neural Networks is re-formulated within the framework of generalized statistics. A numerical algorithm for unmixing endmembers in hyperspectral imaging is formulated using Hebbs rule derived for graded response Hopfield networks using a q-deformed sigmoid logistic function to relate inputs and outputs, and, the gradient descent method. Numerical results for unmixing mixtures of observation data possessing a high Pearson's correlation index are presented. A self-consistent methodology to assign values to the Lagrange multipliers based on the theory of second-order phase transitions and Landau symmetry breaking, is presented.

8058-24, Session 8

Infrared imaging using carbon nanotube-based detector

N. Xi, Michigan State Univ. (United States)

Using carbon nanotubes (CNT), high performance infrared detectors have been developed. Since the carbon nanotubes have extraordinary optoelectronics properties due to its unique one dimensional geometry and structure, the CNT based infrared detectors have extremely low dark current, low noise equivalent temperature difference (NETD), high response time, and high dynamic range. Most importantly, it can detect 3-5 um middle-wave infrared (MWIR) at room temperature. This unique feature can significantly reduce the size and weight of a MWIR imaging system by eliminating a cryogenic cooling system. However, there are two major difficulties that impede the application of CNT based IR detectors for imaging systems. First, the small diameter of the carbon nanotubes 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, a new CNT based IR imaging system will be presented. Integrating the CNT detectors with photonic crystal wave guide, the fill factor of the CNT based IR sensor can reach as high as 0.91. Furthermore, using the compressive sensing technology, a high resolution imaging can be achieved by CNT based IR detectors. The experimental testing results show that the new imaging system can achieve the superb performance enabled CNT based IR based detectors, and, at same time, overcame its difficulties to achieve high resolution and efficient imaging.

8058-25, Session 8

Catalytic nanomotors: challenges and opportunities

Y. Zhao, The Univ. of Georgia (United States)

The fabrication of integrated nanomachinary systems can enable break-through applications in nanoelectronics, photonics, bioengineering, and drug delivery or disease treatment. Naturally occurring nanomotors are biological motor proteins powered by catalytic reactions, which converts the chemical energy into mechanical energy directly. It has been demonstrated recently that using a simple catalytic reaction and an asymmetric bimetallic nanorod, one can produce catalytic nanomotors that mimic the autonomous motions of bionanomotors. Yet, the construction of artificial nanomachines remains a major contemporary challenge due to the lack of a flexible fabrication technique that can design the desired dynamic components. Thee are five biggest challenges for manmade nanomotor systems: (1) how to build different motion parts; (2) how to assembly different motion parts and functionality into an integrated system; (3) how to control and program different functionality; (4) how to power the nanomotor system; and (5) what are the physical and chemical performance of those nanomotor system in fluidic environment. In this talk, I will discuss how to tackle some of those challenges using a fabrication method called dynamic shadowing growth technique, and will show some nanomotor components, systems, and the way to control the motion.

8058-26, Session 8

Adaptive hyperspectral sensing with carbon nanotubes

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Y. Shen, K. H. Ou, The George Washington Univ. (United States); R. Kit, Air Force Office of Scientific Research (United States)

Adaptive sensing is possible to achieve a compressive sensing, when we reverse the direction of Einstein photo-electric effect of Nano Solar Cells for imaging. Each pixel will be designed as a fireman staircase, of which each run is made of Carbon Nanotubes (CNT) at a different diameter. Saito-Wallace bandgap formula may be understood as de Broglie matter wave around the circumference. Thus, the band gap may be re-derived as follows: ε_BG=C_Fermi P=C_Fermi h/λ=C_graphene h/πd, and λ=2πR=πd of the CNT diameter , where use is made of Geim and Novoselov result (2010 Nobel Laureates) that single wall CNT enjoys a ballistic propagation C_Fermi identically to one thousandth of the speed of light in the single sheet grapheme C_graphene= 10 ^(-3) C_o. We control the grid field effect of CNT to turn current signal on or off. We evaluate the dark current, the polarization, the quantum efficiency and the SNR

8058-27, Session 9

How to build a smart sensing surveillance net

K. Chu, U.S. Dept. of Homeland Security (United States); C. Hsu, Trident Systems Inc. (United States)

A smart sensing surveillance net is a dense wireless network with small, low-cost sensors to collect and disseminate environmental data. They have applications in a variety of fields such as environmental monitoring, military purposes and gathering sensing information in inhospitable locations with various challenges including detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating the information, formulating meaningful user displays, and performing decision-making and alarm functions. The information needed by smart environments is provided by a distributed wireless sensor network, which are responsible for sensing as well as for the first stages of the processing hierarchy. This paper describes the key-establishment processes in terms of radio frequency selection, wireless communication network analysis, sensor technology study, sensor signal process, power management, decision-making and user interface, which experiences were learned of the Semantic Mesh of Intelligence Sensors (SMIS) System sponsored by the DHS. All the sensor nodes in the smart sensing net shall be connected with a robust and reconfigurable LPI/LPD (Low Probability of Intercept/ Low Probability of Detect) wireless network under the FCC regulations. The basic issue in wireless communication networks is the transmission of messages to achieve a prescribed message throughput (Quantity of Service) and Quality of Service (QoS). The distributed sensor nodes with sophisticated sensor processes shall provide the capability to collect, process, and disseminate heterogeneous sensor data to deal with chemical, biological, and radiological threats. Power efficiency and management are the key factors to maintain the smart sensing net operated in long term usability. Software power management techniques can be used to greatly decrease the power consumed by RF sensor nodes. The intended user-application of the smart sensing net shall use an open, publically available standards based solution with provides the capability for discovery, command and control. Additionally, a net centric service oriented architecture (SOA) shall be integrated such that remote applications can also interact with the sensor network.

8058-28, Session 9

What is a missing link among a persistent surveillance?

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. Hsu, Trident Systems Inc. (United States); J. Wu, WJ Associates (United States)

A persistent surveillance requires netted sensors that is preferred to be covert for fear of deliberate avoidance and destruction. The communication links must be noise-like as the UWB wireless, ad hoc push-pull meshed self-healing hierarchical network. We propose a Hermitian wavelets for the time domain direct sequence mode to enjoy the de-noise enhancement of SNR.

8058-29, Session 9

How to sequentially update eigen face

C. C. Hsu, Trident Systems Inc. (United States); H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The paper describes the updates of eigen faces using outer production of sequential data.

8058-30, Session 9

What is a good biometrics at distance?

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. Hsu, Trident Systems Inc. (United States); I. Kohlberg, Institute for Defense Analyses (United States)

For standoff biometrics, we explore human iris phase singularity code of Daugman as an exemplar for the distant performance of noncooperative biometrics. We recommend another method to improve the robustness and uniqueness attribute in the deja vu persistent surveillance sense.

8058-31, Session 9

A review of the current state-of-the-art in crowd behavior analysis and simulation

K. A. Byrd, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The computer vision community has made significant progress in designing algorithms to classify normal and abnormal behavior of pedestrians in dense crowds and urban environments. Many existing approaches are based on Helbing's Social Force Model (SFM), whereas a pedestrian's dynamics is represented by its "actual force", a superposition of their personal desired and interaction forces. SFM is then augmented with algorithms to 1) "track" pedestrians or particles (individual image pixels), normally using optical flow, 2) extract features, 3) reduce the dimensionality of feature vectors and 4) partition the dataset to calculate the distribution/degree of normal/abnormal behavior. While mature, the user/operator is limited to using the information that quantifies the social interaction of pedestrians as seen through visual sensors (i.e., the magnitude and direction of velocity vectors given by optical flow estimation). This paper presents a review of the state-of-the-art techniques being employed to simulate and analyze the behavior of pedestrians in crowds. In addition, future research directions and applications are discussed.

8058-32, Session 9

Distributed signal decorrelation in wireless sensor networks using the sparse matrix transform

L. R. Bachega, Purdue Univ. (United States); S. Hariharan, The Ohio State Univ. (United States); C. A. Bouman, Purdue Univ. (United States); N. Shroff, The Ohio State Univ. (United States)

Wireless Sensor Networks can effectively be deployed to monitor a geographical region, such as in target detection. The sensors cooperatively gather measurements and report back to the end-users. These measurements are typically correlated, and it is important to decorrelate them in order to accurately determine the quantity the end-user is interested in. Further, since decorrelation requires a huge amount of computation, it is preferable if its computation could be performed in a distributed manner instead of performed by a centralized node.

This paper shows how to detect high dimensional signals in a multi-hop wireless sensor network with spatially correlated clutter. Each sensor measures one dimension of a p-dimensional signal. The core idea behind our method is the signal decorrelation using a distributed version of the Sparse Matrix Transform (SMT), which was previously shown to produce accurate estimates of the signal's eigen decomposition even when the number of training samples, n is substantially less than p. The resulting decorrelating transform is sparse, and can be applied with complexity O(p).

First, we propose a distributed algorithm for the SMT design in a multi-hop wireless network. Second, we show how to apply the resulting decorrelating transform in the network, in a distributed manner. Finally, we use the distributed SMT decorrelation as the building block for a signal detection mechanism in a multi-hop wireless network. Experiments with deterministic and random signal detection show the advantages of our algorithm when compared to other competing methods in terms of detection accuracy and communication costs.

8058-33, Session 9

Real-world Nyquist sampling rate (of facial ordering)

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Hsu, The George Washington Univ. (United States)

We review a simple disturbance correction methodology from the macroscopic turbulence propagation to a nanoscopic imaging medium distortions.

8058-35, Session 11

YURAGI: analysis for detecting heart-rate by mat-type sensor in bed

Y. Hata, K. Ho, K. Kuramoto, S. Kobashi, Univ. of Hyogo (Japan); N. Tsuchiya, H. Nakajima, OMRON Corp. (Japan)

Heart rate is the one of important factors of our wellness, and this analysis is used for evaluating autonomic nervous system and sicknesses such as diabetes and Parkinson's diseases. Electrocardiograph is widely used for measuring heart rate variability. However, this system constrains patients during the measurement. Therefore, non-constraining monitoring systems are required.

This paper discusses a data analysis by YURAGI for a heart rate non-constraining monitoring system Three signals are employed: first one is the signal obtained by a mat-type sensor, which is placed between a bed and subject, the second one is the signal obtained by an ultrasonic vibration senor attached to bed frame, and third one is Gaussian noise. We compare the synthesized data of the first and second ones with that of first one and the noise. We consider the ultrasonic sensor signal and Gaussian noise as YURAGI. The extraction algorithm is developed based on fuzzy logic. The comparison is done on 10 healthy volunteers and we evaluated the accuracy for various weight ratio. Here, we must concern the accuracy because the tiny accuracy difference causes large difference in the autonomic nerve system assessment. Consequently, the former had higher accuracy. This accuracy was the highest (correlation coefficient=0.890±0.088) when the ratio is 0.10. The accuracy of the latter was the highest (0.875±0.099) when the ratio is 0.17. Thus, the former is superior, and YURAGI analysis is useful to this study.

8058-36, Session 11

Visceral fat estimation method by bio-impedance and causal analysis

H. Nakajima, H. Tasaki, N. Tsuchiya, OMRON Corp. (Japan); T. Hamaguchi, T. Shiga, OMRON Healthcare Co., Ltd. (Japan)

The term of "metabolic syndrome" has been well known in many nations. Because it causes serious cardiovascular disease and it is caused by daily lifestyle habit. The gold standard diagnosis of the syndrome in medical field is measurement of visceral fat area by X-ray CT scan image at umbilical level. Waist measure is used in primary diagnosis because of its ease of use but it cannot discriminate visceral fat, subcutaneous fat, and lean body with accuracy. Thus, waist measure is easy but has problem of accuracy and CT scan is accurate but requires high cost and has serious problem of X-ray exposure. Medical field requires much more easy and accurate visceral fat measurement method. In response to the needs, bio impedance is employed to measure body composition and cause-effect structural analysis method is applied to estimate visceral fat area from the measurement data. The principle of visceral fat area measurement can be simply designed by the causal relation of "sectional area" minus "subcutaneous fat one" minus "lean body one". According to the causal relation, the feature valuables are designed as much as possible with redundancy. Then, Akaike Information Criterion is employed to select the suitable variables and Variance Inflation Factor is used to check the multicollinearity of variable combination. Finally, multiple linear regression analysis is applied to construct the estimation model. Through these methods, the model of visceral fat area is acquired with the performance of around 0.9 correlation coefficients with the reference values provided by CT scan.

8058-37, Session 11

Mulitscale edge detection for small blood vessel segmentation in magnetic resonance angiograpy

R. Chandramohan, S. P. Kozaitis, Florida Institute of Technology (United States)

The boundaries of small blood vessels may be difficult to detect due to the lack of blood flow from disease or injury. To improve edge detection, we considered an approach that compares the products of wavelet coefficients at different scales. This approach is beneficial in the presence of noise or in low-contrast settings. It can be used to detect higher-order vessels that may be difficult to detect under normal conditions. This is important in the case where small blood vessels branch off from larger ones. The smaller size reduces blood flow, which is further limited by disease or injury. Identifying these small blood vessels is important for further treatment, and by detecting their edges in MRA imagery, their visibility can be increased.

8058-38, Session 11

Heart-rate monitoring by air pressure and causal analysis

N. Tsuchiya, H. Nakajima, OMRON Corp. (Japan); Y. Hata, Univ. of Hyogo (Japan)

Among vital-signals, heart rate (HR) provides important information of humans' health transit such as condition of autonomic nerve system and an early stage of cardiac disease. It is important to measure HR continuously against health changes during our daily life. In medical fields, an electrocardiography (ECG) is used as the gold standard for measuring HR variability. However, ECG is highly intrusive and invasive to patients because of putting electrodes. Besides, the system is complex and the cost is high. Non-intrusive, low-invasive, unconscious, and low-cost method is required to measure our daily life activities.
In response to the requirements, an air-pressure sensor which simply consists of a rubber tube and a pressure sensor is employed to detect HR. As a first step of daily life activity monitoring, the situation is during sleep or lying on the bed. Even though the simple constraint, the sensor superimposes information from HR, respiration, and body movement on its signals. The article proposes causal transformation analysis and fuzzy logic based filtering method to extract HR from the sensor signals. The causality of the sensor signals and HR is firstly designed by conceptual level and then, it is transformed into much more concrete level with considering extracting just information related to HR. The filtering is realized by applying knowledge about HR represented in fuzzy logic. The experiments were conducted to prove the performance of the proposed method. The results were around 0.85 correlation coefficients with ECG.

8058-39, Session 11

Biomedical wellness by tai chi and sports

D. C. Chin, The Johns Hopkins Univ. Applied Physics Lab. (United States); A. G. Chin, Virginia Commonwealth Univ. (United States)

Tai-chi masters demonstrate their power effortlessly stopping pushers and un-balancing people. People are flying everywhere around them. They are gentle and quick. A biosystem is based on the tai-chi described

Return to Contents

in the publications of Master Wang and Master Cheng, Man-ch'ing using body dynamic, Newton principle, and forcing functions. This paper describes the biosystem and discusses its applications. The basic rules for games and exercises are similar; the differences in instruments and purposes. This paper is also using the basic rule of Tai-chi analyzing sports activities for understanding and improvements; examples are shown in dancing, golfing, etc.

8058-52, Session 11

YURAGI: analysis for trans-skull brain visualizing by ultrasonic array probe

N. Yagi, Y. Oshiro, O. Ishikawa, Ishikawa Hospital (Japan); Y. Hata, Univ. of Hyogo (Japan); Y. T. Kitamura, T. Yanagida, Osaka Univ. (Japan)

In the human brain diagnostic system, the imaging of the brain is essential. Currently, X-ray computed tomography (CT) and magnetic resonance imaging are widely used, but the both cannot provide the dynamics and X-ray CT has a serious problem of X-ray exposure. This paper proposes a YURAGI-Analysis for brain imaging under the skull. In it, we employ 1.0MHz and 0.5MHz ultrasonic waves. We consider the weighted sum of these waves and attempt to extract the skull depth and image the sulcus under it. We add 1.0MHz and 0.5MHz, and we add the waves of 1.0MHz and Gaussian noise as the YURAGI analysis. We visualize the sulcus and skull. First, we calculate the thickness of the skull from the each of two synthesized waves.. The thickness is determined from the surface and bottom points determined from the wave based on fuzzy inference. The sulcus surface was extracted from B-mode images for the each of two synthesized waves. As the result using a cow scapula as the skull and steel ditch as the human sulcus, we successfully calculated skull thickness. We extracted the sulcus width within the error of 5.86 mm and depth within the error of 1.94 mm. As for imaging the sulcus under the skull, the highest effectiveness of the synthesized wave is 96.30% when the weight of 0.5MHz waves is 0.60, and the one of YURAGI-Analysis wave is 97.15% when the weight is 0.003. Thus, the YURAGI-Analysis is useful to this study.

8058-57, Session 11

Biometrics security by dynamics of left and right sole pressure while walking

T. Takeda, K. Kuramoto, S. Kobashi, Y. Hata, Univ. of Hyogo (Japan)

This paper describes a biometric personal authentication method based on fuzzy logic using dynamics of sole pressure distribution while walking. The method employs a pair of right and left sole pressure data. These data are acquired by a mat type load distribution sensor. The proposed method has two processes. First, we calculate a fuzzy degree of each sole pressure data. In this process, we extract several gait features based on weight shift and shape of footprint. Fuzzy if-then rules for each registered person are introduced. In it, their parameters are statistically optimized in learning process. Second, we combine fuzzy degrees of right and left sole pressure data. In this process, we employ four operators: average, minimum, maximum and product operator as the combination operator. The method authenticates walking person with the combined fuzzy degree. We calculate the fuzzy degree of an interest person for all registered persons, and identify the interest person as the registered person with the highest fuzzy degree. While, we verify the interest person as the target person if the fuzzy degree of the interest person calculated for a target person is higher than his/her threshold. In our experiment, we employed 50 volunteers and evaluated the method by five hold cross validation method. We obtained lowest false rejection (12.6%) and false acceptance rates (0.26%) by combining average operator. These rates are superior to those of the other proposed methods.

8058-58, Session 11

A fuzzy automated object classification by infrared laser camera

S. Kanazawa, Univ. of Hyogo (Japan); K. Tanigushi, Kinden Corp. (Japan); A. Kazunari, Kansai Electric Power Co., Inc. (Japan); K. Kuramoto, S. Kobashi, Y. Hata, Univ. of Hyogo (Japan)

Home security in night is very important, and the system that watches a person's movements is useful in the security. This paper describes a classification system of adult, child and the other object from distance distribution measured by Infrared laser camera. This camera radiates infrared waves (850nm) and receives reflected ones. Then, it converts the time of flight into distance distribution, and provides them as the 3D image. Our method consists of 4 steps. First, we do background subtraction in the distance distribution, and remove the background noise. Second, we do fuzzy clustering in the distance distribution, and from several clusters. Third, we extract features such as the height, thickness, aspect ratio, area ratio of the cluster. Then, we make fuzzy if-then rules from knowledge of adult, child and the other object so as to classify the clusters. Here, we made the fuzzy membership function with respect to each features. Finally, we classify the clusters to one with the highest fuzzy degree among adult, child and the other object. In our experiment, we set up the camera in room and tested three cases including adults, children and a box. The method successfully classified them in real time processing. The accuracy shows over 80% for adult and the others, and 70% for children.

8058-40, Session 12

Defense-related insights and solutions from neuroscience and neuroengineering

G. Schalk, New York State Dept. of Health (United States) and Albany Medical College (United States) and Univ. of New York at Albany (United States); A. Gunduz, P. Brunner, New York State Dept. of Health (United States) and Albany Medical College (United States)

Our laboratory is taking advantage of exciting opportunities in systems and cognitive neuroscience and in translational neuroengineering. Our neuroscience research investigates the neural basis of motor, language, and cognitive function using recordings from the surface of the brain (electrocorticography (ECoG)) in humans and using behavioral and computational techniques. For example, we study how local field potentials in different cortical areas (e.g., in PM and M1) prepare for and execute hand and finger movements. Our neuroengineering research combines this neuroscientific understanding with efforts in electrical engineering, bioengineering, and computer science to address particular problems relevant to the defense or other communities. These problems include the restoration or augmentation of function using brain-computer interfaces (BCIs). BCI systems translate neural activity from the brain into control signals that drive applications that allow people to communicate with or control their environment. This work includes statistical signal processing, machine learning, and real-time system design and implementation. For example, how can we design brain-based communication systems with performance that rivals that of spoken language?

In this talk, I will describe the types of signals that can be detected in ECoG and the emerging understanding of their physiological origin. I will then demonstrate that ECoG encodes detailed aspects of function at high spatial and temporal resolution. Finally, I will show how this understanding allows us to work toward novel solutions for different clinical problems.

8058-41, Session 12

Wavelets for full reconfigurable ECG signal acquisition system

D. P. Morales, A. García, E. Castillo, Univ. de Granada (Spain); U. Meyer Baese, The Florida State Univ. (United States); A. J. Palma, Univ. de Granada (Spain)

This paper present a set of wavelets cores for a full reconfigurable electrocardiogram signal (ECG) acquisition system. The system is compound by two reconfigurable devices, a FPGA and a FPAA. The FPAA is in charge of the ECG signal acquisition. This device is a versatile and reconfigurable analog front-end for biosignals. The FPGA is in charge of FPAA configuration, digital signal processing and information extraction, such as, heart beat rate. Wavelet analysis has become a powerful tool for ECG signal processing since it perfectly fits ECG signal shape. The use of these cores has been integrated in the LabVIEW FPGA module development tool that makes possible to employ VHDL cores within the usual LabVIEW graphical programming environment and it frees the designer from tedious and time consuming design of communication interfaces. This enables rapid test and result graphical representation.

8058-42, Session 12

Wavelet domain analysis of EEG data for emotion recognition: evaluation of recoursing energy efficiency

T. Aspiras, V. K. Asari, Univ. of Dayton (United States)

In this paper, we evaluate the feature extraction technique of Recoursing Energy Efficiency on dense array electroencephalograph data for human emotion recognition. An experiment protocol has been established using the International Affective Picture System (IAPS) to elicit six distinct emotions (happy, sadness, disgust, fear, surprise, and neutral). EEG signals are collected using a 256-channel system (EGI Dense Array EEG Data Capture System) and are preprocessed using Independent Component Analysis (ICA) for eye artifact reduction to reduce noise. The resulting signals are then processed using Discrete Wavelet Transform (DWT) to decompose the signal into five frequency bands (Theta, Delta, Alpha, Beta, and Gamma bands). The energy of each frequency band is calculated for each channel and the Recoursing Energy Efficiency (REE) is calculated to obtain energy features suitable for classification. These features are then applied to a Multi-Layer Perceptron (MLP) network with Back-Propagation (BP) learning algorithm for classification of different emotions. The MLP architecture consists 1280 input nodes for the input data encompassing all the feature elements of various frequency bands and channels. It has 6 output nodes to represent 6 distinct emotions. The network is trained with various number of hidden layer nodes (10, 15, 20 etc) to verify the recognition accuracy of the system. We compare the performance of the REE based energy features with the conventional energy based features to validate the effectiveness of the REE approach for emotion recognition. We also present an alternate REE computation strategy for further improvement in classification of emotional states of mind.

8058-43, Session 12

Gaussian graphical models reveal specific lipid correlations in glioblastoma cells

N. S. Mueller, Max-Planck-Institut für Biochemie (Germany); J. Krumsiek, F. Theis, Helmholtz Zentrum München GmbH (Germany); C. Böhm, Ludwig-Maximilians-Univ. München (Germany); A. D. Meyer-Bäse, The Florida State Univ. (United States)

Advances in high-throughput measurements of biological specimens necessitates the development of biologically driven computational techniques. To understand the molecular level of many human diseases, such as cancer, lipid quantifications offer an excellent opportunity to reveal disease-specific regulations. The analysis of the lipid levels, however, remains a challenging task and cannot be accomplished solely based on intuitive reasoning. We have developed a method to identify disease-specific lipid correlations beyond arbitrary thresholding of correlation networks on Glioblastoma data. To induce programmed cell death (apoptosis) in apoptosis resistant brain tumor cell lines, only a combination of perturbations was shown to be effective. To identify the effects on lipid levels as a result to the perturbations many lipid species were quantified by mass spectrometry. A powerful method to then correlate lipid levels across various treatments is a Gaussian Graphical Model (GGM). In contrast to simple Pearson correlation networks, a GGM only contains direct correlations while indirect associations are eliminated. By implementing disease driven GGM, we revealed Glioblastoma specific lipid correlations to advance biomedical research on novel gene therapies.

8058-44, Session 12

Gut feeling is electric

J. Familoni, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Although “gut feeling” is a cliché in english parlance, control of the gut, the gastro-intestinal (GI) tract is by an integration of neuro-hormonal influences from the local, i.e., myogenic to the central nervous system level. Gastric contractile activity, which is responsible for the motor properties of the stomach, is regulated by this integrated complex. One of this control mechanism is by the intrinsic gastric electrical activity (GEA). It has two distinct components: a high-frequency spike activity or a postdepolarization potential termed the electrical response activity superimposed on a lower frequency, rhythmic depolarization termed the control activity. Therefore, the state of wellness or disease of the gut may be objectively divined by analysis of the electrograstrogram (EGG).

GEA or the EGG not only provides a way to diagnose gut dysmotility, it has more recently become an avenue for a paradigm shift in the treatment of such disorders as gastroparesis that is refractory to drug therapy. In this study, we examine the development of gastric electrical stimulation as an efficacious treatment for drug refractory gastroparesis.

8058-45, Session 12

Reconstruction algorithms for optoacoustic imaging based on fiber optic detectors

D. C. Gallego, H. Lamela, R. Gutiérrez, Univ. Carlos III de Madrid (Spain); A. A. Oraevsky, TomoWave Labs., Inc. (United States)

OptoAcoustic Imaging (OAI), a novel hybrid imaging technology, offers high contrast, molecular specificity and excellent resolution to overcome limitations of the current clinical modalities for detection of solid tumors. OA effect refers to the generation of acoustic waves by the absorption of optical energy inside a tissue. Angiogenesis induces an increase of blood content in malignant tumors respect to normal tissues. Hemoglobin, the strongest endogenous chromophore in the near-infrared spectral range, provides the main source of optical contrast for solid tumors, such as breast cancer.

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. Another approximation to the

OAI reconstruction arises from the use of integrating area detectors in combination with an inverse Radon algorithm.

In this paper, we compare the results provided by these different approximations of OAI with real OA signals collected from a physical phantom using an intrinsic fiber optic detector. 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 the clear definition of the object boundaries.

8058-17, Session 13

Independent component analysis (ICA) of fused wavelet coefficients of thermal and visual images for human face recognition

M. K. Bhowmik, D. Bhattacharjee, D. K. Basu, Jadavpur Univ. (India)

In this paper, an image fusion technique based on weighted average of Daubechies wavelet transform (db2) coefficients from visual face image and their corresponding thermal images have been presented. Further, a comparative study has been conducted for dimensionality reduction based on Principal Component Analysis (PCA) and Independent Component Analysis (ICA). Fused images thus obtained are classified using a multi-layer perceptron (MLP). For experiments IRIS Thermal/Visual Face Database has been used. Experimental results show that the performance of ICA architecture-I is better than the other two approaches i.e. PCA and ICA-II. The average success rate for PCA, ICA-I and ICA-II are 91.13%, 94.44% and 89.72% respectively. However, approaches presented here achieves maximum success rate of 100% in some cases, especially in case of varying illumination.

In this paper, the investigation on filter based fusion of thermal and visual face images to protect the private data using ICA feature extraction method is presented. The reasons behind use of ICA in comparison to PCA are: (i) ICA has better architecture than PCA, which can easily understand where the data is mainly concentrated in n-dimensional space; (ii) In case of PCA it reconstructs the data on the orthogonal basis, but on the other hand it is not necessary for ICA; and (iii) ICA can easily reconstruct the data even in the presence of noise.

8058-46, Session 13

NIOS II processor-based acceleration of motion compensation techniques

D. González Rodríguez, Univ. Complutense de Madrid (Spain); G. Botella Juan, U. Meyer Baese, A. D. Meyer-Bäse, The Florida State Univ. (United States)

"This paper focuses on the hardware acceleration of motion compensation techniques suitable for the MPEG video compression. The methods and designs described here are qualified for medical imaging area where are involved larger images. The structure of the processing systems considered has a good fit for reconfigurable acceleration. The system is based in a platform like FPGA working with the Nios II Microprocessor platform applying C2H acceleration.

The paper shows the results in terms of performance and resources needed."

8058-47, Session 13

PCA method for automated detection of mispronounced words

Z. Ge, S. R. Sharma, M. J. T. Smith, Purdue Univ. (United States)

Learning to speak a foreign language well requires practice in order to master proper pronunciation. Algorithms that can detect mispronunciations can serve as part of an automated system to assist students in learning. The current software products do not address mispronunciations interactively. In this paper, we present a new algorithm for detecting and classifying mispronunciations. Although the algorithm is not language specific, we have focused on Spanish in this work, involving male and female native and non-native speakers. The algorithm integrates Principle Component Analysis (PCA) in the detection process. Compared with hidden Markov models (HMMs), which are now used pervasively in recognition applications, this particular approach is computational efficient and is effective even when limited training data are available.

The algorithm involves computing feature vectors and eigenspaces for training and testing data. Detection is formulated with respect to these eigenspaces using a Euclidean measure of the original-to-projection differences and the mapping differences inside eigenspaces. It is hierarchical with each successive step refining the estimate underlying the decision to classify the test word as being mispronounced or not. Preprocessing before detection such as normalization and time-scale modification is implemented to guarantee the uniform inputs of the feature vectors to the detection system.

The performance of various types of input features, including spectrograms, Mel-Frequency Cepstral Coefficients (MFCCs) and Discrete Cosine Transforms (DCTs) are compared and evaluated. Best results were obtained using the wideband spectrogram and MFCC, achieving close to 100% accuracy for mispronunciation detection and 93% accuracy for classification.

8058-48, Session 13

Applying genetic algorithm to optimization parameters of robust optical flow system

O. Zavala, G. Botella Juan, A. D. Meyer-Bäse, U. Meyer Baese, The Florida State Univ. (United States)

"We propose a new approach for optimization in gradient-based optical flow using genetic algorithm.

A model for estimation of optical flow has been implemented, whose main characteristics are its bioinspiration and robustness against contrast, static patterns and noise among working consistently with several optical illusions where other algorithms fail. The model implemented depends of many parameters which conform the number of channels, the orientations required, the length and shape of the kernel functions used in the convolution stage as well as many more. As result we find a set value which improves the accuracy and efficiency that permits to reconfigurate dinamically the system with potentially applications to robotic, medical imaging and complex neuromorphic systems."

8058-49, Session 13

Intellectual property protection (IPP) using lossless obfuscation in C, VHDL, and Verilog coding

U. Meyer Baese, G. Botella Juan, The Florida State Univ. (United States); E. Castillo, A. García, Univ. de Granada (Spain)

One of the big challenges in the design of embedded systems today is how to combine design reuse and intellectual property protection (IPP) schemes. Strong IP schemes such as hardware dongle or layout watermarking usually have a very limited design resuse for different FPGA/ASIC design platforms. Some techniques also do not fit well with protection of software in embedded microprocessors.

Another approach to IPP that allows an easy design reuse and lossless synthesis but a somehow reduced protection is code "obfuscation." Obfuscation is a method to hide the design concept or program algorithm included in the C or RTL source. Obfuscation methods include, for instance, renaming identifiers, removing comments or formatting of the code. More sophisticated obfuscation methods include adding code hierarchy or control flow changes. The goal of obfuscation is not to make reverse engineering impossible, but reverse engineering should be more expensive than a complete new design.

Depending on the obfuscation implemented the code may become less efficient. The paper presents speed/area/power penalty results and show obfuscation limits imposed on C, VHDL and Verilog code.

8058-50, Session 13

Polarimetric detection for slowly moving/ stationary targets in inhomogeneous environments

C. Hsu, H. B. Mendelson, A. Burgstahler, D. Hibbard, J. Faist, Trident Systems Inc. (United States)

The detection of slowly moving/stationary targets in heavy-clutter environment is a challenging problem in a surveillance system. Recent researches [1-3] illustrate that polarization diversity can provide a measure to detect the symmetry of a target in inhomogeneous clutter, especially when discrimination by Doppler effects is not possible, and detection performance could be further enhanced if the polarization of transmitted signal is optimally selected to match the target polarimetric aspects. In this paper, we address the challenges of threat detection in inhomogeneous clutter such as in the riverine wetland environment. Second, a polarimetric space-time adaptive process (PSTAP) algorithm using dual (horizontal and vertical) polarizations is presented to calculate the singularity of polarization diversity for potential threat detection. The singularity of polarization diversity is a measure to discriminate the difference (less similarity) of targets from the neighborhood (background), which area can be decided by the size of the sliding processing window. Next, a field test using a Vector Network Analyzer collected dual-polarized scatterings of targets and accomplished a multiple frequency band (200 MHz - 18 GHz from UHF-Ku bands) threat characterization and detection on the same stationary threats. Finally, we show the testing result using the PSTAP robust to detect potential threats in inhomogeneous environments.

8058-51, Session 14

Receptor-mediated regulation in biology

D. A. Lauffenburger, Massachusetts Institute of Technology (United States)

No abstract available

8058-53, Session 15

Biomedical wellness (BMW) concerns

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Our definition of BMW extends beyond the standard wellness as it further encompasses the public health of aging world citizens and those that contribute through the understanding of wellness through fundamental biological science. For the past decade, our conferences have awarded the Biomedical Wellness (BMW) Award for contributions made in the diagnostic/treatment and imaging/engineering device areas. We further inject that BMW should be guided by the smart sensors should follow one of 4 P goals: participatory, personal, preventive, and pre-emptive, given by NIH former director in the call of translational research program from the benches to the beds. Also, the user-friendly interface is in favor of four preferences: non-invasive, non-contact, non-tethered and non-stop to measure. We will review current state of art of distributive points of care for the home alone senior in low cost & high tech arenas.

8058-54, Session 15

Solving channel assignment problems using local search methods and simulated annealing

L. Wang, Nanyang Technological Univ. (Singapore)

We deal with the channel assignment problems (CAPs) with the main objective of minimizing the overall interference level while meeting the channel demand requirements. The benchmark instances used by Smith & Palaniswami are used for comparison. We first use the traditional local search (LS) method in the convergence test (CT) to solve for the CAPs and an acceptance ratio is introduced as the controlling parameter to re-initialize the search at a predefined threshold. Three different perturbation functions namely one-exchange random (1-ER), one-exchange sequential (1-ES) and two-exchange random (2-ER) are proposed and tested in the CT. The 1-ER outperforms other perturbation functions and the minimum interference (cost) solutions obtained are superior to other heuristics. We then use Simulated Annealing (SA) to solve the CAPs. The SA performance is evaluated at different perturbation functions (1-ER & 1-ES) and various cooling schedules. Similarly, the results obtained using SA outperform other heuristics on both the average and minimum cost solutions. We then improve the local search (ILS) technique used in CT by introducing two control parameters, namely Restart (RS) and Stop (ST) thresholds, to increase the probability and consistency in searching for optimum solutions. Interestingly, this simple technique outperformed SA in some relatively simple test instances in terms of better average cost and faster convergence speed. Nevertheless the ILS is still inferior to SA in more difficult test problems. In general the ILS can still produce near optimum solutions and comparatively superior to results obtained in other heuristics as well.

8058-55, Session 15

Reverse engineering cellular decisions for hybrid reconfigurable network modeling

H. A. Blair, Syracuse Univ. (United States)

Cells as microorganisms and within multicellular organisms make robust decisions. Knowing how these complex cells make decisions is essential to explain, predict or mimic their behavior. The discovery of multi-layer multiple feedback loops in the signaling pathways of these modular hybrid systems suggests their decision making is sophisticated. Hybrid systems coordinate and integrate signals of various kinds: discrete on/off signals, continuous sensory signals, and stochastic and continuous fluctuations to regulate chemical concentrations. Such signaling networks can form reconfigurable networks of attractors and repellors giving them an extra level of organization that has resilient decision making built in. Work on generic attractor and repellor networks and on the already identified feedback networks and dynamic reconfigurable regulatory topologies in biological cells suggests that biological systems probably exploit such dynamic capabilities. We present a simple behavior of the swimming unicellular alga Chlamydomonas that involves interdependent discrete and continuous signals in feedback loops. We show how to rigorously verify a hybrid dynamical model of a biological system with respect to a declarative description of a cell's behavior. The hybrid dynamical systems we use are based on a unification of discrete structures and continuous topologies developed in prior work on convergence spaces. They involve variables of discrete and continuous types, in the sense of type theory in mathematical logic. A unification such as afforded by convergence spaces is necessary if one wants to take account of the affect of the structural relationships within each type on the dynamics of the system.

8058-56, Session 15

Approximate nearest neighbors in high-dimensional vector spaces via dictionary learning

A. Cherian, V. Morellas, N. Papanikolopoulos, Univ. of Minnesota, Twin Cities (United States)

Approximate Nearest Neighbors (ANN) in high dimensional feature spaces is a fundamental, yet challenging problem in many areas of computer science, including computer vision, data mining, and robotics. In this work, we investigate this problem using the paradigms of compressive sensing, especially the dictionary learning aspect.

High dimensional feature vectors are never seen to be sparse in the feature domain; examples include, but not limited to Scale Invariant Feature Transform (SIFT) descriptors, Histogram Of Gradients, Shape Contexts, etc.

Compressive sensing advocates that if a given vector has a dense support in a feature space, then there should exist an alternative high dimensional subspace where the features are sparse. This idea is leveraged by dictionary learning techniques through learning an overcomplete projection from the feature space so that the vectors are sparse in the new space.

The learned dictionary aids in refining the search for the nearest neighbors to a query feature vector into the most likely subspace combination indexed by its non-zero active basis elements. Since the size of the dictionary is generally very large, distinct feature vectors are most likely to have distinct non-zero basis. Utilizing this observation, we propose a novel representation of the feature vectors as tuples of non-zero dictionary indices, which then reduces the ANN search problem into hashing the tuples to an index table; thereby dramatically improving the speed of the search.

A drawback of this naive approach is that it is very sensitive to feature perturbations. This can be due to two possibilities: (i) the feature vectors are corrupted by noise, (ii) the true data vectors undergo perturbations themselves. Existing dictionary learning methods go by the first model; while in this work we investigate the second possibility and approach it from a robust optimization perspective. This boils down to the problem of learning a dictionary robust to feature perturbations, viz. paving the way for a novel Robust Dictionary Learning (RDL) framework.

8058-59, Session 15

The golden ratio in peripheral monochromatic and central chromatic vision

J. C. Jenkins, H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The golden ratio was introduced by ancient Greek artists and mathematicians, stating: $(a+b)/a=a/b=\phi=(1+\sqrt{5})/2 \approx 1.61803$ where a is the longer segment of the line a+b. What does this ratio have to do with our vision? In art it is aesthetically pleasing to place the foreground object $1/\phi$(.61803) units away from the center of the canvas. We believe that the topology of our retina is equivalent to an artist's canvas. Thus, it is natural to assume that our retina is geometrically arranged in a similar way, since we find it comfortable to view paintings as well as architecture which incorporate the golden ratio to separate important items. The solar spectrum may even contain the golden ratio. In human photoreceptors, the peak (preferable) wavelength of blue light is .475 micron, green light is .51 micron, yellow light is .58 micron, and red light is .65 micron. ((Red(wavelength)-Blue(wavelength)))/((“Golden(wavelength) - Blue(wavelength)))≈ϕ. In the visible spectrum, we find that yellow (.58 micron) happens to be the wavelength that satisfies the ratio, perhaps explaining the large use of this color by many famous artists. Recent reports have showed that cold light illumination has been causing emotional discomfort. Interestingly enough, this might be due to the limited R-G-B bandwidth ratio of this illumination. We will design a color vision test pattern to identify the boundary of peripheral vision using the golden ratio as a size metric, as well as a detailed analysis of the golden ratio's significance in the human differentiation of color.

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8059-01, Session 1

Using concepts from biology to improve problem-solving methods

E. Goodman, Michigan State Univ. (United States)

No abstract available

8059-02, Session 2

PADF RF localization experiments with multi-agent caged-MAV platforms

C. Barber, M. Gates, Louisiana Tech Univ. (United States); H. Alissa, Univ. of Dayton (United States); A. K. Mitra, Air Force Research Lab. (United States); R. R. Selmic, Louisiana Tech Univ. (United States); R. Ordonez, Univ. of Dayton (United States)

This paper provides a summary of preliminary RF direction finding results generated within an AFOSR-funded testbed facility recently developed at Louisiana Tech University. This facility, denoted as the Louisiana Tech University Cyberspace Micro-Aerial Vehicles and Sensor Networks (MAVSeN) Laboratory, has recently acquired a number of state-of-the-art MAV platforms that enable us to analyze, design, and test some of our recent results in the area of multi-platform position-adaptive direction finding (PADF) for localization of RF emitters in challenging embedded multipath environments. Discussions within the segmented sections of this paper include our basic formulation of PADF. This novel approach to multi-platform RF direction finding is based on the investigation of iterative path-loss based (i.e. path loss exponent) metrics estimates that are measured across multiple platforms in order to robotically/intelligently positionally adapt (i.e. self-adjust) the location of each distributed/cooperative platform. After this general summary and discussion on analytical PADF techniques, the body of this paper provides a summary of our recent results on PADF and includes a discussion on state-of-the-art Sensor Mote Technologies as applied towards the development of sensor-integrated multi-agent caged-MAV platforms for PADF applications. Also, an preliminary experimental discussion of recent results that incorporate sample approaches to real-time multi-platform data pruning is included as part of a discussion on potential approaches to refining a basic PADF technique in order to integrate and perform distributed self-sensitivity and self-consistency analysis as part of a PADF technique with distributed robotic/intelligent features. These techniques are extracted in analytical form from a parallel study denoted as "PADF RF Localization Criteria for Multi-Model Scattering Environments". The focus here is on developing and reporting specific approaches to self-sensitivity and self-consistency within this experimental PADF framework via the exploitation of specific multi-agent caged-MAV trajectories that are unique to this experiment set. Potential derivative concepts under consideration for follow-up investigations include the design of ejectable/detractable caging mechanisms that function jointly as RF-apertures under low-altitude operating conditions. This type of novel and straightforward low-cost structural modification concept can enable a large number of commercial MAV platforms to be fitted with low-cost add-on technologies that in-turn enable additional operating and sensing modes at low-altitudes to achieve higher sensing performance and survivability gains.

8059-03, Session 2

Discriminative feature sets for object detection in layered sensing environments

M. P. Dessauer, Louisiana Tech Univ. (United States)

Objects of interest can exhibit discriminate characteristics at varying degrees of granularity based on sensor domain attributes. When sensors of multiple domains engage a specific object, registered sensor data can create cooperative features which better differentiate objects from the background. In this paper, we will present and evaluate several sets of features that are used to detect objects from a cluttered environment. We will explore the combination of edge and texture histograms resulting in combined both independently and fused between sensors operating at different wavelengths. The created feature sets will be used to train and test a series of supervised classifiers. We will employ a novel filtering method that uses wavelet decomposition, hierarchical clustering, and local statistics to reduce false alarms and increase computation speed. After the detection stage is completed, we will use non-maximal suppression to retain only the optimal detected object segment, which will then get compared to ground truth information for evaluation. We conclude the paper with a recommendation of specific feature and detection algorithms that perform best for layered sensing applications.

8059-04, Session 2

Multisensor registration using correlation-based, mutual information-based and scale invariant feature transform (SIFT) algorithms

Y. Xu, Wright State Univ. (United States)

In this paper, three popular image registration methods, correlation-based, mutual information (MI) and the Scale Invariant Feature Transform (SIFT), are applied to register the multi-sensor images in the Columbus Surrogate Unmanned Aerial Vehicle (CSUAV) dataset. The CSUAV dataset includes electro-optical (EO) and mid-wave infrared (MWIR) data collected from two surrogate UAVs. The performances of the three methods are evaluated individually as well as for single-sensor and multi-sensor basis. Image registration is a fundamental image processing task, and registration methods can be categorized into two approaches: intensity-based and feature-based. The correlation-based method is intensity-based, the mutual information based method is intensity-based, and the Scale Invariant Feature Transform (SIFT) algorithm is feature-based. The RMSE is used as the performance metric.

8059-05, Session 2

Boresight calibration of the aerial multi-head camera system

A. Yilmaz, Y. Lee, The Ohio State Univ. (United States)

This paper compares two boresight calibration methods for the aerial multi-head camera system. The first method uses synthetic images. The synthetic images have large FOV that is suitable for photogrammetric processing. Although there are unknown boresight angles which cannot be ignorable, generated synthetic images without knowing these boresight angles still can be used for boresight calibration. The other method uses individual images acquired from each physical camera. This method does not use re-projected images that may cause errors. However, small FOV and relatively small size of images make calibration process unstable. This paper will discuss advantages and disadvantages of two methods.

8059-06, Session 2

Initial data sampling in high dimensional design optimization

H. L. Southall, T. H. O'Donnell, Air Force Research Lab. (United States)

Evolutionary design optimization techniques such as genetic algorithms (GA) or the efficient global optimization (EGO) technique require an initial set of data samples on the order of ten times the dimensionality. The samples are obtained by evaluating a cost function at selected sites within the input space of design parameters (variables). Since the cost functions for our application (antenna design) can be quite expensive in terms of computation, we concentrate on EGO which is good for very expensive black box functions. We have used standard Latin hypercube data sampling for an 11 parameter design of a wideband fragmented patch antenna and found acceptable designs with far fewer cost function evaluations than using a GA. A Latin square is a statistical sampling technique which samples a square grid such that there is only a single sample in each row and column. The Latin hypercube is the generalization to an arbitrary number of dimensions. A standard random Latin hypercube can result in sample sets which may be highly correlated and may not have good space-filling properties. There were sometimes issues in obtaining global minima solutions for the patch antenna problem since the initial data sampling contained correlated input variables. There have been techniques developed which can overcome these problems. We apply these techniques to obtain better initial sampling, i.e. less correlation and better space-filling and revisit the wideband fragmented patch antenna design problem.

8059-07, Session 2

A robust regularization algorithm for polynomial networks for machine learning

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 an improvement to the fundamental Group Method of Data Handling (GMDH) Data Modeling algorithm that overcomes the parameter sensitivity to novel cases presented to derived networks. We achieve this result by regularization of the output and using a genetic weighting that selects intermediate models that do not exhibit divergence. The result is the derivation of multi-nested polynomial networks following the Kolmogorov-Gabor polynomial that are robust to mean estimators as well as novel exemplars for input. The full details of the algorithm are presented.

8059-08, Session 2

A scaled, performance driven evaluation of the layered-sensing framework utilizing polarimetric infrared imagery

H. S. Clouse, H. Krim, North Carolina State Univ. (United States); O. Mendoza-Schrock, Air Force Research Lab. (United States)

The layered-sensing framework, in application, provides a useful, but complex integration of information sources, e.g. multiple sensing modalities and operating conditions. It is the implied trade-off between sensor fidelity and system complexity that we address here. Abstractly, each sensor/source of information in a layered-sensing application can be viewed as a node in the network of constituent sensors. Regardless of the sensing modality, location, scope, etc. each sensor collects information locally to be utilized by the system as a whole for further exploitation. Consequently, the information may be distributed throughout the network and not necessarily coalesced in a central node/location. We present, initially, an analysis of polarimetric infrared data as one of the input modalities to such a system. We then proceed with statistical and geometric analyses of an example network, thus quantifying the advantages and drawbacks of a specific application of the layered-sensing framework.

8059-09, Session 3

The knowledge instinct and the mathematical implementation of the mechanisms of the mind

L. I. Perlovsky, Air Force Research Lab. (United States)

No abstract available

8059-10, Session 4

Categorification of the layered sensing construct

J. L. Culbertson, Air Force Research Lab. (United States); M. E. Oxley, Air Force Institute of Technology (United States); S. K. Rogers, Air Force Research Lab. (United States); K. Sturtz, Universal Mathematics (United States)

The nature of modern warfare demands that improving capabilities in intelligence, surveillance and reconnaissance (ISR) be an ever increasing priority. Layered sensing is a construct developed by the Air Force Research Laboratory Sensors Directorate and is designed to encapsulate the need to provide situational awareness to decision makers in a variety of contexts by effectively and efficiently integrating information across all domains. We propose a mathematical formulation for a layered sensing architecture based on the theory of categories that will allow us to abstractly define agents and their interactions in such a way that we can treat human and machine (or systems of these) agents homogeneously. One particular advantage is that this general formulation will allow the development of multi-resolution analyses of a given situation that is independent of the particular models used to represent a given agent or system of agents. In this paper, we define the model and prove basic facts that will be fundamental in future work. Central to our approach is the integration of uncertainty and evolution over time into our model. Such a framework is necessitated by our desire to define (among other things) measures of alignment and efficacy for systems of heterogeneous agents operating in a diverse and complex environment.

8059-11, Session 4

Cross layers decision fusion model in layered sensing systems

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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 cross layers for better situation awareness. This research focuses on the development of a model for information fusion at the decision level in layered sensing systems using the cloud theory for uncertainty modeling and processing. In the research we propose the addition of a new processing level to the Joint Directors of Laboratories (JDL) processing model. The new processing level is called "Information Assessment and Control (IAC)." Through this level, the different sensing layers will evaluate information about a given situation in terms of a threat level. Also, IAC module will be able to exchange processed information to determine the overall situation's threat level among all layers. The situation threat level assessment by each layer will be formulated in a form of decision

using the Cloud backward generator. The different decisions made by the different decision-makers of a layered system will contain levels of uncertainties. These uncertain decisions will be fused together using the cloud model of uncertainty processing methodology. Using this methodology, a cognitive element will be added to the process of information assessment module leading to more accurate situation awareness. The developed system will be implemented and tested on set of sensors embedded in a layer system using the ATR-TSU test-bed. The test-bed consists of a set of cameras mounted on a building.

8059-12, Session 4

Wide-threat detection: recognition of adversarial missions and activity patterns in Empire Challenge 2009

G. M. Levchuk, C. Shabarekh, C. Furjanic, Aptima Inc. (United States)

In this paper, we present results of adversarial activity recognition using data collected in Empire Challenge (EC 09) exercise. EC09 was a demonstration of ISR interoperability, executed by US JFCOM at China Lake, CA. In a terrain vaguely resembling the Afghan mountainous desert, the “Blue” forces (BLUFOR) conducted convoy operations while “Red” forces (OPFOR) were setting up ambushes against them, using roadside and vehicle bombs, firing mortars against bases and logistics operations. To collect the data about enemy, BLUFOR used reconnaissance and patrol teams, as well as airborne intelligence-gathering platforms.

The EC09 experiment provided an opportunity to evaluate our probabilistic spatiotemporal mission recognition algorithms using the data from live air-born and ground sensors. Using ambiguous and noisy data about locations of entities and motion events on the ground, the algorithms inferred the types and locations of OPFOR activities, including reconnaissance, cache runs, IED emplacements, logistics, and planning meetings. In this paper, we present details about the types of data used for activity detection and explain how the knowledge of terrain features and enemy TTPs allows increasing detection accuracy and reducing false alarms. Our algorithms detected on average 78% of adversarial activities, while producing manageable levels of 50% false alarms. For the analysis reported in this paper, we have used manually coded motion events; we discuss approaches to generate such events in automated manner using wide-area motion imagery and consequent target tracking and track-to-event association. We also discuss our current work to reduce false alarm rates and improve detection accuracy.

8059-13, Session 4

Layered learning approach for event detection

M. Blowers, Air Force Research Lab. (United States)

Making best use of multi-point observations and sensor information to forecast future events in complex real time systems is a challenge which presents itself in many military and industrial processes. The first step in tackling these challenges is to analyze and understand the data. Depending on the algorithm used to forecast a future event, improvements to a prediction can be realized if one can first determine the nature and extent of variable correlations, and then quantify the strength of the correlations of input variables to output variables. This is no easy task since sensor readings and analyst/operator logs are sometimes inconsistent and/or unreliable, some catastrophic failures can be almost impossible to predict, and time lags and leads in a given system may vary from one day to the next. Presented in this paper is a layered learning system which makes use of a combination of bio-inspired learning methods to characterize events of interest.

8059-14, Session 4

Intelligent information dissemination to hand-held devices

J. Spina, Air Force Research Lab. (United States)

Although more information than ever before is available to support the knowledge discovery and decision making processes, the vast proliferation of types of data, devices, and protocols makes it increasingly difficult to ensure that the right information is received by the right people at the right time. It becomes even more challenging when the information has security classifications that need to be processed as well. This paper investigates methods and procedures for handling and disseminating information to users and groups of users that possess varying constraints, including security classifications. The cross-domain implications are critical in that certain users must only be allowed access to information that meets their clearance level and need-to-know.

There are several important components to an intuitive system that can provide timely information in a receiver-preferred manner. Besides the ability to format information to accommodate the user’s device and profiles, it’s very important to address multi-level security, which could provide ability to properly send classified information across different domains, thus enabling faster dissemination of time critical information. One factor that may simplify this process is the information provider’s disregard for the recipient’s device limitations. The system that provides or “proxies” the transfer of information should handle the presentation to the receiver.

This technology would enable analysts and troops in the field the ability push and pull critical information regardless of their computation circumstances.

These topics will be the main theme of this paper.

8059-15, Session 4

Wavelet-based polarimetry image analysis

A. Ngo, S. Ezekiel, Indiana Univ. of Pennsylvania (United States); O. Mendoza-Schrock, Air Force Research Lab. (United States)

Wavelet transformation has become a cutting edge and promising approach in the field of image and signal processing. A wavelet is a waveform of effectively limited duration that has an average value of zero. Wavelet analysis is done by the breaking up of the signal into shifted and scaled versions of the original signal. The key advantage of this approach is that it is capable of revealing smaller changes, trends, and breakdown points that are missed by other techniques such as Fourier analysis. The phenomenon of polarization has been studied for quite some time and is very a useful tool for target detection and tracking. Long Wave Infrared (LWIR) polarization is beneficial for detecting camouflaged objects and is a useful approach when identifying and distinguishing manmade objects from natural clutter. In addition, the Stokes Polarization Parameters, which are calculated from 0°, 45°, 90°, 135°, right circular, and left circular intensity measurements, provide spatial orientations of target features and suppress natural features. In this paper, we propose a wavelet based method to analyze Long Wave Infrared Polarimetry Imagery to discriminate targets, dismounts, and vehicles from background clutter. Our method also computes refractive index n and extinction coefficient , from Stokes polarization parameters S2 and S3. These parameters can be used for thresholding, segmentation, and to classify materials. Experimental results show the efficiency of this method and can be used in a wide range of applications such as change detection, shape extraction, target recognition, and feature-aided tracking.

8059-16, Session 5

Graph-visualization techniques for representing glycomic response in GSC11 glioblastoma cells

A. D. Meyer-Bäse, The Florida State Univ. (United States)

Newly emerging advances in both measurement as well as bio-inspired computation techniques have facilitated the development of so-called lipidomics technologies and offer an excellent opportunity to understand regulation at the molecular level in many diseases such as cancer. The analysis and the understanding of the global interactional behavior of lipidomic networks remains a challenging task and can not be accomplished solely based on intuitive reasoning. The present contribution aims at applying graph-clustering methods as powerful correlation networks which enable a simultaneous exploration and visualization of co-regulation in glioblastoma stem cells and reveal their response to STAT3 phosphorylation inhibition and serum-induced differentiation. This new paradigm is providing unique “fingerprints” by revealing how the intricate interactions at the lipidome level can be employed to induce apoptosis (cell death) and are thus opening a new window to biomedical frontiers by determining the success of novel therapies.

8059-17, Session 5

Improved computer-aided diagnosis for breast lesions in DCE-MRI based on motion artifact removal and integration of morphologic and dynamic information

A. D. Meyer-Bäse, The Florida State Univ. (United States)

Motion induced artifacts represent a major problem in detection and diagnosis of breast cancer in dynamic contrast-enhanced magnetic resonance imaging. The goal of this paper is to evaluate the performance of an improved optical flow-based motion correction algorithm based on different feature extraction techniques and subsequent classification techniques. Based on several simulation results, we determined the optimal motion compensation parameters, the optimal feature number and tested different classification techniques such as support vector machines with several kernels. Our results have shown that motion compensation can improve in some cases classification results.

8059-18, Session 6

Evolving wavelet and scaling numbers for optimized image compression: forward, inverse, or both? A comparative study

F. W. Moore, B. J. Babb, S. Aldridge, Univ. of Alaska Anchorage (United States); M. R. Peterson, Univ. of Hawai’i (United States)

The 9/7 wavelet is used for a wide variety of image compression tasks. Recent research, however, has established a methodology for using evolutionary computation to evolve wavelet and scaling numbers describing transforms that outperform the 9/7 under lossy conditions, such as those brought about by quantization or thresholding. This paper describes an investigation into which of three possible approaches to transform evolution produces the most effective transforms. The first approach uses an evolved forward transform for compression, but performs reconstruction using the 9/7 inverse transform; the second uses the 9/7 forward transform for compression, but performs reconstruction using an evolved inverse transform; the third uses simultaneously evolved forward and inverse transforms for compression and reconstruction. Three image sets are independently used for training: digital photographs, fingerprints, and satellite images. Results strongly suggest that it is impossible for evolved transforms to substantially improve upon the performance of the 9/7 without evolving the inverse transform.

8059-19, Session 6

Evolving matched filter transform pairs for satellite image processing

M. R. Peterson, T. Horner, Univ. of Hawai’i (United States); F. W. Moore, Univ. of Alaska Anchorage (United States)

Wavelets provide an attractive method for efficient image compression. For transmission across noisy or bandwidth-limited channels, a signal may be subjected to quantization in which the signal is transcribed onto a reduced alphabet in order to save bandwidth. Unfortunately, the performance of the discrete wavelet transform (DWT) degrades at increasing levels of quantization. In recent years, evolutionary algorithms (EAs) have been employed to optimize wavelet-inspired transform filters to improve compression performance in the presence of quantization. Wavelet filters consist of a pair of real-valued coefficient sets; one set represents the compression filter while the other set defines the image reconstruction filter. The reconstruction filter is defined as the biorthogonal inverse of the compression filter. Previous research focused upon two approaches to filter optimization. In one approach, the original wavelet filter is used for image compression while the reconstruction filter is evolved by an EA. In the second approach, both the compression and reconstruction filters are evolved. In both cases, the filters are not biorthogonally related to one another. We propose a novel approach to filter evolution. The EA optimizes a compression filter. Rather than using a wavelet filter or evolving a second filter for reconstruction, the reconstruction filter is computed as the biorthogonal inverse of the evolved compression filter. The resulting filter pair retains some of the mathematical properties of wavelets. This paper compares this new approach to existing filter optimization approaches to determine its suitability for the optimization of image filters appropriate for defense applications of image processing.

8059-20, Session 6

Image sets for satellite image processing systems

M. R. Peterson, T. Horner, A. Temple, Univ. of Hawai’i (United States)

The development of novel image processing algorithms requires a diverse and relevant set of training images to ensure the general applicability of such algorithms for their required tasks. Images must be appropriately chosen for the algorithm’s intended applications. Image processing algorithms often employ the discrete wavelet transform (DWT) algorithm to provide efficient compression and near-perfect reconstruction of image data. Defense applications often require the transmission of images and video across noisy or low-bandwidth channels. Unfortunately, the DWT algorithm’s performance deteriorates in the presence of noise. Evolutionary algorithms are often able to train image filters that outperform DWT filters in noisy environments. Here, we present and evaluate two image sets suitable for the training of such filters for satellite and unmanned aerial vehicle imagery applications. We demonstrate the use of the first image set as a training platform for evolutionary algorithms that optimize discrete wavelet transform (DWT)-based image transform filters for satellite image compression. We evaluate the suitability of each image as a training image during optimization. Each image is ranked according to its suitability as a training image and its difficulty as a test image. The second image set provides a test-bed for holdout validation of trained image filters. These images are used to independently verify that trained filters will provide strong performance on unseen satellite images. Collectively, these image sets are suitable for the development of image processing algorithms for satellite and reconnaissance imagery applications.

8059-21, Session 6

Evolving point-cloud features for gender discrimination

B. Keen, A. Fouts, M. M. Rizki, L. A. Tamburino, Wright State Univ. (United States); O. Mendoza-Schrock, Air Force Research Lab. (United States)

In this paper we explore the use of histogram features extracted from 3D point clouds of human subjects for gender discrimination. Experiments are conducted using point clouds 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. Features are extracted from each point cloud by embedding the cloud in series of cylindrical shapes and computing a point count for each cylinder that characterizes a region of the subject. These measurements define rotationally invariant histogram features that are processed by a classifier to label the gender of each subject. Preliminary results using cylinder sizes defined by human experts demonstrate that gender can be predicted with 98% accuracy for the type of high density point cloud found in the CAESAR database. When point cloud densities are reduced to levels that might be obtained using stand-off sensors; gender discrimination accuracy degrades. We introduce an evolutionary algorithm to optimize the number and size of the cylinders used to define histogram features. The objective of this optimization process is to identify a set of cylindrical features that reduces the error rate when predicting gender from low density point clouds. The evolutionary algorithm operates on a hybrid representation that uses a mixture of integer and real values to represent the number and geometry of the cylindrical features. A wrapper approach is used to interleave feature selection with classifier evaluation to train the evolutionary algorithm. Results of discrimination accuracy achieve using the evolved features are compared to the baseline feature set defined by human experts.

8059-22, Session 7

Behavioral analysis of malicious code through network traffic and system call monitoring

A. R. A. Gregio, D. S. Fernandes Filho, V. M. Afonso, Ctr. de Tecnologia da Informação Renato Archer (Brazil) and Univ. Estadual de Campinas (Brazil); R. D. Coelho dos Santos, Instituto Nacional de Pesquisas Espaciais (Brazil); M. Jino, P. L. de Geus, Univ. Estadual de Campinas (Brazil)

Malicious code (malware) spread through Internet - such as viruses, worms and trojans - is a major threat to information security nowadays and a profitable business for criminals. The amount of malware variants arising daily difficults antivirus vaccines generation and make manual analysis impracticable. On the other side, there are several approaches to analyze malware by monitoring its actions while it is running in a controlled environment, helping to identify malicious behaviors. These approaches rely on capturing system calls from a victim's operating system while avoiding their detection from the malware sample being monitored. Some techniques used to system call monitoring are: Virtual Machine Introspection (VMI), Application Programming Interface (API) Hooking and System Service Dispatch Table (SSDT) Hooking, which are discussed here in more details. In this paper we propose a tool to analyze malware behavior in a non-intrusive and effective way by widening analysis possiblity to malware samples that bypass current approaches and by fixing some issues from them by using a mixed environment (emulated and real), filling a gap in the field. Thus, we can avoid some anti-analysis techniques that detect Qemu emulator and must be analyzed in real environments, at the same time we keep scalability by analyzing most of the samples in emulators. We also present some case studies involving recent malware behavioral analysis to validate the tool, compare it to the main publicly available systems and point to possible future works based in our behavioral database.

8059-23, Session 7

An adaptive neural swarm approach for intrusion defense in ad hoc networks

J. D. Cannady, Nova Southeastern Univ. (United States)

Wireless sensor networks (WSN) and mobile ad hoc networks (MANET) are being increasingly deployed in critical applications due to the flexibility and extensibility of the technology. While these networks possess numerous advantages over traditional wireless systems in dynamic environments they are still vulnerable to many of the same types of host-based and distributed attacks common to those systems. Unfortunately, the limited power and bandwidth available in WSNs and MANETs, combined with the dynamic connectivity that is a defining characteristic of the technology, makes it extremely difficult to utilize traditional intrusion detection techniques. This paper describes an approach to accurately and efficiently detect potentially damaging activity in WSNs and MANETs. It enables the network as a whole to recognize attacks, anomalies, and potential vulnerabilities in a distributive manner that reflects the autonomic processes of biological systems. Each component of the network recognizes activity in its local environment and then contributes to the overall situational awareness of the entire system. The approach utilizes agent-based swarm intelligence to adaptively identify potential data sources on each node and on adjacent nodes throughout the network. The swarm agents then self-organize into modular neural networks that utilize a reinforcement learning algorithm to identify relevant behavior patterns in the data without supervision. Once the modular neural networks have established interconnectivity both locally and with neighboring nodes the analysis of events within the network can be conducted collectively in real-time. The approach has been shown to be extremely effective in identifying distributed network attacks.

8059-24, Session 7

Combined bio-inspired/evolutionary computational methods in cross-layer protocol optimization for wireless ad hoc sensor networks

W. S. Hortos, Jr., Associates in Communications Engineering Research and Technology (United States)

A wireless ad hoc sensor network is a configuration for area surveillance that affords rapid, flexible deployment in arbitrary threat environments, e.g., battlefield spaces or enterprise premises. With no infrastructure support, sensor nodes communicate with each other only when they are within wireless transmission range. The nodes in a wireless sensor network (WSN) are typically unattended and severely resource-constrained, with limited processing, memory and power capacities. They operate cooperatively to process sensor data to aggregate information to fulfill the surveillance mission.

The metrics of quality of service (QoS) for each sensor type in a WSN can be associated with metrics for multimedia that describe the quality of fused information, e.g., throughput, delay, jitter, error rates, information correlation, data integrity, etc. The dependencies of the QoS metrics on the performance of the higher layers of the Open System Interconnection (OSI) reference model of the WSN protocol, together with that of the lower three layers, are the basis for a comprehensive cross-layer approach to QoS optimization in a general WSN model of multiple sensor types.

Published studies focus on use of one bio-inspired or evolutionary computational method for the functions of a single WSN protocol layer. For example, swarm intelligence in the form of ant colony optimization (ACO), has often been considered for the routing of data/information, a network-layer function, while genetic algorithms (GAs) have been applied in the selection of transmission frequencies and power levels, a physical-layer function. Similarly, auto-immune systems (AISs) as well as trust models of quantized data reputations have been invoked for detection

of network intrusions that cause anomalies in data and information, methods affecting the application and presentation layers. Most recently, a self-organizing scheduling scheme inspired by frog-calling behavior, termed anti-phase synchronization, has been applied to realize collision-free transmissions in WSNs between neighboring nodes, a MAC-layer function. In an original departure from previous work, the cross-layer approach to WSN protocol design suggests applying more than one bio-inspired/evolutionary method to the functions of appropriate layers to enhance the QoS performance of the protocol design beyond that of one method applied to a single layer's functions. A baseline WSN protocol design, embedding GAs, anti-phase synchronization, ACO, and a trust model based on quantized data reputations at the physical, MAC, network, and application layers, respectively, is constructed. Simulation results demonstrate that the synergies among the bio-inspired/evolutionary methods of the baseline improve the overall QoS performance of designs where only one computational method is used at a single protocol layer.

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8060-01, Session 1

A high-performance computing framework for physics-based modeling and simulation of the mobility of military ground vehicles

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The on-chip power dissipation, memory speed gap, and exhaustion of the potential of instruction-level parallelism (ILP) represent three factors adversely impacting the role that sequential computing could play in scientific computing in the foreseeable future. Given that Moore's law is conjectured to hold for at least one more decade, any significant improvement in terms of accuracy and/or efficiency in physics-based simulation will necessarily have to draw on many-core heterogeneous (CPU/GPU) hardware architecture solutions. This contribution discusses a Heterogeneous Computing Framework (HCT) whose role is twofold. First, it provides a software design methodology; i.e., an application development blueprint, or template, that can be used to leverage these emerging heterogeneous architectures in physics-based modeling and simulation. Second, it provides the parallel library support and the associated Application Programming Interface (API) required to implement or instantiate this blueprint/template. The library support draws on the Message Passing Interface (MPI) and the NVIDIA's CUDA parallel programming interface to assist projects aimed at large scale physics-based simulation code development in five areas: domain decomposition, element proximity computation (focus on collision detection), inter-subdomain data exchange, parallel numerical algorithms (focus on parallel iterative methods), and distributed post-processing (focus on parallel rendering of complex scenes). The developed software components and the underlying HCT have been used to assemble a Computational Dynamics simulation capability to investigate (a) the mobility of a tracked vehicle operating on granular material, and (b) the coupling between vehicle dynamics and fluid dynamics (fluid-structure interaction) in a liquid sloshing analysis.

8060-02, Session 1

Rolling partial prefix-sums to speedup evaluation of uniform and affine recurrence equations

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As multithreaded and reconfigurable logic architectures play an increasing role in HPC, the scientific community is in need for new programming models for efficiently mapping existing applications to the new parallel platforms. In this work we show how we can effectively exploit tightly coupled fine-grained parallelism in such architectures (e.g., GPU and FPGA architectures) to speedup applications described by uniform recurrence equations. We introduce the concept of rolling partial-prefix sums to dynamically keep track of and resolve multiple dependencies without having to evaluate the intermediary values. Rolling partial-prefix sums are applicable in low-latency evaluation of dynamic programming problems expressed as uniform or affine equations. To assess our approach, we consider two common problems in computational biology, HMMER for protein motif finding and the Smith-Waterman algorithm. We present a platform independent, linear time solution to HMMER, which is traditionally solved in bilinear time, and a platform independent, sub-linear time solution to Smith-Waterman, which is normally solved in linear time.

8060-03, Session 1

Accelerating sparse linear algebra using 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 CPUs. 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. Our work is on a GPU accelerated implementation of sparse linear algebra routines. We present results from both direct and iterative sparse system solvers and their applications.

The GPU execution model featured by NVIDIA GPUs based on CUDA demands very strong parallelism, requiring between hundreds and thousands of simultaneous operations to achieve high performance. 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 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 the graph theory portion of the direct solvers while the GPU simultaneously performs the low level linear algebra routines.

8060-04, Session 1

High-level GPU computing with jacket: for MATLAB and C/C++

G. Pryor, B. Lucey, P. Yalamanchili, C. McClanahan, J. Malcolm, AccelerEyes LLC (United States)

In this paper, we describe Jacket, a data-parallel programming runtime and routine library for MATLAB currently targeted at NVIDIA GPUs and its new counterpart, libJacket for C/C++. Jacket and libJacket provide seamless integration of GPU computing into developer workflows. With Jacket, the MATLAB development platform is enhanced with a just-in-time compiler that converts MATLAB code to optimized NVIDIA GPU code (PTX assembly) as well as through black-box routines that provide an extensive set of GPU-accelerated functions, from BLAS and LAPACK to image and signal processing. In this paper, we describe the practical design decisions that allow Jacket to run general MATLAB codes from a multitude of disciplines quickly. We will also discuss the new libJacket C/C++ framework and present an in-depth look at two major routines (SGEMM and 2D convolution) which outperform MKL, cuBLAS, and IPP, respectively.

8060-05, Session 2

Roles and assessment methods for models of sensor data exploitation algorithms

A. R. Nolan, Etegent Technologies, Ltd. (United States); T. D.

Return to Contents

Ross, L. G. Clark, Air Force Research Lab. (United States)

The modern battlespace is populated with a variety of sensors and sensing modalities. The design and tasking of a given sensor is therefore increasingly dependent on the performance of other sensors in the mix. The volume of sensor data is also forcing an increased reliance on sensor data exploitation and content analysis algorithms (e.g., detecting, labeling, and tracking objects). Effective development and use of interconnected and algorithmic (i.e., limited human role) sensing processes depends on sensor performance models (e.g., for offline optimization over design and employment options and for online sensor management and data fusion). Such models exist in varying forms and fidelities. This paper develops a framework for defining model roles and describes an assessment process for quantifying fidelity and related properties of models. A key element of the framework is the explicit treatment of the operating conditions (OCs - i.e., target, environment and sensor properties that affect exploitation performance) that are available for model development, testing data, and model users. The assessment methodology is basically a comparison of model and reference distributions, but is made non-trivial by reference limitations (availability for OC distributions of interest) and differences in reference and model OC representation. A software implementation of the assessment process is also described. Future papers will report assessment results for specific models.

8060-06, Session 2

Multiframe atmospheric compensation under moving camera conditions

A. L. Paolini, D. Price, F. Ortiz, EM Photonics, Inc. (United States)

Multi-frame algorithms for the removal of atmospheric turbulence have proven effective under ideal conditions where the scene remains static; however, movement of the camera across a scene often introduces undesirable effects that degrade the quality of processed imagery to the point where it becomes unusable. This paper discusses the development of two solutions to this problem, each with different computational costs and levels of efficacy. We discuss an ideal solution to this problem that uses robust registration methods to align a window of input images to each other and processes them to obtain a single improved frame, repeating the process of realignment and processing each time a new frame arrives. While this approach produces high quality results, the associated computational cost precludes real-time implementation, even on accelerated platforms. Another solution involves measuring scene movement through lightweight registration and quantification. The magnitude and history of scene movement are then used to make a global determination of a “safe” number of frames to average such that results are not degraded. This particular method is computationally inexpensive at the cost of efficacy. We discuss the performance of both of these solutions against the original, uncompensated algorithm in terms of computational cost and quality of output imagery. Additionally, we will briefly discuss more recent developments that aim to both minimize additional computation while maximizing processing efficacy.

8060-07, Session 2

Power versus performance tradeoffs of GPU-accelerated backprojection-based synthetic aperture radar image processing

R. Portillo, S. Arunagiri, P. 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, S. J. Park, D. R. Shires, U.S. Army Research Lab. (United States)

The continuing miniaturization and parallelization of computer hardware has facilitated the development of mobile and field-deployable systems that can accommodate terascale processing within once prohibitively small size and weight constraints. Unfortunately, the added computational capability of these small systems often comes at the cost of larger demands on power, an already strained resource in these systems. This study explores power versus performance issues for a workload that can take advantage of terascale capability and is targeted to run on these systems, i.e., Synthetic Aperture Radar (SAR) image processing. Specifically, we focus on a high-end CPU/GPU hybrid implementation of backprojection-based SAR image processing and, using realistic datasets, evaluate performance tradeoffs in terms of time-to-solution, phase and image output quality, and total energy consumption for single- vs. double-precision runs. Special attention is placed on the Image Formation (IF) phase of this SAR workload, the most compute-intensive and, thus, the most energy-intensive phase, which, due to its high data parallelism, runs exclusively on the GPU. Fine-grained current and voltage probes are used to directly measure the energy consumption of individual system components, including the GPU, host processor, and main memory. Radar-centric metrics, including Impulse-Response and Peak-to-Sidelobe- Ratio, are used to evaluate phase and image output quality. Ultimately, our goal is to demonstrate that SAR power vs. performance criteria can be evaluated automatically, thus, laying the groundwork for the implementation of an autonomous decision system that can choose at runtime between single- and double-precision executions to target specified power consumption and output quality constraints.

8060-08, Session 2

A hardware-in-the-loop simulation program for ground-based radar

E. P. Lam, Thales-Raytheon Systems Co. LLC (United States)

A radar system created using an embedded computer system need testing. The way to test an embedded computer system is different from the debugging approaches used in desktop computers. One way to test a radar system is to feed it artificial inputs and analyze the outputs of the radar. More often, not all of the building blocks of the radar system is available to test. This will require the engineer to test parts of the radar system using a “black box” approach.

One common way to test software code on a desktop simulation is to use breakpoints so that is pauses after each cycle through its calculations. The outputs are compared against the values that are expected. This requires the engineer to use valid test scenarios. This knowledge of timing delays and the effects on the real-time system is necessary for proper evaluation of the radar. But this requires the engineer to question, given the past inputs and present inputs, what are the inputs that are used valid test scenarios? Another issue the engineer needs to address are how timing delays in the software will affect the system operation in the real system. These effects may not be easily observed in a real-time system.

One way to perform simulation for the embedded system is to make the embedded system that is operating in the real-world on an actual computer board. A hardware-in-the-loop simulator (HILS) allows the embedded system to think it is operation with real-world inputs and outputs. From the embedded system’s point of view, it is operating in real-time. In this paper we will introduce a hardware in the loop simulation based on our PC Simulation (PCS) testbed. In the past, PCS was used for ground-based radars. This embedded simulation, called Embedded PCS, allows a rapid simulated evaluation of ground-based radar performance in a laboratory environment.

8060-09, Session 2

An agile acquisition decision-support workbench for evaluating ISR effectiveness

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The U.S. Air Force is consistently evolving to support current and future operations through the planning and execution of intelligence, surveillance and reconnaissance (ISR) missions. However, it is a challenge to maintain a precise awareness of current and emerging ISR capabilities to properly prepare for future conflicts. We present a decision-making tool for acquisition managers to empirically compare ISR capabilities and approaches to employing them, thereby enabling the DoD to acquire ISR platforms and sensors that provide the greatest return on investment. We have developed an analysis environment to perform modeling and simulation-based experiments to objectively compare alternatives. First, the analyst specifies an operational scenario providing terrain and threat information; a set of nominated collections; sensor and platform capabilities; and processing, exploitation, and dissemination capacities. Next, the analyst selects and configures ISR collection strategies to generate collection plans. The analyst then defines customizable measures of effectiveness or performance to compute during the experiment. Finally, the analyst empirically compares the effectiveness of each solution and generates concise reports to document their conclusions, providing traceable evidence for acquisition decisions. Our capability demonstrates the utility of using a workbench environment for analysts to design and run experiments. Crafting impartial metrics enables the acquisition manager to focus on evaluating solutions based on specific military needs. Finally, the metric and collection plan visualizations provide an intuitive understanding of the suitability of particular solutions. This facilitates a more agile acquisition strategy that handles rapidly changing technology in support of current military needs.

8060-10, Session 3

Electrically tuned slow light-based coupled photonic crystal waveguides using a laterally doped p-i-n junction

A. S. Sharkawy, Lumilant, Inc. (United States); M. J. Zablocki, D. Grund, D. W. Prather, Univ. of Delaware (United States)

Laterally doped p-i-n Junction is used to tune a slow light based Coupled Photonic Crystal waveguide system, which can be used for switching, routing, filtering or encoding an optical signal. p-i-n junction is numerically optimized to account for Photonic crystal structure and optimal doping concentrations for p- and n-regions are identified for lower power operation. Preliminary experimental results are shown to match numerical simulations.

8060-11, Session 3

Modeling of hybrid organic/inorganic dual RF-photonic slot waveguide modulator

S. Shi, Univ. of Delaware (United States); A. S. Sharkawy, Lumilant, Inc. (United States); M. J. Zablocki, Lumilant. Inc. (United States); D. W. Prather, Univ. of Delaware (United States)

Low driving voltage and high-speed electro-optic (EO) modulators are of great interest due to their wide variety of applications including broadband communication, RF-photonic links, millimeter wave imaging and phased-array radars. In this paper we propose symmetric design, analysis, and optimization of a novel, high speed and ultra-low driving voltage traveling wave EO modulator based on a dual RF-photonic slot waveguide. The dual slot waveguide can be constructed in horizontal and vertical fashions. The dual horizontal slot waveguide consists of a lower index organic EO polymer sandwiched vertically by two silicon membranes. The slot waveguide is then enclosed in a microstrip line with ferroelectric materials, i.e., LiNBO3 or TiO2, as its cladding layers. These ferroelectric materials have low optical refractive indices and very high RF dielectric constants compared to silicon. As a consequence, strong optical and RF modes can be simultaneously established in the nano-slot where the nonlinear EO polymer resides, thereby leading to a large mode overlap. In addition, the high-dielectric-constant material potentially allows for an increased electrode separation between signal and ground without significantly scarifying the electric field confinement in the slot. As a result, the RF mode will experience reduced conduction loss. This becomes of particular importance for operation of the modulator at high frequencies. In addition, the device is carefully optimized to minimize an index mismatch between RF and optical guiding modes as low as 0.007 at high frequencies, i.e., 100 GHz. Preliminary simulation results demonstrate the DC electro-optic response and half-wavelength voltage-production V -L of 0.1~0.2 V cm can be achieved for this design, which is about two orders magnitude lower than that of conventional LNB EO modulators. The electro-optic response demonstrates the proposed device is capable of ultra-high speed operation that covers entire RF spectrum.

8060-12, Session 3

Reconfigurable chip-scale optical router

A. S. Sharkawy, Lumilant, Inc. (United States); M. J. Zablocki, D. W. Prather, Univ. of Delaware (United States)

The function of an optical router is to switch optical channels from input to output ports and input to output wavelength. The functions in an optical routing node include providing light path, rerouting, restoring failed light path, monitoring performances, access to test signals, wavelength conversion and multiplexing and grooming.

To accomplish all these functions, the optical router needs three building blocks:

(1) Fiber switching, to route all of the wavelengths on an incoming fiber to a different outgoing fiber (optical space switches

(2) Wavelength switching, to switch specific wavelengths from an incoming fiber to multiple outgoing fibers (multiplexing/demultiplexing) ---- the focus of the current talk

(3) Wavelength conversion, to take incoming wavelengths and convert them to another optical frequency on the outgoing port.

Possibilities for building an optical interconnect network for optical routers out of photonic crystal structures are significant.

8060-13, Session 3

Advances in computational fluid dynamics solvers for the GPU

J. R. Humphrey, Jr., D. Hertenstein, 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 (HPC) is the graphics processing unit (GPU); driven by market leader NVIDIA, the GPU has become a highly respected platform for computing. There are many well-known codes in the CFD space that can benefit from this technology, such as FUN3D, AVUS, and TetrUSS, owing to their parallel structuring for execution in a CPU/supercomputer based environment. Such codes are widely used in the commercial, government, and defense sectors. In this session, we will describe our results in parallelizing one or more of these well-known codes for faster execution on the hybrid manycore GPU platform. The result is a many fold improvement in performance, granting better resolution results in less time without sacrificing accuracy.

8060-22, Poster Session

Naval Electronic Warfare Simulation for effectiveness assessment and softkill programmability facility

F. Lancon, SAGEM SA (France)

The ASM threat to be faced by ships will become more diverse and difficult. Intelligence, rules of engagement constraints, fast reaction-time for effective softkill solution require specific tools to design EW systems and to integrate it onboard ship.

So SAGEM company is provided decoy launcher system and its associated Naval Electronic Warfare Simulation tool (NEWS) to permit softkill effectiveness analysis for anti-ship missile defense.

NEWS tool generates virtual environment for missile-ship engagement and counter-measure simulator over a wide spectrum: RF, IR, EO. It integrates EW Command & Control process which is implemented in decoy launcher system and performs Monte-Carlo batch processing to evaluate softkill effectiveness in different engagement situations.

NEWS is designed to allow immediate EWC^2 process integration from simulation to real decoy launcher system. By design, it allows the final operator to be able to program, test and integrate its own EWC^2 module and EW library onboard, so intelligence of each user is protected and evolution of threat can be taken into account through EW library update.

The objectives of NEWS tool are also to define a methodology for trial definition and trial data reduction. Growth potential would permit to design new concept for EWC^2 programmability and real time effectiveness estimation in EW system. This tool can also be used for operator training purpose.

This paper will present the architecture design, the softkill programmability facility concept and the flexibility for onboard integration on ship. The concept of this operationaly focused simulation, which is to use only one tool for design, development, trial validation and operational use, will be demonstrated.

8060-23, Poster Session

Implementation and research of the linkage IDS based on Windows XP

P. Qiao, Harbin Univ. of Science and Technology (China)

The linkage of intrusion detection and firewall is the focus of the research in the Internet security, this paper proposes a novelty method of a distribution internet security defense system which based on windows IPSec and IDS. This method gives fully play to open source and plug--ins of SNORT and combines two of them successfully by adding keywords, new rules and making IP security policy, in addition, the paper details on the system structure, work processes, and the specific implementation of the integrated strategies, and also describes an attack experiment. Besides, a encryption algorithm which named twofish is applied to encrypt the sending data, so, it can provide the effective protection for the computer and the internet.

8060-24, Poster Session

An efficient geometric computation for ladar simulation

S. Hwang, S. Kim, I. Lee, The Univ. of Seoul (Korea, Republic of)

LADAR (Laser Detection and Ranging) is widely used for reconnaissance or target detection, being mounted on various moving vehicles in the defense field. During the design and development process of a LADAR system, they often perform the simulation of the system to assess its performance and provide test data for applications. The generation of simulated LADAR data with a high degree of reality and accuracy requires to derive the precise geometric model of the sensors and to calculate the locations where the rays (laser pulses) reflected using the geometric model. Because ten thousands of laser beams are transmitted to the targets every second during the real operation, a LADAR simulator should perform the tremendously overloaded geometric computations to determine the intersections between the rays and the targets. In this study, we attempted to develop an efficient method for such geometric computation for LADAR simulation. In the computation process, we first search for the candidate facets highly possible to intersect with a ray, determine the actual intersecting facet, and compute the intersection. To reduce the computation time, we successfully employed an incremental algorithm and parallel processing based on CUDA using a GPU. We expect that our proposed methods will contribute in enhancing LADAR simulator software for its running almost in real-time.

8060-25, Poster Session

Network M&S techniques based on the interworking of real systems for the interoperability T&E

S. Shim, Agency for Defense Development (Korea, Republic of)

To acquire the superiority of information for the Network Centri Warfare, interoperability is the essential factor of weapon systems. To analyze timeliness and correctness of the information exchange, we have developing the NetSPIN that is the tool to analyze the performance of the information exchange based on the communication environment using the network M&S technique. In this paper, the network M&S techniques based on the interworking between real systems for the interoperability test and evaluation are suggested. In detail, to evaluate the information exchange capability between the control center and the unit, we have developed models of the radio network which is the transmission route of data between the operation control computer of the control armored vehicle and the Korea army C4I system. And then, by interworking both real systems and the simulated radio network, the interoperability T&E is conducted on the simulated environment of real communication networks. The end-to-end transmission delay and the transmission success rate are computed to evaluate the ability of information exchange between the control center and the unit. Using these results, communication effectiveness is able to be analyzed according to the geographical interference and the traffic that have an effect on performance of information exchange.

8060-14, Session 4

Automation of air defence commander using Bayesian decision trees

A. H. Ali, G. Markarian, Lancaster Univ. (United Kingdom); A. Tarter, Ultra Electronics (United Kingdom); R. Koelle, European Organisation for the Safety of Air Navigation (Belgium)

Defending a key asset against an air threat is a task requires making critical decisions in a short time window and comprehends key-events in an environment characterized by having wide degrees of uncertainties. The more cues required to make informed decisions, the more time an air defence commander would need to respond, which in turn, might reduce the significance of his/her decision. The authors propose Bayesian decision trees to automate the process of combining and assigning degrees of uncertainty to events from an environment and computing the maximum expected utility of each possible decision. The network's principle of operation was validated by comparing the network responses with that of an expert in a computer generated environment.

8060-15, Session 4

Improving representation of situational awareness in constructive combat simulation

K. D. Lee, M. Colony, Decisive Analytics Corp. (United States)

Modeling and simulation has been established as a cost-effective means of supporting the development of requirements, exploring doctrinal alternatives, assessing system performance, performing design trade-off analysis, and providing an environment for training. The Army's constructive simulation for the evaluation of equipment effectiveness in small combat unit operations is currently limited to representation of situation awareness without inclusion of the many uncertainties associated with real world combat environments. The goal of this research is to provide an ability to model situation awareness and decision process uncertainties in order to improve evaluation of the impact of battlefield equipment on ground soldier and small combat unit decision processes. Our Army Probabilistic Inference and Decision Engine (Army-PRIDE) system provides this required uncertainty modeling through the application of two critical techniques that allow Bayesian network technology to be applied to real-time applications. First, an Object-Oriented Bayesian Network (OOBN) methodology utilizes object-oriented principles to enable data-driven, automated model construction, which is crucial for accurate modeling of complex, dynamically changing environments. Second, a structured inference technique called Object-Oriented Inference (OOI) addresses the biggest obstacle for Bayesian network applications - computational scalability. In this research, we implement decision process and situation awareness models for a reference scenario using Army-PRIDE and demonstrate its ability to model a variety of uncertain elements, including: confidence of source, information completeness, information loss, pedigree, and time constraints. We also demonstrate that Army-PRIDE improves the realism of the current constructive simulation's decision processes through Monte Carlo simulation

8060-16, Session 4

Simulating cyber warfare and cyber defenses: information value considerations

M. R. Stytz, S. B. Banks, Calculated Insight (United States)

Simulating cyber warfare is critical to the preparation of decision-makers for the challenges posed by cyber attacks. Simulation is the only means we have to prepare decision-makers for the inevitable cyber attacks upon the information they will need for decision-making and to develop cyber warfare strategies and tactics. Currently, there is no theory regarding the strategies that should be used to achieve objectives in offensive or defensive cyber warfare, and cyber warfare occurs too rarely to use real-world experience to develop effective strategies. We have no choice but to turn to simulation to develop cyber strategies and to develop expertise among decision-makers for dealing with the informational and decision-making challenges posed by cyber warfare.

Decision-making, information protection, and cyber warfare simulation are inter-related challenges. Decision-making requires accurate information in order to make decisions that are effective and timely. Information protection is therefore crucial to decision-making. Because of the massive volume of information that is available to the decision-maker, the decision-maker must know how to prioritize available information so that the most important information is given the most consideration and the remaining information is given due consideration. Because information must be prioritized to be used effectively, the priorities determine how to allocate information protection (or cyber defense) resources because the information that is the most important to an effective decision must be afforded the most protection. Information priorities, and therefore cyber defense resource allocation, change as circumstances and the decision context change; or at least they should. Our approach to preparing decision-makers for cyber events uses a set of protection rings to model the relative priorities of information; the number of rings and the information content of each ring are determined by the decision-making context at any moment. In our approach, not all of the information of equal importance to a decision context is altered or destroyed, only some of the information in the affected ring is changed. The unpredictability of information alteration increases realism.

In the paper we discuss cyber warfare simulation, our ring approach for modeling context-dependent information value, and our means for considering information value when assigning cyber resources to information protection tasks. The first section of the paper introduces the cyber warfare simulation challenge and the reasons for its importance. The second section contains decision-making background information. The third section contains a discussion of the information ring technique and its use for simulating cyber attacks. The fourth section contains a summary and suggestions for research.

8060-17, Session 4

Advancing bot army simulation techniques for simulation environments

S. B. Banks, M. R. Stytz, Calculated Insight (United States)

Simulation environments serve many purposes, but they are only as good as their content. One of the most challenging and pressing needs for improved simulation capability is the portrayal of bot armies (botnets) and their effects upon networks, computer systems, users, and decision-making. Bot armies are a type of malware that is more powerful and dangerous than any other type of malware. A bot army's power comes from its mix of unique capabilities, which include the following: the ability to be controlled and directed throughout all phases of its activity, the ability to be retargeted at any time, the use of increasingly sophisticated and secure command and control structures, and the ability of a bot army's owner to securely update the bot software at any time. Not only is a bot army powerful and agile in its tactics and technical capabilities, a bot army can be extremely large; being composed of tens of thousands, if not millions, of infected computers that surreptitiously communicate with each other and their command and control centers. Bot army capabilities allow it to execute technically sophisticated, difficult to trace, massive, coordinated attacks. Clearly, bot armies pose a significant threat to users and data as well as computing and network systems. To improve our understanding of bot army operation we believe that it is necessary to develop computer security simulation models that can portray bot army activities and bot army evolution throughout its lifecycle, with the goal of including these simulations and capabilities into distributed simulation environments.

The development of bot army simulation capabilities requires advances in three main areas: improving our understanding of bot army technologies, developing bot army simulation standards, and developing technologies to simulate bot army operations. Bot army research and simulation standards development will yield improved bot army simulations as well as more realistic and useful simulation environments. The importance of the need for standardizing and improving bot army simulation stems not only from their potential use in military operations but also from the affect bot armies can have upon support functions, such as logistics and medical support.

In the paper, we discuss the need for and uses of bot army simulation environments along with the benefits of their incorporation into distributed simulations. Section One contains an introduction to bot army technologies, the motivation for our research, and the challenges posed by a lack of bot army simulation standards. Section Two presents background material and a discussion of related topics as well as our previous research. Section Three contains a discussion of the challenges faced and the solutions we developed. We also discuss the need for standards in this area of simulation as well as suggest the formats and characteristics for the bot army simulation standards that are needed. Section Four contains the conclusion and suggestions for further work.

Return to Contents

8060-18, Session 4

The National Operational Environment Model (NOEM)

J. J. Salerno, Jr., B. C. Romano, W. Geiler, Air Force Research Lab. (United States)

The National Operational Environment Model (NOEM) is a strategic analysis/assessment tool that provides insight into the complex state space (as a system) that is today's modern operational environment. The NOEM supports baseline forecasts by generating plausible futures based on the current state. It supports what-if analysis by forecasting ramifications of potential "Blue" actions on the environment. The NOEM also supports sensitivity analysis by identifying possible pressure (leverage) points in support of the Commander that resolves forecasted instabilities, and by ranking sensitivities in a list for each leverage point and response. The NOEM can be used to assist Decision Makers, Analysts and Researchers with understanding the inter-workings of a region or nation state, the consequences of implementing specific policies, and the ability to plug in new operational environment theories/models as they mature.

The NOEM is built upon an open-source license-free set of capabilities, and aims to provide support for pluggable modules that make up a given model. The NOEM currently has an extensive number of modules (e.g. economic, security & social well-being pieces such as critical infrastructure) completed along with a number of tools to exercise them. The focus this year is on modeling the social and behavioral aspects of a populace within their environment, primarily the formation of various interest groups, their beliefs, their requirements, their grievances, their affinities, and the likelihood of a wide range of their actions, depending on their perceived level of security and happiness. As such, several research efforts are currently underway to model human behavior from a group perspective, in pursuit of eventual integration and balance of populace needs/demands within their respective operational environment and the capacity to meet those demands. In this paper we will provide an overview of the NOEM, the need for and a description of its main components. We will also provide a detail discussion of the model and sample use cases.

8060-19, Session 5

Applying risk-based M&S VV&A techniques to test and laboratory facilities

D. Hall, Survice Engineering Co. (United States); J. N. Elele, J. S. Smith, Naval Air Systems Command (United States)

Because there can be serious negative consequences from acting on erroneous M&S and analysis conclusions, the DOD has developed and is exercising a risk-based process for verifying, validating and accrediting M&S used in system acquisition. Basing the M&S VV&A process on risk allows the practitioner to focus activities on the areas of greatest potential impact to the program, and to those areas that reflect the most uncertainty in M&S outputs.

Test and laboratory facilities can potentially have even greater potential negative consequences to a program than M&S if there are errors present in the test and analysis results; test results are usually considered closer to the "truth" than M&S results, and consequently errors in those test results are more likely to result in inappropriate decisions being made based on those results.

We are applying the M&S VV&A process to test and laboratory facilities being used to support the testing of a new identification-friend-or-foe (IFF) system at the Naval Air Systems Command. The use of erroneous outputs from the test facility and analysis process (should they exist) could influence design and implementation decisions.

This paper will discuss how the risk-based M&S VV&A process is being applied to the test and laboratory facility, issues associated with this different application of the process, and thoughts on the broader applicability of risk-based VV&A beyond the current application.

8060-20, Session 5

Lessons learned in the process of conducting the verification and validation of live virtual and constructive distributed environment (LVC-DE)

J. N. Elele, Naval Air Systems Command (United States); D. Turner, SURVICE Engineering Co. (United States)

To bring reality into models and simulations (M&S), DOD combines mathematical M&S with real equipments operated by humans in actual field environments. When such live, virtual, and constructive distributed environment (LVC-DE) is assembled, there exist ample opportunities for success or failure depending on a lot of issues. Each M&S tool, along with the means used to connect it to the others must be examined independently. The combined M&S, the interfaces and the data they exchange must be tested to confirm that the entire system is interoperable, and is achieving its intended goals. Verification and Validation (V&V) is responsible for systematically investigating, creating, and documenting the artifacts needed to assess the credibility of such LVC-DE. The ultimate goal for V&V is to evaluate the capability, the accuracy and the usability of such LVC-DE.

The Battlespace Modeling and Simulation V&V Branch has extensive experience performing V&V of LVC-DEs. In a recent project, the task consisted of conducting the V&V of the LVC-DE, the supporting infrastructure and the legacy M&S tools. From a V&V perspective, many things were done correctly, however, several adjustments was necessary to improve the credibility of the LVC-DE. This paper will discuss lessons learned during the implementation, and provide recommendations for future LVC-DE applications.

8060-21, Session 5

Utility of information

D. J. Thornley, Imperial College London (United Kingdom)

The NATO code of best practice for assessment of command and control recommends characterizing subsystems by their performance, and identifying their effectiveness in context as a contribution to overall performance. The Mission Abstraction Requirements and Structure (MARS) project in the Network and Information Sciences International Technology Alliance (ITA) is developing theory and computation for analyzing effectiveness in this sense using stochastic modelling, generalizing subsystems to include information elements. Making the best use of available information and bandwidth in choosing between elements to fill a given requirement, or combinations of elements to exhaust a budget to best overall effect, necessitates a normalized, meaningful measure of the contribution of that information. The Network Utility Maximization (NUM) paradigm uses a concept of utility to support the proposal of optimizing network management against an objective function. However, characterizing the utility of information is an open problem. To implement measures that can be used in managing effectiveness in practice we need computation that is tractable on the relevant timescales, requiring only those inputs that can be made available to the management process. The ITA MARS project has identified computable utility in reduced time and energy consumption. For a given system in a given scenario, distributions of consumption can be predicted and related to pragmatic or doctrinal budgets. Characterizing the resulting bounds on uncertainty and the specifics of the case will be key to creating a transitionable technology.

Conference 8061: Wireless Sensing, Localization, and Processing VI

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8061-01, Session 1

Wireless sensor network for sniper detection: experiment and simulation

A. L. Schneider, M. Laurenzis, S. Hengy, Institut Franco-Allemand de Recherches de Saint-Louis (France)

We present a wireless sensor network which is used in an acoustic-optical system for sniper detection. The network consists of mobile nodes, carried by soldiers or mounted on vehicles as well as fixed nodes which are used to forward data to a base station. The mobile nodes are equipped with a microphone array, a GPS receiver and an electronic compass. In case of a sniper attack, each mobile node is capable of estimating the distance and direction of the threat. In addition, preprocessed audio-data from each mobile node will be sent via the wireless network to a base station, where the data will be processed to further enhance the accuracy of the threat localization.

In order to properly design the wireless network, we carried out simulations using the freely available network simulator ns-3. This simulator allows to include real hardware into a simulation. It is therefore possible to use real mobile nodes to generate real network traffic while the fixed nodes can be simulated. The wireless network can thus be easily investigated by modifying parameters like node location, number of nodes, bandwidth etc. without expensive field experiments and without realizing real hardware in advance. In addition, several experiments have been carried out with real nodes in a rural area. We present a comparison between these experiments and the simulations made with ns-3.

8061-02, Session 1

Ant-based power efficient, adaptive, reliable, and load balanced (A-PEARL) routing for smart metering networks

R. Muraleedharan-Sreekumaridevi, Syracuse Univ. (United States)

The future of metering networks requires adaptation of different sensor technology while improving reliable communication to reduce energy exploitation. In this paper, a routing protocol with capabilities to adapt and load balance communication reliably over varied IEEE standards is proposed. Due to sensor's resource constraints, such as memory, energy, processing power an algorithm that balances resources without compromising performance is preferred. The proposed A-PEARL protocol is tested under harsh simulated scenarios such as sensor failure and fading conditions. The inherent features of A-PEARL protocol such as data aggregation, fusion and channel hopping enables minimal resource consumption and secure communication.

The application based A-PEARL protocol is best suited for flat, distributed and de-centralized networks. A routing path with feasible solution with balanced load, reliable communication, energy efficient and less error prone in metering application poses multi-objective optimization problem. The ant based algorithm is well-known for solving Non-deterministic polynomial time (NP) problem. Thus, A-PEARL protocol requires minimal human intervention in finding solution unlike other algorithms. The application considered in this paper consists of sensor technology whose standards follow IEEE 802.15.4, IEEE 802.11 and IEEE 802.15.1, adding a dimension of interoperability constraint in routing. Our previous work clearly justifies the importance of swarm based algorithm and its key features for sensor based application. The proposed A-PEARL is tailored for smart metering network to accomplish routing information while the data can also be used for future human behavior model analyzes.

8061-03, Session 1

Optimization of the relay position and resource allocation in cooperative broadcast wireless networks

Y. Jin, Y. D. Zhang, Villanova Univ. (United States)

Cooperative communication provides significant advantages in wireless networking for a number of advantages. In particular, the improved spectral and energy efficiency as well as the enhanced communication reliability make it very attractive for a large class of wireless network systems where the power resources are limited. In this paper, we consider the use of cooperative communication techniques for broadcast wireless networks, where the destination users are distributed within a service area. Broadcast wireless networks find their importance in various military operations as well as emergency responses. With the exploitation of cooperative communications in such a network, the signals transmitted from a source node will be delivery to the destination users through direct paths as well as relayed paths. For the latter, the transmitted signals are received and processed at the relays and retransmitted to the destination users. The objective of our studies is, given the available power resources, proper determination of the relay positions and the distribution of power resources such that certain optimization criterion, such as the average outage probability or sum mean square error (MSE) evaluated at the user nodes, is minimized. The relay nodes will assume orthogonal space-time block codes and no channel state information (CSI) is assumed at the relay nodes. While the optimization is based on the assumption that the user nodes are densely distributed, validation in sparsely distributed network will also be examined.

8061-04, Session 1

Adaptive beamforming and rate control in real-time wireless sensor networks for QoS optimization

W. S. Hortos, Jr., Associates in Communications Engineering Research and Technology (United States)

The metrics of quality of service (QoS) for each sensor type in a wireless sensor network (WSN) of resource-constrained nodes can be associated with 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 are typically established by the highest, or application, layer of the protocol stack to ensure that performance requirements for each type of sensor data are satisfied. Application-layer metrics, in turn, depend on the support of the lower protocol layers: session, transport, network, media access control (MAC), and physical. The cross-layer interactions in the WSN protocol are represented by a set of concatenated parameters and enabling resource levels. The "best" cross-layer designs to achieve optimal QoS are established by applying the general theory of martingale representations to the parameterized multivariate point processes (MVPPs) for discrete random events occurring in the WSN. Adaptive control of network behavior through the cross-layer design is realized through the parametric factorization of the stochastic conditional rates of the MVPPs. The cross-layer protocol parameters that optimize QoS are determined in terms of solutions to stochastic dynamic programming conditions derived from models of transient flows for heterogeneous sensor data and fused information over a finite time horizon.

To improve the QoS metrics of packet-loss ratio and the fairness among wireless nodes, it is proposed that wireless sensors use transmission beamforming with randomly chosen predefined directions

Return to Contents

while transmitting to access points. Here, fairness among sensors is considered in the form of harmonic fairness, defined as a harmonic mean of the transmission success ratios of all active sensors. The sensor node itself selects one weight vector randomly for sending each packet. In other words, since the access point location is not known by the sensor node, the nodes just select a random direction in which to send packets. Beamforming makes it possible to use wireless sensors without a receiver and a feedback channel. The beamforming enables multiple access in the uplink case between wireless transmitters and possibly wired sink nodes.

Transmission power control, adaptive beamforming, and transmission rate control are parametrized in the cross-layer model. The techniques are considered separately and jointly to evaluate the impact on QoS through radio-channel sharing. Transmission power control balances the signal-to-interference ratios on wireless links, adaptive beamforming performs spatial filtering of transmit signals, and transmission rate controls adapt information flows to real-time traffic and channel conditions. Simulation results demonstrate the proposed cross-layer design, that adapts antenna beamforming and rate allocations, improves upon the overall QoS performance of a baseline cross-layer protocol design without such adaptation. The adaptive cross-layer approach results in rate allocations that are shown to be fairer between sensor nodes than allocations obtained via maximizing throughput for certain high-value inputs.

8061-05, Session 1

Sensor deployment optimization based on optimal recovery interpolation

S. D. Cabrera, V. Moram, J. G. Rosiles, The Univ. of Texas at El Paso (United States)

In Wireless Sensor Network (WSN) data collection arrangements, samples of fields of interest are obtained on irregular sampling grids in space and time. The problem can be addressed using spline interpolation schemes or wavelet/multi-resolution signal representations on irregular grids. In this paper, we instead apply the deterministic framework of Optimal Recovery (OR) that can use a priori bandwidth or spectral shape information in the interpolation. In addition, analysis of worst case errors and the signals which cause these errors can be used to assess the quality of a configuration of sensors and to optimize the placement of additional sensors.

The formulation that makes the approach optimal is a min-max error criterion that uses information about the location of the samples as well as the knowledge of the signal's energy bound and it's bandwidth. The error to be minimized is the maximum possible over the set of feasible signals. Thus, the error depends highly on the location of the available samples which in turn determines the signal(s) that would produce the worst case error at one fixed interpolated sample location (linear functional estimation) or on multiple samples (linear transformation estimation). In this paper, the computation of these error bounds is done numerically by simulation of the set of feasible signals. Except for the case of linear functional estimation, mathematically derived results are not available, to our knowledge.

Examples are presented using 1-D test signals and comparisons are made with the cubic spline approach. More detailed examples are included using a 2-D spatio-temporal test signal with non-separable spectral support. Finding the locations of the worst case errors provides a strategy to optimally add new sensors. The optimal addition of sensors is illustrated and compared with the addition of new, randomly located sensors to show the improvement that is possible using the OR framework.

8061-06, Session 2

Performance evaluation of CCI on the reverse CDMA channel

S. Alsharif, M. S. Alam, Univ. of South Alabama (United States)

This paper focuses on the performance of cochannel interference (CCI) which is the primary factor to limit the capacity of wireless communication systems. Several cellular network architectures have been proposed in the literature to reduce the cochannel interference, but none of them appears to effectively tackle this problem. Consequently, we propose a new cellular architecture that will effectively overcome the effect of cochannel interference on the reverse CDMA channel. The objective of this paper is to analyze the performance of cochannel interference on the reverse channels of the proposed microzone based CDMA cellular systems operating with perfect power control in an effort to reduce the cochannel interference. Test results show that the proposed technique can effectively minimize cochannel interference and the proposed architecture can be used for practical applications.

8061-07, Session 2

Equalisation for continuous phase modulation using basis functions

C. Brown, P. Vigneron, Communications Research Ctr. Canada (Canada)

This paper presents novel receiver processing for wideband continuous phase modulation (CPM). It is shown, that a relatively simple basis function expansion can be used to reduce the receiver complexity for channel estimation and equalisation of CPM signals in tactical networks. Simulation results show that, in general, only two orthogonal basis functions are required in the receiver irrespective of the parameters for the transmitted CPM waveform. In addition, error rate performance curves demonstrate a close approximation when using basis functions compared to more traditional channel equalisation schemes.

8061-08, Session 2

Iterative detection of continuous phase modulation on multipath channels

J. W. Nieto, Harris Corp. (United States)

This paper will investigate the performance of iterative detection demodulators for continuous phase modulation waveforms on multipath channels.

8061-09, Session 2

Application and analysis of rake receiver to hybrid CPM modulation

J. A. Norris, Harris Corp. (United States)

Constant Envelope, Spread Spectrum Modulation is highly desirable for low-power, battery-operated systems. It has been demonstrated that Hybrid CPM is a constant envelope modulation with similar frequency diversity properties to the standard spread-spectrum m-PSK DSSS and spread-MSK modulation schemes while retaining a superior emissions profile. This paper continues the analysis of the novel constant envelope spread spectrum modulation technique with an analysis of the commonly utilized rake receiver signal processing. Initially, a simple channel model is developed to illustrate and compare the convergence of the channel estimate over a fixed, non-time-varying channel. A more complex, wireless channel model is then developed and a new corresponding method for channel estimation created. A Monte-Carlo simulated bit error rate performance of Hybrid CPM is then generated to evaluate the overall performance of the Hybrid CPM modulation scheme.

8061-10, Session 3

Location-dependent RF geotags for positioning and security

D. Qiu, Sigtem Technology, Inc. (United States); R. S. Lynch, Jr., Naval Undersea Warfare Ctr. (United States); C. Yang, Sigtem Technology, Inc. (United States)

Geo-security service, which refers to the authorization of persons or facilities based on their distinctive location information, is an application of the fields of position navigation and time (PNT). Location features from radio navigation signals are mapping into a precise verification tag or geotag to block or allow certain action or access [1]. A device that integrates a location sensor and geotag generation algorithm is tamper-resistant, that is, one cannot spoof the device to bypass the location validation.

The performance and the security of a location-based security system is determined by the quantity and quality of location features. By quantity, we mean the number of different features that are location-dependent and the number of stations that are usable. By quality, we mean that amount of unique location information and its consistency provided by each feature that can be used to generate a robust geotag. Consistency of the features is a fundamental requirement for any security application. It is desirable to have the features be relatively insensitive to temporal changes, which weakens the uniqueness of the information. As a result, repeatable accuracy is a desirable quality. It allows a user to provide his location features or the derived geotag at calibration step-and still have those features valid at a latter time or verification step. In other words, the signal characteristics should be consistent enough so that when the user is ready to validate his location, measurements at the same location will yield the same previously generated tag.

Several types of errors presented in the radio frequency (RF) signals can degrade the performance of the location-based security system. The most common error source is thermal noise, that is considered as white Gaussian noise. This noise cannot be eliminated and is always present in all electronic devices and transmission media. It depends on the propagation path, the distance between transmitter and receiver, and the quality of the receiver and the noise level. Another error source is seasonal bias that is the extra delay in propagation time due to the signals travel over land with various conductivities. Unlike the previous errors, this last type of error comes from the operations of the RF system. For instance, base stations or signal transmitters might be offline or shut down temporarily due to maintenance or other implementation issues. In this case, the reduction in number of received location features will result in an incorrect geotag.

The most common geotag generation is to quantize the features with adequate quantization steps and to map the quantized features into a binary string. The method is easy to implement but introduces quantization error, which is the difference between the value of a continuous feature and its quantized value. This causes the system to produce an incorrect geotag. The quantization error is usually correlated with the random noise and the seasonal biases.

To reduce the impact of the errors on geotag reproducibility, we propose three fuzzy extractor schemes for location data. A fuzzy extractor is an algorithm that can reliably extract desired information from input, and is error tolerant in the sense that this information will be the same even if the input changes. The first proposed construction is designed to deal with random noise, seasonal bias, and quantization errors that are considered to be in a Euclidean metric. The second and third proposed constructions target the error type while there are missing features. The distance measure in these constructions is the hamming metric. The second approach is based on the theory of error correcting codes and allows the exact recovery of location features from noisy input data. The third approach is based on the idea of secret sharing, which is a method to share and distribute a secret between N participants, and any subset of M (M <= N) participants can reconstruct the secret. The number of missing features that can be recovered is also a design parameter. A combination use of the Euclidean and hamming constructions will produce a more robust location-based security system.

Another geotag generation algorithm uses pattern classification, which is the concept of assigning a physical object or measured data to one of the pre-specified groups using a priori knowledge or statistical information [2]. Three different classifier-based geotag generation algorithms - Linear Discriminant Analysis (LDA), k-Nearest Neighbor (kNN) and Support Vector Machines (SVM) -- are proposed. All the classifier-based geotag generation algorithms can minimize the effect of random noise and seasonal biases on system reliability, thus maximizing the spatial discrimination, which is essential to the security level of a geo-security system. Real Loran data are used to evaluate and compare the performance of the classifiers-based geotags.

[1] D. Qiu, D. Boneh, S. Lo, and P. Enge, “Robust geotag generation from noisy location data for security applications,” Proceedings of ION ITM 2009.

[2] D. Qiu, S. Lo, P. Enge, and D. Boneh, “Pattern classification for geotag generation,” Proceedings of ION GNSS, Sept, 2009.

8061-11, Session 3

Single-node MMSE for MMSE cooperative positioning

S. Xi, M. D. Zoltowski, Purdue Univ. (United States); Y. Zhao, L. Dong, Western Michigan Univ. (United States)

We proposed in our previous work an iterative minimum-mean-square-error (MMSE) cooperative localization algorithm, which achieves better root-mean-square-error (RMSE) performance than existing classical estimators. To circumvent the intense computation burden of the numerical multiple integral computation methods, we proposed to implement it in an iterative pattern where only a single-node MMSE needs to be computed at each iteration. Obviously, the single-node MMSE, a special case of the MMSE cooperative method when the number of node N being 1, is the basis of the iterative MMSE. In this work, we study the properties of the single-node MMSE and propose three variants to improve the performance.

The first variant is named large scale MMSE (LS-MMSE), where a virtual a priori PDF that covers a larger area than the actual a priori PDF is used. The second variant is referred to as MMSE-mapping, where we map the originally obtained estimated position to another position according to certain rules and use the position after mapping as the final estimated positions. The third variant, called two-stage MMSE (TS-MMSE) is to add one more step to MMSE-mapping. At this second step, original MMSE is applied again assuming that each true position is uniformly distributed within a new smaller square whose center is the obtained estimated position.

The single-node MMSE and its variants can also be used to produce initial position estimation for the maximum likelihood estimator (MLE), one of the most popular existing classical estimators and achieve better performance than randomly generated initial position estimation.

8061-12, Session 3

A novel grid density-based geolocation algorithm for noncooperative radio emitters using power difference of arrival

S. Guo, B. R. Jackson, S. Wang, Defence Research and Development Canada (Canada); W. Arnold, Univ. of Waterloo (Canada); R. Inkol, Defence Research and Development Canada (Canada)

Various geolocation methods based on multilateration or probability theory have been studied using different types of measurements, such as angle of arrival, time difference of arrival, frequency difference of arrival, and received signal strength (RSS). RSS difference, also known as power difference of arrival (PDOA), is very attractive for certain applications since power readings can be achieved very easily and with low-cost. This paper presents a novel grid density-based geolocation

algorithm for localizing a non-cooperative radio emitter using PDOA. Consider a 2D space in a Cartesian coordinate system with M sensors and one stationary radio emitter and assume that the distance from a sensor to the radio emitter is the hypotenuse of a right triangle. For any three sensor combinations, there exists a system of three Pythagorean equations that can be transformed into a system of three circle equations using PDOA, each with a known center and radius. The intersections of the circles represent possible locations for the emitter. For M sensors, we can have at maximum M(M-1) circle intersections. Dividing the 2D space into a grid, each grid cell contains a certain number of circle intersections. This method finds the grid cell with the highest intersection density and uses the center of this cell as the position fix estimate of the radio emitter. An advantage of this method is that outliers in the data from multipath effects, for example, do not impact the accuracy of the results as much as alternative techniques. MATLAB-based numerical simulations are presented that allow its performance to be evaluated under different scenarios, including various number of sensors, sensor placement, and power variance.

8061-13, Session 3

Low-complexity narrowband adaptive beamforming based on symmetrically distributed arrays

L. Zhang, W. Liu, R. J. Langley, The Univ. of Sheffield (United Kingdom)

In narrowband adaptive beamforming, the beamformer coefficients are normally complex-valued. Recently, based on the specific structure of symmetrically distributed arrays, which include the commonly used uniform linear arrays, and the resultant persymmetric structure of their covariance matrices, it was shown that the optimum weight vector for maximum output SINR (signal-to-interference-plus-noise ratio) beamforming has a generalized conjugate symmetric property, which is then employed to regularize the weight update equation as a constraint, leading to an improved performance.

In this paper, this property is further exploited by designing a novel transformation matrix, which is applied to the received array signals as a preprocessing step. It will be shown that after this transformation, the resultant beamformer will have a real-valued optimum weight vector for either achieving a minimum output mean square error (MSE) or a maximum output SINR. Based on this structure, a new class of adaptive beamformers is then derived with real-valued coefficients. The key parameter of the transformation matrix takes different values for different beamforming scenarios and two representative examples are studied: the linearly constrained minimum variance beamformer (and its alternative implementation - the generalized sidelobe canceller) and the reference signal based beamformer. The advantage of the proposed method is twofold: 1) with real-valued coefficients, the computational complexity of the overall system is reduced significantly; 2) a faster convergence speed is achieved and given the same stepsize, the system arrives at a lower MSE or a higher output SINR.

Extensive simulation results will be provided to demonstrate the performance of the proposed method.

8061-14, Session 3

A spatial filtering approach to electronic wideband beam steering

W. Liu, The Univ. of Sheffield (United States); D. R. Morgan, Alcatel-Lucent Bell Labs. (United States)

Electronic wideband beam steering can be achieved by either physical temporal delays or digital circuits via FIR/IIR filtering.

When we need to change the beam direction frequently, the most convenient and flexible way is the digital approach.

The first step in implementing digital delays is to sample the signals with a frequency at least twice the highest frequency of the involved signals. This gives roughly a theoretical limit on this approach and it becomes unfeasible when the signal frequency and bandwidth are extremely high. For example, consider the millimeter wave band which extends from approximately 30 GHz to 300 GHz. In the current passive millimetre wave security imaging system, beam steering is normally done mechanically. Although digital beamforming can provide many obvious advantages compared to mechanical steering, such as simplicity, flexibility, personnel throughput enhancement, and significantly reduced volume, it is still a challenging open problem due to the extremely high sampling frequency required (even after downconversion to an intermediate frequency).

To solve this problem, in this paper, a spatial filtering approach will be proposed for wideband beam steering. Instead of sampling the signals in temporal domain for digital processing, we sample the signals spatially with more sensors positioned behind the original array of sensors. The spatially sampled signals are then processed using simple analogue circuits (variable gain amplifiers) to form the required steering delays. The delay between the spatially sampled signals is dependent on the distance between adjacent sensors and the directions of the designed beams, not limited by the signal frequency. Design examples will be provided to show that different delays can be simulated effectively by a spatial filtering system to steer an existing beam to the required directions.

8061-15, Session 4

Source location detection using unique characterizations of multipath propagation in an urban environment

B. R. Phelan, R. M. Narayanan, E. H. Lenzing, The Pennsylvania State Univ. (United States)

This paper introduces a receiver system capable of determining the location of coherent point sources. An eigenstructure technique employing the use of a spatial smoothing preprocessing scheme is used to avoid the inherent problems of direction-of-arrival (DoA) estimation of coherent (fully correlated) signals. The DoA estimations for each multipath are used to characterize a unique 'signature' which is a function of the transmitter location and neighboring environment geometry. A database containing the multipath signatures for each transmitter location in an area of interest is populated via ray-tracing software simulations. Due to the high density of the simulated multipath signature database, a clustering algorithm is used to quickly eliminate areas of the database that correspond to locations with a low probability of being the source location. By minimizing the difference between calculated (received) & simulated multipath signatures, we can determine the source location via the information collected from a single receiver location. Furthermore, since this technique utilizes a simulated multipath signature database, the need for a priori soundings from the area of interest is eliminated, thus making this location detection system ideal for use in hostile territories.

8061-16, Session 4

Accurate position service based on interacting multiple model with enhanced Kalman filter

J. Li, Y. Cao, N. Wu, Nanjing Univ. (China); X. Li, New York City College of Technology (United States)

In our previous paper, we proposed and studied a model of location-based service (LBS) in the wireless sensor network. In this paper, we study the data process for tracing an object motion using the proposed model. Compared with a single model used to trace the object motion, the Interacting Multiple Model (IMM) with an enhanced Kalman filter provides a more powerful framework on tracing of a position service in LBS system. We also provide an enhanced Kalman-filter-based algorithm that is used to smooth the trace of a positioned object.

8061-17, Session 5

Navigation of robotic systems using cricket motes

Y. Patil, K. S. Rattan, N. A. Baine, Wright State Univ. (United States)

Autonomous robotic systems are becoming an integral part of the current and future commercial and military applications. Remote tracking, monitoring and navigation of these autonomous robotic systems in indoor environment are becoming more and more important. Global Positioning System (GPS), satellite based navigation system, plays a vital role in these applications. However, receiving satellite signals in indoor locations is a major problem. This problem can be overcome by using indoor localization systems like Cricket motes. Cricket is an inexpensive wireless sensor mote, which provides indoor localization of a given object. They have good accuracy, easy to configure and deploy. However, to configure these motes to a co-ordinate system requires manual assistance. The objective of this project is to develop a new technique for localization and navigation of robots, especially in indoor locations, with little or no manual support. The primary focus of this paper is to present a novel algorithm for the Cricket motes to create a robust local co-ordinate system and then use these self-mapping Cricket motes to track, monitor and navigate multiple autonomous robotic systems. The algorithm uses the trilateration technique to obtain a robust co-ordinate system. The experimental field data has shown that it is possible to configure the Cricket motes to a self-mapping mode and furthermore can be use to navigate a robotic system.

8061-18, Session 5

An improved antenna circuit model utilizing a transmission line

A. Hollister, Physical Optics Corp. (United States); J. T. Armstrong, Probe Science, Inc. (United States)

As electronic products shrink and wireless requirements grow, antenna matching is the key to reaching high performance goals. Small antennas (< 0.15) exhibit rapid changes in impedance with frequency, and failure to provide proper matching leads to production rejects and waste.

Antennas that are modeled as either series or parallel resonant circuits are exact over a very small range of frequencies. These simple models fail at frequencies removed from the antenna resonance, which is strongly affected by changes in the physical environment.

This paper describes an antenna model that uses a transmission line as an inherent component.

The transmission line allows the modeled impedances to be rotated about the Smith Chart (transformed) in such a way that they closely match the measured data from an actual antenna as measured on a network analyzer. Antenna models with lumped R, L and C elements are constrained to constant reactance or resistance contours, while the proper addition of a transmission line component allows accurate simulation of the antenna response.

The resulting antenna model is valid over a very wide range of frequencies and allows precision matching networks to be created. Measured results from a variety of electrically small chip antennas show high correlation with this new theoretical circuit model

8061-19, Session 5

Robust visible light communications system using filter-based sensor array

C. Chang, Y. Su, National Taipei Univ. of Technology (Taiwan); U. Kurokawa, B. I. Choi, nanoLambda (United States)

With the recent development of solid state lighting (SSL) technologies, visible light communication (VLC) systems using light emitting diodes (LEDs) has been a promising technology to complement wireless communication. While LEDs offers advantageous properties such as high brightness, lower power consumption, long lifetime, and short transient time for high transmission rates, few researches have been exploited on the receiver side.

Conventionally, photoelectric-diodes are implemented to convert optical signals into electronic signals. Since conventional photoelectric-diodes cannot distinguish inputs of different spectra, using conventional photoelectric-diodes have the disadvantage that the system is vulnerable to interference, and cannot achieve wavelength-division-multiplexing (WDM) for light sources of different wavelengths,

In this work, a spectral sensor array is proposed to be implemented on the receiver side to achieve interference rejection and WDM. Due to recent advances in semiconductor technologies, spectral sensors with different spectral transmission properties can be integrated into a chip-scale sensor-array. By proper design of the weightings for individual spectral sensor, the effective output signal to noise ratio (SNR) or signal to interference and noise ratio (SINR) can be maximized. Following the concept of multi-antenna communication systems, signal fusion algorithms, such as maximum ratio combining (MRC), equal gain combining (EGC), and matched filter criterion (MFC) are introduced. Our simulation is conducted based on the specification of a prototype nano-optic filter-based spectrum sensor from nanoLambda. Simulation results demonstrate robust interference rejection and WDM is made possible using the low-cost spectrum sensor array.

8061-20, Session 5

INS aided by an acoustic wireless sensor network and magnetometer

N. A. Baine, P. U. Desai, K. S. Rattan, Wright State Univ. (United States)

Wireless sensor networks equipped with acoustic sensors are showing promise as a solution to the indoor navigation problem. However, they have a low update rate providing position solutions at a rate of 1Hz and require line-of-sight to work optimally. In our previous work, we have used time difference of arrival (TDoA) measurements from a wireless sensor network to aid a low-cost inertial navigation system (INS). This combination of INS and wireless sensor network made an improvement in update rate; unfortunately, the orientation information was not ideal for control of autonomous vehicles. This is due to the fact that the wireless sensor network only provides position information and relies on the vehicle's orientation to provide aiding to the orientation estimation.

This paper introduces the use of magnetometer data in addition to the wireless sensor network for INS aiding. Magnetometer data provides direct information of the vehicles heading and pitch regardless of vehicle's true orientation and consequently improves orientation estimation.

The navigation system in this work is a tightly coupled INS, aided with magnetometer measurements and TDoA measurements. The aiding is performed indirectly using a Kalman filter to perform error and bias estimation for the INS. The error estimates are fed back to the INS to improve the navigation solution. This system was developed through the use of computer simulation (not real-time) with data collected in a laboratory environment. The results of this simulation show a significant improvement in position and orientation estimation relative to the system without aiding from magnetometer data.

8061-21, Session 5

Performance of concatenated convolutional codes with differential modulations: coherent versus non-coherent

F. C. Kellerman, Harris Corp. (United States)

For radio communication systems, powerful error correction codes are necessary to operate in noisy and fading channel conditions. Iterative forward error correction schemes like Turbo codes can achieve near Shannon capacity performance on memory-less channels and also perform well on correlated fading channels. The key to the excellent decoding performance of the Turbo coding systems is the BCJR algorithm in conjunction with the iterative processing of the soft decision information. A very popular modulation technique is Differential Phase Shift Key (DPSK) which is not only a simple non-coherent modulation and demodulation technique, it is also a recursive rate one code. Combining DPSK with a single convolutional code structure as an iterative inner outer forward error correction system can provide excellent Turbo like performance. Other modulation schemes such as QAM and true differential vs. coherent modulations will be explored. Monte Carlo simulation results will be shown for the Additive White Gaussian Noise (AWGN) and Rayleigh fading channels for 1, 2, 3 and 4 bits per symbol.

8061-22, Session 6

Sensing using eigenchannels in RF MIMO communication systems

N. Bikhazi, Sandia National Labs. (United States); W. F. Young, National Institute of Standards and Technology (United States); H. D. Nguyen, Sandia National Labs. (United States)

This paper describes the use of multiple-input, multiple-output (MIMO) communication technology as a radio frequency (RF) sensor. We suggest some possible measures for determining how the changes in MIMO channel are related to objects moving through the MIMO channel. Initially, we examine the singular values of the channel matrix and the related Fourier harmonics. We further demonstrate the effects of the signal-to-noise ratio (SNR) in conjunction with the target physical properties in the creation of eigenchannels. These eigenchannels represent the key factor in the ability of a MIMO system to perform as an effective sensor. Another important feature of MIMO technology is that it allows us to capture spatial information about the target, beyond the typical time and frequency information. Preliminary experimental results at 750 MHz demonstrate that targets can be detected and distinguished based on these simple measures. For example, a vehicular target is distinguishable from a person or groups of people.

Our concept is closely related to a MIMO radar approach. However, a key difference is that we make use of the natural process of establishing a MIMO communication link rather than interrogate a specific physical region via a pulsed RF waveform. MIMO communications requires sounding of the physical environment and the creation of a channel matrix in order to maximize data throughput. We leverage this information about the area of interest already captured by the communication system. This allows the use of a MIMO system for both sensing and communication.

8061-23, Session 6

Computation-efficient blind estimation of OFDM signal parameters for interception and data recovery

Q. Chen, X. Wang, D. Fan, The Univ. of Western Ontario (Canada); S. Guo, Defence Research and Development Canada (Canada)

Orthogonal Frequency Division Multiplexing (OFDM) has recently been adopted in many military communications systems due to its high spectral efficiency and robust performance in hostile channel conditions. Consequently, blind estimation of OFDM system parameters has received considerable research attentions for the recovery of the transmitted data.

Many techniques have been developed for blind estimation of various OFDM parameters, whereas estimation of the sampling frequency is often ignored. In addition, the sampling frequency estimation of an OFDM signal has to be very accurate for data recovery due to the high sensitivity of OFDM signals to sampling clock offset, which inevitably results in high computational complexity.

To address the aforementioned problems, we propose a two-step progressive cyclostationary based algorithm with low computational complexity to estimate the oversampling ratio of a captured OFDM signal. In the first step, a coarse estimation is employed to roughly determine the range of interest in the cyclic-correlation to handle potential OFDM signals with dynamic bandwidth. In the second step, fine estimations are carried out over the selected range using zoom fast Fourier transform to improve the estimation accuracy and reduce the computational complexity. Benefiting from the two-step estimation, computations can be mainly concentrated on the useful part of the cyclic-correlation result. Hence, the computational complexity reduction and the accurate estimation can be achieved simultaneously.

Simulation results confirm the improvements of the estimation precision and computational efficiency of the proposed algorithm. With the estimated sampling rate, OFDM signals can be decoded based on other system parameters such as number of subcarriers and cyclic prefix duration.

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8062-01, Session 1

VFILM: a value function driven approach to information lifecycle management

J. Cleveland, J. P. Loyall, J. Webb, BBN Technologies (United States); J. Hanna, Air Force Research Lab. (United States)

Information Management (IM) services need lifecycle management, i.e., determining how long persistent information is retained locally and when it is moved to accommodate for new information. This is important when bridging IM services from enterprise to tactical environments, which can have limited onboard storage and be in highly dynamic situations with varying information needs. In this paper, we describe an approach to Value Function based Information Lifecycle Management (VFILM) that balances the value of existing information to current and future missions with constraints on available storage. VFILM operates in parallel with IM services in dynamic situations where missions and their information needs, the types of information being managed, and the criticality of information to current missions and operations are changing. In contrast to current solutions that simply move the oldest or least frequently accessed information when space is needed, VFILM manages information lifecycle based on a combination of inputs including attributes of the information (its age, size, type, and other observable attributes), ongoing operations and missions, and the relationships between different pieces of information. VFILM has three primary innovative features: (1) a fuzzy logic function that calculates an ordering of information value based on multiple relative valued attributes; (2) mission/task awareness that considers current and upcoming missions in information valuation and storage requirements; and (3) information grouping that treats related information collectively. The paper describes the VFILM architecture, a VFILM prototype that works with Air Force Research Laboratory IM services, and the results of experiments showing VFILM's effectiveness and efficiency.

8062-02, Session 1

Evaluating QoS-enabled information management services in a Navy operational context

A. Paulos, J. P. Loyall, M. Gillen, BBN Technologies (United States); A. Sinclair, Air Force Research Lab. (United States)

Information Management (IM) services support the discovery, brokering, and dissemination of mission-critical information based on the information's content and characteristics. IM services support the dissemination of future information (through subscriptions) and past information (through queries) regardless of its source. To be useful across enterprise and tactical environments, IM services need mission-driven Quality of Service (QoS) features as part of their core functionality. We have developed QoS management features, QoS Enabled Dissemination (QED), that extend an Air Force Research Laboratory (AFRL) developed set of IM services, Phoenix. The paper describes the results of a joint services experiment evaluating QED and Phoenix in a US Navy scenario involving multiple ships connected by a Disconnected, Intermittent, Limited (DIL) satellite network. The experiments evaluate QED and Phoenix's ability to (1) provide IM in the Wide Area Network (WAN) context of the satellite communications, which includes long latencies and background traffic not under QED control; (2) control and utilize active-precedence and queue management features provided by the WAN; (3) handle severe network overload, network disruptions, and dynamic changes in policies; and (4) successfully enforce deadlines and information replacement policies.

8062-03, Session 1

An enterprise service set for adaptive role-relevant operational displays

J. D. Zaientz, Soar Technology, Inc. (United States); M. Hultner, Lockheed Martin Orincon (United States); D. Ray, L. Hamel, Soar Technology, Inc. (United States)

Next generation Command and Control (C2) systems are breaking down information stovepipes by leveraging Service Oriented Architecture (SOA) based data and display services. These systems will provide operational commanders with battlespace visualizations that integrate data to speed information assimilation and improve operational decision-making. The additional volume and complexity of information available to the new COP displays must be tailored to the operational role of the information consumer. Not doing so would result in limited-data displays that privilege the needs of some C2 roles (e.g. BattleWatch) over others (e.g. Network Operations) or in unlimited-data displays that overload the operator with information intended to meet the needs of other roles. Despite the opportunities presented by the new C2 systems, the consequence not provide role-relevant visualization would be a net loss of operational effectiveness.

Designing effective, role-relevant displays within a DoD SOA environment requires adopting common display configuration description formats and an enterprise service set that generates display configurations based on the current operational context and user role. We have developed a set of services that provide XML- and JSON-based configuration file and visual iconography generation and role and context modeling capabilities. These capabilities were tested within a large DoD C2 SOA prototype by applying them to the management of three different COP displays, a Web Map Feature query engine, and a set of custom web tables. In each case, the previously single configuration display was rapidly retro-fitted into role-relevant, context sensitive display. These displays are now being evaluated in a DoD operational command.

8062-04, Session 1

Net-centric interoperability

M. T. Sevening, The Boeing Co. (United States)

Abstract: This presentation proposes an approach to address interoperability design, engineering, testing, and fielding concerns. First, it classifies interoperability into three distinct areas with specific attributes and discusses the attributes of each interoperability classification. Second, it discusses the three classifications in relation to the seven open system interconnection layers. Third, it presents a sample matrix to use in measuring interoperability. Last, it details analysis possibilities using the interoperability matrix presented.

This presentation classifies interoperability into three distinct areas: integrated interoperability, system-to-system interoperability, and collaborative interoperability. The presenters define the three areas as follows. Integrated interoperability is a function of messages sent through the network to a destination. System-to-system interoperability is a function of information and other participating elements use of perishable data. Collaborative interoperability is a function of awareness and coordination actions by each participating elements and of the entire system of systems.

Ultimately, the presenters propose their method for use across the designing, engineering, testing, fielding, and analysis phases of the Ballistic Missile Defense System to improve the effectiveness of interoperability.

During the conference proceedings, the author(s) will also provide observations and tips on solving common interoperability issues.

8062-05, Session 1

SMASHUP: secure mashup for defense transformation and net-centric systems

M. D. Heileman, Modus Operandi, Inc. (United States); G. L. Heileman, The Univ. of New Mexico (United States); M. P. Shaver, Air Force Research Lab. (United States); M. D. Gilger, Modus Operandi, Inc. (United States); J. Benner, Jr., Booz Allen Hamilton Inc. (United States)

Existing and new DoD systems are exposing more and more information via web service techniques and technologies. However usage of these services has not extended much beyond the developer community as the technical skills and tools needed to invoke these services have remained out of reach of the average end user. Additionally the certification and accreditation of such tools discourages and/or prevents the average end user from modifying the manner in which information reaches them due to concerns regarding confidentiality, integrity, and availability.

On the Internet, Web 2.0 services are widely available for users to mashup or aggregate information in novel manners that meet their needs. The availability of such services in DoD environments could provide tremendous advantages to decision-makers. However in the absence of mechanisms for managing the usage of resources, any mashup service in a DoD environment also opens up significant security vulnerabilities to insider threat and accidental leakage of confidential information. In the SMASHUP research project, a framework was developed that will allow integration via mashups of content from various data sources in a secure manner. The framework is based on mathematical logic by means of which addressable resources have formal usage terms applied to them, and these terms are used to specify and enforce usage policies over the resources. An advantage of this approach is it provides a formal means for controlling the usage of resources within highly complex secure mashups. The SMASHUP design considers cross-domain mashups (i.e., cross-domain sharing) in both “sandwich” and “sidecar” architectures.

8062-06, Session 2

Issues in defense innovation

A. Seraphin, Office of Science and Technology Policy (United States)

No abstract available

8062-07, Session 2

Gotcha radar update

M. L. Bryant, Air Force Research Lab. (United States)

No abstract available

8062-08, Session 2

Adaptive radar

M. Rangaswamy, Air Force Research Lab. (United States)

No abstract available

8062-09, Session 2

Developing an open architecture (OA) roadmap and defining OA levels

M. Cramer, U.S. Navy (United States); B. Cordes, Naval Surface Warfare Ctr. Panama City Div. (United States); J. R. Stack, Office of Naval Research (United States)

No abstract available

8062-10, Session 2

Improving network utilization over heterogeneous airborne networks

B. Rickenbach, General Dynamics Advanced Information Systems (United States)

Existing and future military networks vary widely in bandwidth and other network characteristics, potentially challenging deployment of services and applications across heterogeneous data links. To address this challenge, General Dynamics and MIT Lincoln Laboratory created network services allowing applications to more efficiently utilize wireless data links. The basis for the network services is a network control plane that forms topologies and establishes connectivity between platforms in the airborne networking environment. The control plane can monitor heterogeneous data links on a platform and also reports link availability and parameters such as latency and bandwidth. A service-oriented architecture then wrapped the link data into a service accessible to other services and applications. These services and applications were then able to tune parameters and content based on network parameters. The experiment was housed onboard a Boeing 707 with data links such as Tactical Common Data Link (TCDL), Tactical Targeting Network Technology (TTNT), INMARSAT, and Iridium. We show results from participation in Red Flag 07-3 where we tested the transfer of imagery over various data links using three IP-based transport protocols: Nack-Oriented Reliable Multicast (NORM), Stream Control Transmission Protocol (SCTP), and TCP. The results show the ability to significantly improve the transfer of data over wireless data links.

8062-11, Session 2

Vision and critical challenges in exploiting distributed data for distributed decision making

G. Pearson, Defence Science and Technology Lab. (United Kingdom)

This paper set out a number of fundamental challenges to be overcome to enable the large volumes of data in modern distributted and networked defence information systems (including sensor systems) to be used to support decision making; taking into account the fundamental trends in Information Communications Technology (ICT) associated with bandwidth, storage capacity and processing power; as well as the changing nature of the information (particularly the growth in informal information and soft sensor data).

The paper builds on work conducted in the first 5 years of the Network Information Science (NIS) International Technology Alliance (ITA) (particularly on agile distributed information access) a joint UK MoD and US ARL research programme (together with developments elsewhere) to set out three key core technical challenges (and a set of associated sub-challenges) which research needs to address to enable next generation exploitation, for decision making, of networked military information systems (where the richest data is frequently distributed at the edge of the network).

As such it extends and builds on a paper on network centric sensing presented at SPIE DSS in 2008.

8062-12, Session 2

A multi-agent infrastructure for hard and soft information fusion

J. C. Rimland, D. L. Hall, The Pennsylvania State Univ. (United States)

Current needs in tactical situational awareness require a new type of infrastructure to encode, transmit, store, fuse, and display vastly heterogeneous data that may include "hard" sensor types including video, radar, multispectral, acoustic sensor array, 3D flash LIDAR, and "soft" sensor inputs such as textual reports from trained and untrained personnel, unsolicited and solicited open source web information, and hybrid "hard/soft" data such as human-annotated image or video data - which can be highly useful, but very difficult to categorize and exploit.

While the demand for scalability, rapid deployment, and decentralized access to data and services grows, the need for data security and integrity is as critical as ever. Methods for handling the conflicting needs between access and security are addressed.

Furthermore, the evolving role of humans in data fusion systems must be addressed by the infrastructure. In addition to systems enhancing human data analysis capabilities through advanced visualization and sonification techniques, the data itself is more likely to contain information about humans - which is not always a task well suited to conventional data storage and retrieval methods.

This paper describes a multi-agent approach to designing a secure, distributed, service-oriented infrastructure to support human-centric hard and soft information fusion.

8062-13, Session 2

3DSF: three-dimensional spatiotemporal fusion

R. L. Tutwiler, D. J. Natale, M. S. Baran, D. L. Hall, The Pennsylvania State Univ. (United States)

Flash LIDAR focal plane array devices are currently commercially available. Such devices give the ability to measure and record registered 3D point cloud sequences at video frame rates. For many 3D computer vision applications this allows the processes of structure from motion or multi-view stereo reconstruction to be circumvented. This allows the construction of simpler, more efficient, and more robust 3D computer vision systems. The system will accomplish the detection, segmentation, and tracking of objects using a combination of fundamental point cloud processing algorithms. This is a particular advantage for ground-based vision tasks which necessitate real-time or near real-time operation. The goal of this work is introduce several important considerations for dealing with commercial 3D Flash LIDAR data and to describe useful strategies for noise filtering, structural segmentation, fusion with 2D sensor modalities (i.e., VNIR, SWIR, MWIR, and HSI) and meshing of ground-based data. The results of this work are directly applicable to many ground-based computer vision tasks, as well as perimeter surveillance and site security.

8062-14, Session 2

A new synthetic dataset for evaluating soft and hard fusion algorithms

J. Graham, D. L. Hall, J. C. Rimland, The Pennsylvania State Univ. (United States)

There is a great demand for the development of data fusion techniques and algorithms that are capable of combining conventional "hard" sensor inputs such as video, radar, and multispectral sensor data with "soft" data including textual situation reports, open-source web information, and "hard/soft" data such as image or video data that includes human-generated annotations. New techniques that assist in sense-making over a wide range of vastly heterogeneous sources are critical to improving tactical situational awareness in counterinsurgency (COIN) and asymmetric warfare situations. A major challenge in this area is the lack of realistic datasets available for test and evaluation of such fusion algorithms. While "soft" message sets exist, they tend to be of limited use for data fusion applications due to a lack of critical message pedigree and other metadata. They also lack corresponding hard sensor data that presents reasonable "fusion opportunities" to evaluate the ability to make connections and inferences that span the soft and hard data sets. This paper outlines the design methodologies, content, and some potential use cases of a COIN-based synthetic soft and hard dataset created under a United States multi-disciplinary university research initiative (MURI) program funded by the U.S. Army Research Office. The dataset includes realistic synthetic reports from a variety of sources, corresponding synthetic hard data, and an extensive supporting database that maintains "ground truth" through logical grouping of related data into "vignettes." The supporting database also maintains the pedigree of messages and other critical metadata.

8062-15, Session 2

JDL level 0 and 1 algorithms for processing and fusion of hard sensor data

J. C. Rimland, G. M. Iyer, R. R. Agumamidi, S. V. Pisupati, J. Graham, The Pennsylvania State Univ. (United States)

The current trend in information fusion is moving toward distributed methods of combining both conventional "hard" sensor data and human-based "soft" information in a manner that exploits the most useful and accurate capabilities of each modality. In addition, new and evolving technologies such as Flash LIDAR have greatly enhanced the ability of a single device to rapidly sense attributes of a scene in ways that weren't possible before.

Researchers at The Pennsylvania State University are participating in a multi-disciplinary university research initiative (MURI) program funded by the U.S. Army Research Office to investigate issues related to fusing hard and soft data in counterinsurgency (COIN) situations. In working toward this goal, it became necessary to re-evaluate the current state-of-the-art in hard sensor data alignment, tracking, recognition, and identification and to modify current techniques and algorithms to reflect the new technologies that are available and the new goals associated with the MURI program mentioned above. This paper describes various hard sensor processing algorithms and their evolving roles and implementations within a distributed hard and soft information fusion system.

8062-09, Session 3

JEFX 10 demonstration of cooperative hunter killer UAS and upstream data fusion

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The Johns Hopkins University Applied Physics Laboratory deployed and demonstrated a prototype Cooperative Hunter Killer (CHK) Unmanned Aerial System (UAS) capability and a prototype Upstream Data Fusion (UDF) capability as participants in the Joint Expeditionary Force Experiment 2010 in April 2010. The CHK capability was deployed at the Nevada Test and Training Range to prosecute a convoy protection operational thread. It used mission-level autonomy (MLA) software applied to a networked swarm of three Raven hunter UAS and a Procerus Miracle surrogate killer UAS, all equipped with full motion video (FMV). The MLA software provides the capability for the hunter-killer swarm to autonomously search an area or road network, divide the search area, deconflict flight paths, and maintain line of sight communications with

mobile ground stations. It also provides an interface for an operator to designate a threat and initiate automatic engagement of the target by the killer UAS. The UDF prototype was deployed at the Maritime Operations Center (MOC) at Commander Second Fleet, Naval Station Norfolk to provide intelligence analysts and the ISR commander with a common fused track picture from the available FMV sources. It consisted of a video exploitation component that automatically detected moving objects, a multiple hypothesis tracker that fused all of the detection data to produce a common track picture, and a display and user interface component that visualized the common track picture along with appropriate geospatial information such as maps and terrain as well as target coordinates and the source video.

8062-11, Session 3

Dynamic replanning on demand of UAS constellations performing ISR missions

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Unmanned aerial systems (UAS) have proven themselves to be indispensable in providing intelligence, surveillance, and reconnaissance (ISR) over the battlefield. Constellations of heterogeneous, multi-purpose UAS are being tasked to provide ISR in an unpredictable environment. This necessitates the dynamic replanning of critical missions as weather conditions change, new observation targets are identified, aircraft are lost or equipment malfunctions, and new airspace restrictions are introduced. We present a method for generating coordinated mission plans for constellations of UAS with multiple flight goals and potentially competing objectives, and updating them on demand as the operational situation changes. We use a fast evolutionary algorithm-based, multi-objective optimization technique. The updated flight routes maintain continuity by taking into account where the ISR assets have already flown and where they still need to go. Both the initial planning and replanning take into account factors such as area of analysis coverage, restricted operating zones, maximum control station range, adverse weather effects, military terrain value, and sensor performance. Our results demonstrate that by constraining the space of potential solutions using an intelligently-formed air maneuver network with a subset of potential airspace corridors and navigational waypoints, it is possible to ensure global optimization for multiple objectives by taking into account the situation both before and after the replanning is initiated. We employ sophisticated visualization techniques using a geographic information system to help the user ‘look under the hood’ of the algorithms and understand the effectiveness and viability of the generated ISR mission plans and identify potential gaps in coverage.

8062-13, Session 3

All weather sense and avoid system (AWSAS) for all UAS and manned platforms

V. M. Contarino, R-Cubed Engineering, LLC (United States)

For decades, military and other national security agencies have been denied unfettered access to the National Air Space (NAS) because their unmanned aircraft lack a highly reliable and effective collision avoidance capability. The controlling agency, the Federal Aviation Administration, justifiably demands “no harm” to the safety of the NAS. To overcome the constraints imposed on Unmanned Aircraft Systems (UAS) use of the NAS, a new, conformable collision avoidance system has been developed - one that will be effective in all flyable weather conditions, overcoming the shortfalls of other sensing systems, including radar, lidar, acoustic, and EO/IR, while meeting form factor and cost criteria suitable for Tier II UAS operations. The system also targets Tier I as an ultimate goal, understanding the operational limitations of the smallest UASs may require modification of the design that is suitable for Tier II and higher.

The All Weather Sense and Avoid System (AWSAS) takes into account the FAA’s plan to incorporate ADS-B (out) for all aircraft by 2020, and it is intended to make collision avoidance capability available for UAS entry into the NAS as early as 2013. When approved, UASs can fly mission or training flights in the NAS free of the constraints presently in place. Upon implementation this system will achieve collision avoidance capability for UASs deployed for national security purposes and will allow expansion of UAS usage for commercial or other civil purposes. This work has been funded by ONR and is undergoing flight testing in May 2011.

8062-16, Session 3

Biologically-inspired approaches for self-organization, adaptation, and collaboration of heterogeneous autonomous systems

M. L. Steinberg, Office of Naval Research (United States)

This paper presents a survey of recent theoretical and experimental progress in the development of biologically-inspired approaches for complex search and coverage problems with multiple, heterogeneous autonomous systems. The focus is on approaches that may address ISR problems that can quickly become mathematically intractable or otherwise impractical to implement using traditional optimization techniques as the size and complexity of the problem is increased. These problems require dealing with complex spatio-temporal objectives and constraints at a variety of levels from motion planning to task allocation. There is also a need to ensure solutions are reliable and robust to uncertainty and communications limitations. First, the paper will provide a short introduction to the current state of relevant biological research as relates to collective animal behavior and the underlying neural and cognitive mechanisms. Second, the paper will describe research on largely decentralized, reactive, or swarm approaches that have been inspired by biological phenomena such as schools of fish, flocks of birds, ant colonies, and insect swarms. Next, the paper will discuss approaches towards more complex organizational and cooperative mechanisms in team and coalition behaviors in order to provide mission coverage of large, complex areas. Relevant team behavior may be derived from recent advances in understanding of the social and cooperative behaviors used for collaboration by tens of animals with higher-level cognitive abilities such as mammals and birds. Finally, the paper will briefly discuss challenges involved in user interaction with these types of systems.

8062-17, Session 3

Migration strategies for service-enabling ground control stations for unmanned systems

J. B. Kroculick, Winifred Associates (United States)

Future unmanned systems will be integrated into the Global Information Grid (GIG) and support net-centric data sharing, where information in a domain is exposed to a wide variety of GIG stakeholders that can make use of the information provided. Adopting a Service-Oriented Architecture (SOA) approach to package reusable ground control station functionality into common control services provides a number of benefits including enabling dynamic plug and play of components depending on changing mission requirements, supporting information sharing to the enterprise, and integrating information from authoritative sources such as mission planners with the ground control station’s data model. It would also allow the wider enterprise community to use the services provided by unmanned systems and improve data quality to support more effective decision-making.

We explore current challenges in migrating ground control stations that control multiple types of vehicles to a Service-Oriented Architecture (SOA). Service-oriented analysis involves reviewing legacy systems and determining which components can be made into a service. Existing ground control stations provide audio/visual, navigation, and vehicle

health and status information that are useful to C4I systems. However, many were designed to be closed systems with proprietary software and hardware implementations, message formats, and specific mission requirements. An architecture analysis can be performed that reviews legacy systems and determines which components can be made into a service. A phased SOA adoption approach can then be developed that improves system interoperability.

8062-29, Session 3

Autonomous sustain and resupply: what is the future?

G. S. Broten, Defence Research and Development Canada (Canada)

As autonomous ground vehicles (UGVs) acquire more capabilities, their possible military roles have become a topic of much speculation. Given a UGVs' limited sensing capabilities and the resulting lack of situtational awareness, behind the front line roles have been posited as an attractive option. A role in autonomous convoying has been researched, but only in support of traditional human manned convoys. As UGVs gain more and more capabilities, there is the open question of how to applied these capabilities to the sustain and resupply problem. Defence R&D Canada - Suffield, in conjunction with Simon Fraser University has conducted research that investigate these issues.

Under autonomous resupply, a fleet of UGVs co-ordinate their actions to service a group of consumers. The consumer could be other autonomous vehicles, manned vehicles or static sites. The supply UGVs must also monitor their internal expendables and ensure that they have sufficient resources on hand. In its generalized form, the UGV fleet is heterogeneous with individual vehicles having varying performance characteristics and offering differing resupply capabilities. Consumers are also heterogeneous, and demand the delivery of various commodities, in varying quantities. The resupply point may be a specified geographical location or it could be a point negotiated between the consumer and the supplier. Finally, at supply sites, supply vehicles acquire goods for either personal usage or to offer as goods to other consumers.

This research produced a novel theoretical analysis of the sustain and resupply problem, which lead to new concepts in sustain and rendezvous methods for UGVs teams. These concepts have been investigated via large scale simulations. These extensive simulations have shown that large UGV teams can self-organize conveys to deliver goods while ensuring each UGV sustains its own expendables.

8062-18, Session 4

Trident Spectre 2010: agile integration and demonstration of a multisensor airborne pod

G. Twaites, B. Rickenbach, General Dynamics Advanced Information Systems (United States)

TRIDENT SPECTRE is an annual battle lab experiment hosted jointly by members of the United States DoD and the Intelligence Community. The experiments involve technical collections, Geospatial Intelligence, Analysis, Human Intelligence, and communications. It offers a unique opportunity to test new ideas and concepts in a secure environment with users, operators, technicians, engineers, and industry partners collaboratively. Trident Spectre is intended to improve tactical intelligence capabilities for the warfighter, provide an operational assessment to validate successes, help to accelerate (not defeat) the acquisition process, and bring new technologies to the surface in a secure environment. The goal for the exercise is to examine and select technologies that are useful and mature enough to forward deploy in a timely manner. Selected technologies are evaluated in a controlled environment, simulating front line conditions. Successful experiments are selected for quick reaction capability, in theatre deployment. General Dynamics Advanced Information Systems participated in Trident Spectre 2010 during April through September of 2010 at the US Navy facilities at Ft. Story, Virginia. This paper provides a description of the Trident Spectre 2010 exercise, focusing on the agile process of developing a prototype airborne ISR pod that integrated technologies from multiple companies. The pod provides the capability to: identify targets of interest based on RF detections or accepted cueing information from off-platform sensors; geo-locate the detected network nodes; cross-cue WAMI sensors on another platform; cross-cue other airborne sensors (EO, IR, SAR, etc); and downlink motion imagery and metadata into the Governments RAPTOR-X ground station.

8062-19, Session 4

Discovering geospatial networks from ambiguous track data

J. E. Bevington, General Dynamics Advanced Information Systems (United States); M. Evans, S. Shekhar, Univ. of Minnesota, Twin Cities (United States)

Wide area motion imagery (WAMI) sensors increasingly are being used for persistent surveillance of large urban areas. One of the potential uses for such surveillance is the discovery of geo-spatial networks, which are sets of locations linked by repeated traffic flow over an extended period of time. Detection of such networks may be of interest for example in uncovering networks of terrorist or criminal activity given initial seed locations, or in detailed analysis of traffic patterns for urban planning. WAMI sensors produce extremely large volumes of data, so automated exploitation is a critical need. While moving target tracking technology is an important element of the exploitation process, WAMI-derived tracks will always be imperfect because of occlusions and shadowing. Processes that derive information from track data must be robust to track discontinuities and linking errors.

In this work we present a simple method of deriving geo-spatial network links from ambiguous track segments or tracklets. The method avoids making explicit tracklet linking decisions and instead considers all locations reachable through kinematically feasible tracklet associations. Temporal aggregation filters out the false origin-destination location pairs arising from incorrect tracklet associations and enables discovery of the true network nodes. We also present a novel method of generating realistic track data for analysis and experimentation using street maps and routing information available through the Google Maps on-line API. Track discontinuities are introduced by applying occlusion maps to ideal track data. We present experimental network discovery results using simulated high density track data for a downtown urban setting.

8062-20, Session 4

Network exploitation using WAMI tracks

R. D. Rimey, D. Keefe, J. N. Record, Lockheed Martin Corp. (United States); L. Kennedy, C. E. Cramer, Signal Innovations Group, Inc. (United States)

Creating and exploiting network models from wide-area motion imagery (WAMI) is an important task for intelligence analysis. Tracks of entities observed moving in the WAMI sensor data are extracted, then large numbers of tracks are studied over long time intervals to determine specific locations that are visited (e.g., buildings in an urban environment), what locations are related to other locations, and the function of each location. This paper describes several parts of the network detection/exploitation problem, and summarizes a solution technique for each: (a) Detecting nodes is tackled via density-based clustering over a spatial hierarchy and also via a hierarchical Dirichlet Process Gaussian Mixture Model clustering algorithm; (b) Detecting links between known nodes is done via link transit frequency; (c) Node attributes to characterize a node are obtained via simple features; (d) Link attributes to characterize each link are tackled via Markov Logic Networks that discover conditional link transitions; (e) Link structure is inferred from node attributes and vice versa via Neighborhood Based Attribute Prediction; and (f) Decomposing a detected network into smaller

Return to Contents

networks is solved via spectral analysis partitioning. Experimental results are presented for each solution technique, and those are used to discuss issues for each problem part and its solution technique. Most of the experiments used GPS tracks (536 taxi cabs in San Francisco over 25 days) as a realistic stand-in for WAMI track data. The node detection experiments use that and also a small set of WAMI tracks. The Markov Logic Network experiment uses simulated data.

8062-36, Session 4

Bio-inspired UAV routing, source localization, and acoustic signature classification for persistent surveillance

J. A. Burman, Teledyne Scientific Co. (United States); J. P. Hespanha, U. Madhow, D. J. Klein, 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 and the Army Research Lab is developing technologies in support of automated data exfiltration from heterogeneous battlefield sensor networks to enhance situational awareness. Uninhabited air 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 were used to reduce the system reaction time by generating autonomous collection routes that are data-driven. Bio-inspired techniques for search provide a novel strategy to detect, capture and fuse data. A fast and accurate method has been developed to localize an event by fusing data from a sparse number of UGSs. This technique uses a bio-inspired algorithm based on chemotaxis or the motion of bacteria seeking nutrients in their environment. A unique acoustic event classification algorithm was also developed based on using swarm optimization. Additional studies addressed the problem of routing multiple UAVs, optimally placing sensors in the field and locating the source of gunfire at helicopters. A field test was conducted in November of 2009 at Camp Roberts, CA. The field test results showed that the system can detect and locate the source of an acoustic event with very high accuracy. In nine independent test runs of a UAV, the system located the position of an explosion nine times with an average accuracy of 3 meters. The time required to perform source localization using the UAV was on the order of a few minutes.

8062-38, Session 4

A Bayesian formulation for auction-based task allocation in heterogeneous, multi-agent teams

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 algorithms scale well because agents generally only need to communicate bid information. In addition, the agents are able to perform their computations in parallel and can operate on local information. Furthermore, it is easy to integrate humans and other vehicle types and sensor combinations into an auction framework. However, standard auction mechanisms do not explicitly consider sensors with varying reliability. The agents' sensor qualities should be explicitly accounted. Consider a scenario with multiple agents, each carrying a single sensor. The tasks in this case are to simply visit a location and detect a target. The sensors are of varying quality, with some having a higher probability of target detection. The agents themselves may have different capabilities, as well. The agents use knowledge of their environment to submit cost-based bids for performing each task and an auction is used to perform the task allocation. This paper discusses techniques for including a Bayesian formulation of target detection likelihood into this auction based framework for performing task allocation across multi-agent heterogeneous teams. Analysis and results of experiments with multiple air and ground systems performing distributed target detection are also included.

8062-39, Session 4

Sensor and information fusion for enhanced detection, classification, and localization

M. V. Scanlon, W. D. Ludwig, U.S. Army Research Lab. (United States)

The U.S. Army Research Laboratory (ARL) has concluded research associated with the Sensor & Information Fusion for Improved Hostile Fire Situational Awareness Army Technology Objective, Research (ATO-R). The joint effort was led by ARL with the Armaments and the Communications & Electronics Research, Development, and Engineering Centers (CERDEC and ARDEC) partners. The ATO culminated with the Capstone Experiment demonstrating the attainment of its research goals to detect hostile fire (subsonic, supersonic, and suppressed small arms, mortars, rockets, RPGs, missiles, and IEDs) events and hostile human activities providing solutions before, during, and after the events; improved sensor networking technologies; and developing multi-modal time diverse data fusion/analysis and effective dissemination techniques of resultant actionable intelligence.

The Capstone Experiment successfully demonstrated a diverse modality of sensors, performance characteristics and sensor fusion benefits, while gathering useful data for future development of ad hoc networking, fusion, and enhanced human factures for dissemination actionable intelligence. These diverse sensor data sets include UV, IR, retro-reflection, visible, glint, LADAR, radar, acoustic, seismic, E-field, and narrow-band emission technologies using mult-modal platforms - small robot, UAV, UGS, manned ground vehicles, helicopter, and soldier-worn. Real time collection and fusion of this sensor data demonstrated distinctive image processing and networking techniques that reduced false positives and provided constant multi-modal surveillance of the battle space, improving both awareness and actionable intelligence. These results provided high confidence detections and accurate grid coordinates of threat location information that was disseminated to tactical commands and operational personnel, ultimately improving strike force efficiency and force protection effectiveness.

8062-21, Session 5

The effects of synthetically augmented training data on parameter tuning for anomaly detection algorithms

J. Natarian, L. Lightfoot, E. Laubie, Air Force Research Lab. (United States)

While many years of research have been dedicated to anomaly detection algorithms and their applications, little research has been devoted to the act of tuning parameters to perfect the performance of these algorithms. This paper investigates three anomaly detection algorithms (Local Outlier Factor, wavelet decomposition, and a simple sliding threshold) and the effect of synthetically augmented training data on the resulting false positive and false negative rates. Four datasets were developed by injecting varying quantities of synthetic anomalies (0.1%, 1%, 5% and 10%) into naturally sampled light sensor data collected from a wireless sensor network. A five-fold cross validation method was implemented for training and testing with the results of each training set applied to all four test sets. The false positive and false negative rates, the traditional accuracy, and the geometric means were analyzed to

determine the relationship of the number of anomalies assumed to occur in a test environment, the number of anomalies that actually occur in the environment, and the resulting performance of the anomaly detection algorithms.

8062-22, Session 5

Strategy for wireless integration into U.S. Army tactical networks

F. R. Carlson, U.S. Army Battle Command Battle Lab.-Gordon (United States)

Technology, much of it open source, is increasing rapidly. One of the largest gaps is the technological gap between commercial and tactical wireless systems. The increasing gap between DoD and Commercial Industry wireless is already significant from a Data Rate Perspective. The gap is very likely much more profound if you were also to compare relative software development environments for modern wireless applications. A gap that the Army is attempting to close with initiatives like the “Apps for the Army” challenge-a program aimed at accelerating the creation of new and improved Web and mobile applications for use across the Army.

Horizontal integration is critical to create a cellular network that allows the warfighter to function. This is an extremely difficult task as the pressures to create “islands” of cellular capability are significant. Further with cellular and to a lesser extent wireless, it is not as straightforward from a technical perspective to enlist the IP protocol to solve our interoperability problems. The cellular, wireless and application development standards require much more definition as to what standards should be used across the tactical network. If those standards are not set as a horizontal framework you will see even more painful integration issues than the Army is facing with IP. The strategy that we lay out here assumes that a “Black Core” has been built around EoIP standards and that this core can accommodate different levels of data classification and encryption.

This paper and presentation will propose current and future ways ahead to allow the Army to have a standardized and integrated infrastructure to meaningfully integrate modern cellular and wireless applications based on commercial standards.

8062-23, Session 5

Potential game models for efficient resource allocation in wireless networks

Y. B. Reddy, Grambling State Univ. (United States)

Spectrum has become a scarce resource due to inefficient allocation and management associated with the increasing demand for wireless and data transfer requirements. Recent research efforts have been diverted towards dynamic spectrum access models for efficient utilization of the unused or idled spectrum. The models include enhancing overlay/underlay techniques by designing a framework to enhance spectrum efficiency, use business modes, and game theoretical models [1-6]. Surveying of these models conclude that the key component for efficient utilization of the unused spectrum is the detection of the unused spectrum at any given time. Further, the unused spectrum can be detected using appropriate techniques including business, game, and/or hybrid models. Recently, game theory has been identified as powerful mathematical tool to detect the unused spectrum and maximize the allocation of detected resource. Therefore, the game models will improve the performance by detection and allocation of the unused or underused spectrum. The spectrum utilization will be increased by:

a) Maximum utilization of unused spectrum through appropriate models including: game, stochastic, business, or other mathematical models

b) Develop the algorithms to access the unused spectrum

c) Using models in (a), share the unused licensed band by cognitive (agile) users

To achieve the maximum utilization of the unused spectrum we need to allocate the transmission power with tolerable noise and interference which otherwise leads to minimum bit error rate.

In this paper, we discussed the required game theory and possible game models for efficient utilization of the spectrum. Further, we derived that game theory technique, particularly potential game models, yield the optimal solution in detecting the unused spectrum and opportunistic access of the unused spectrum. The simulation results show that potential game models yield the optimal solution in detecting and allocating the unused spectrum in an optimal manner.

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8062-24, Session 5

Fast detection of network intrusion

X. Chen, E. L. Walker, Southern Univ. and A&M College (United States)

In this paper, we propose a network intrusion detection technique which promptly detects malicious attack and thus lower the resulting damage. Such technique is especially suitable for detecting attackers routinely perform random ``portscans” of IP addresses to find vulnerable servers to compromise. Our technique is developed based on the most efficient sequential methods of hypothesis testing. Our approach rigorously control the probability of falsely implicating benign remote hosts as malicious. Multistage estimation procedures are proposed for the evaluation of the performance of our technique and existing methods.

8062-25, Session 5

Analyzing the requirements for a robust security criteria and management of multilevel security in the clouds

B. S. Farroha, U.S. Dept. of Defense (United States) and The Johns Hopkins Univ. (United States); D. L. Farroha, U.S. Dept. of Defense (United States)

The new corporate approach is migrating from the in-house or a service-based framework to the newly coined approach of Cloud Computing. This approach advocates thin clients and provides services through the service provider over time-shared resources. The concept is not new, however the implementation approach presents a strategic shift in the way organizations run their IT resources. The requirements on some of the data sets targeted to be run on the cloud vary depending on the data type, originator, user, and confidentiality level. Additionally, the systems that fuse such data would have to deal with the classifying the product and clearing the computing resources prior to allowing new application to be executed. This indicates that we could end up with a Multi-level security system that needs to follow specific rules and one that can send the data output to a protected network and systems in order not to have a data spill or contaminated resources. This paper will discuss these requirements and potential impact on the cloud architecture. Additionally, the paper will discuss unplanned advantages of the cloud framework in providing a sophisticated environment for information sharing and data mining.

8062-26, Session 5

A novel approach to implementing a comprehensive digital policy management as an enabler for dynamic secure information sharing

B. S. Farroha, Northrop Grumman Electronic Systems (United States); D. L. Farroha, U.S. Dept. of Defense (United States)

The method by which we have been approaching policy in many systems is by manually translating laws and regulations into an information technology enabled language. In other words, we have created system commands for the routers, bridges, firewalls to force data transfers and data/system access to comply with the current laws and to protect private and confidential information. As rules change and threat levels change, the system administrators have to manually change the access based on credentials, roles and data classes. The need has been established to have an automated digital policy extraction from all the laws and implantations according to the threat level on an individual access point or network. Automated Audit and Privilege Management will aid in selecting the appropriate action in response to a user or system request.

The comprehensive approach that Enterprise Security Management (ESM) takes to ensuring the 10 ESM components interact with each other effectively to secure the enterprise is a critical component of any Enterprise management service. The paper will describe the 10 ESM components and concentrate on the automation of digital policy within the information domain to ensure equal implementation by independently fielded systems and ensures connected systems a transparent level of security.

8062-27, Session 5

Agile enterprise development framework: utilizing services principles for building pervasive security in the enterprise

D. L. Farroha, U.S. Dept. of Defense (United States); B. S. Farroha, Northrop Grumman Electronic Systems (United States)

The continuously changing needs of Information Systems to accomplish new tasks quicker and be able to change the operational and protection posture to counteract the perceived threats is a challenge that has not been adequately addressed. Many systems have been tasked to run different data sets than what they were originally designed for and they had to interact with multiple new systems that were not considered during the design phase. We have devised a new process that takes agility into a new realm where the product will built to work in a service-based environment but developed using an agile process. The two criteria promise to save development effort, but they contradict each other in philosophy where Services require stable interfaces and Agile focuses on being flexible, tolerating changes up to much later stages in the development. The proposed framework focuses on a process that takes advantage of both philosophies to produce a methodology that capitalizes not only on both viewpoints but also allows security to be integrated from the beginning.

8062-28, Session 5

Single-ended IP roaming solution for dynamic network reconstruction

J. S. White, A. W. Pilbeam, J. McCoy, Everis, Inc. (United States)

Today's networks must maintain functionality in an ever increasing threat environment. To date, much of the PDR (Protection, Detection, Reaction) mechanisms have focused on technologies to defend systems while maintaining consistent network presence. In this paper we discuss a dynamic network schema wherein system protection is accomplished through a unique implementation of IP roaming. This method is shown to mask a system on a network undergoing various types of attacks while maintaining connectivity with trusted clients. Additionally, this method allows for new clients to associate without heavy authentication or knowledge of the remote systems IP Roaming status. This paper will show the advantages of implementing this unique method of IP roaming with the goal of minimizing system overhead and maximizing sustained connectivity.

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8063-01, Session 1

Video scrambling for privacy protection in video surveillance: recent results and validation framework

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Privacy protection is quickly becoming a very central issue in video surveillance. While video surveillance can help repress crime and terrorism, hence benefiting the society, the widespread use of security cameras has led to well documented forms of abuse.

The perspective of forthcoming powerful video analytics tools, combined with pervasive networks of dense cameras is further raising the threat of privacy loss. Fortunately, recent research results have shown that new technologies are emerging with the potential to effectively protect privacy, without hampering video surveillance tasks. These results challenge the common conjecture that increased security should incur a loss in privacy.

Face recognition techniques pose the threat to automatically identify people in a video surveillance scene. However, thorough performance analysis is still lacking. In particular, it is paramount to validate proposed privacy protection solutions against user and system requirements for privacy. Moreover, it is still unclear whether current privacy protection approaches can be efficiently integrated into existing surveillance architecture and deployed in large scale systems.

In this paper, we first review some efficient region-based video scrambling techniques to hide privacy-sensitive information. We then introduce a framework to assess the capacity of privacy protection solutions to hide distinguishing facial information and to conceal identity. For this purpose, we evaluate the performance of face recognition algorithms applied to images altered by privacy protection techniques. By performing extensive and comprehensive experiments, we show the ineffectiveness of naïve privacy protection techniques such as pixelization and blur. Conversely, we demonstrate the effectiveness of more sophisticated scrambling techniques to foil face recognition.

8063-02, Session 1

Ensuring security of H.264 videos by using watermarking

M. Chaumont, Lab. d'Informatique de Robotique et de Microelectronique de Montpellier (France)

Watermarking is known to be a very difficult task. Robustness, Distortion, Payload, Security, Complexity are many constraints to deal with. When applied to a video stream, the difficulty seems to be growing in comparison to image watermarking. Many classical non malicious manipulations of a compressed stream may suppress the embedded information. For example, a simple recompression of a DVD movie (MPEG2 compression) to a DivX movie will defeat most of the current state-of-the-art watermarking systems.

In this talk, we will expose the different techniques in order to watermark a video compressed stream. Before, we will present the H.264/AVC standard which is one of the most powerful video-compression algorithms. The discussion about video watermarking will be illustrated with H.264 streams. The specific example of traitor tracing will be presented. Deadlocks will be discussed, and then the possible extensions and the future applications will conclude the presentation.

8063-03, Session 1

Novel technology for enhanced security and trust in communication networks

A. Milovanov, L. Bukshpun, R. Pradhan, T. Jannson, Physical Optics Corp. (United States)

A novel intelligent technology has been developed to significantly enhance security and trust in communication networks. Technology is based on integration of a novel encryption technique and novel data packet structure with enhanced security tools. A novel data packet structure and encryption technique allow avoiding all additional data/key encryption, resulting in an unprecedented level of protection against cyber attack that has been a nearly impossible and very expensive task for conventional communication methods. Developed technology also provides a new trust management feature and detection and classification of cyber attack at the node level. Being employed in communication networks it provides them with in-built intelligent futures such as self-building, self-awareness, self-configuring, self-healing, self-protecting capabilities. As a result, networks are able to detect any attempts of intrusion and unauthorized access, evaluate network node trust level, dynamically reconfigure/self-heal and protect themselves against cyber attacks providing secure and seamless operation.
In addition, developed approach reduces power consumption and computing/communication overhead in networks. Novel technology can be incorporated into any wireless or wired network that require enhanced security and trust extended to end node and also can be applied for secure data storage.

8063-04, Session 1

System for nondisruptive high-capacity indexed data embedding and recovery using multimedia signal covers

J. C. Collins, The Univ. of Texas at San Antonio (United States)

Over the past several years there has been an apparent shift in research focus in the area of digital steganography and steganalysis - a shift from primarily image based methods to a new focus on broader multimedia techniques. We introduce a new high capacity, covert channel data embedding and recovery system for digital multimedia carrier files using a key based encoding and decoding method. It will be shown that the added information file is interleaved within the carrier file and is fully indexed allowing for segmented extraction and recovery of data at chosen start and stop points in the sampled stream. The original multimedia quality is not affected by the addition of this covert data. The embedded information is also secured by a binary key string and cryptographic algorithm and resists statistical analytic detection attempts. We will also describe how this new method can be used for data compression and expansion applications in the transfer and storage of digital multimedia to increase the overall data capacity and security.

8063-05, Session 1

Establishing trust in decentralized smart sensor networks

H. Vagts, T. Cosar, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Smart sensors can gather all kind of information and process it. Cameras are still dominating and smart cameras can offer services for face recognition or person tracking. To cover a larger area, to save costs and to add more and different sensors, operators build collaborations. Cryptographic methods can achieve integrity and confidentiality between operators, but not trust. Even if a partner or one of his sensors is authenticated, no statements can be made about the authenticity of the sensor data or its quality. Hence, trust must be established between the partners and in their sensors.

Trust can be built based on past experience. A reputation system collects opinions of operators about the behavior of sensors and calculates trust based on these opinions. Many reputation systems have been proposed, e.g., for authentication of files in peer-to-peer networks.

This work presents a new reputation system, which is designed to calculate the trustworthiness of surveillance systems and the authentication of sensor data. A new trust model, including algorithms to calculate and update trust on past experiences, is proposed, as well as protocol for exchanging recommendations. When fusing information of multiple sensors for a surveillance task, it cannot always be reconstructed, which information led to a bad result. Hence, an approach for fair rating is shown. The proposed system has been realized in a Service Oriented Architecture for easy integration in existing surveillance systems. The model itself can be used in every decentralized heterogeneous sensor network.

8063-06, Session 2

An adaptive LMS technique for wavelet polynomial threshold denoising

D. Akopian, S. G. Sathyanarayana, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

Wavelet transforms have been successfully applied for denoising, classification, recognition,compression, and other applications for a number of years. Recently we introduced a new class of polynomial threshold operators for denoising signals using wavelet transforms. The operators are parameterized to include classical soft-and hard-thresholding operators and have many degrees of freedom to optimally suppress undesired noise and preserve signal details. To avoid the complicated process of signal model identification for specific type of signals, a least squares optimization method was proposed for the polynomial coefficients.

In this paper we apply an new adaptive approach to optimize polynomial thresholds for wavelet denoising and apply this approach for the processing of microscope imagery. Biomedical images are the predominant non invasive diagnostic tool for medical and health professionals. They are essential in the detection and treatment of an enormous variety of illnesses, as well as being essential in the process of studying various ailments and the effects that drugs and chemicals have on the respective pathogens at a cellular hence microscopic level.

The noise in biomedical images can occur through inefficiencies in the imaging process itself, through physiological interference, or a number of other sources and is a hindrance to an effective diagnosis of illnesses.

In prior work, the estimation of wavelet thresholding operators has been optimized using MMSE criteria. In this paper we derive and apply an adaptive least mean square solution (LMS) which drastically reduces computational costs. Then we apply the approach for improving the quality of low resolution microscope imagery.

8063-07, Session 2

Accuracy, security, and processing time comparisons of biometric fingerprint recognition system using digital and optical enhancements

S. Alsharif, A. M. El-Saba, Univ. of South Alabama (United States)

Fingerprint recognition is one of the most commonly used forms of biometrics and has been widely used in daily life due to its feasibility, distinctiveness, permanence, accuracy, reliability, and acceptability. Besides cost, issues related to accuracy, security, and processing time in practical biometric recognition systems represent the most critical factors that makes these systems widely acceptable. Accurate and secure biometric systems often require sophisticated enhancement and encoding techniques that burdens the overall processing time of the system. In this paper we present a comparison between common digital and optical enhancementencoding techniques with respect to their accuracy, security and processing time, when applied to biometric fingerprint systems.

8063-08, Session 2

Arabic handwritten baseline estimation, slope correction, and document segmentation into sub-words

M. Maliki, S. A. Jassim, H. Sellahewa, N. Al-Jawad, Univ. of Buckingham (United Kingdom)

Pre-processing and segmentation have played a vital role in the performance of OCR systems and form crucial stages for handwritten/typed text recognition. This paper is concerned with these stages for Arabic text recognition and propose and test the performance of a number of new approaches to deal with these tasks. We first consider the pre-processing needed for baseline estimation, and slope correction. Linear regression is applied to average x-coordinates, y-coordinates, and the part of words that has high density. We then use multi rotation procedures, by rotating word 20°. The maximum vertical and horizontal will determine the peak angle.

Instead of segmentation document into lines, words, and characters, through depending on a seed fill strategy the second proposed algorithm works on segmenting whole document into sub words. These sub word could be segmented, in necessary, into characters. This algorithm also solves the problem of overlapping that occurs between words and subwords. This results in reduced amount of segmentations and leading to improved time complexity.

We shall demonstrate the great benefits from our proposals by conducting and analysing the results of extensive testing experiments on appropriate known and in-house databases.

8063-09, Session 2

Remote object authentication against counterfeiting using elliptic curves

J. Lancrenon, R. D. Gillard, Univ. Joseph Fourier (France); T. Fournel, Univ. Jean Monnet Saint-Etienne (France)

This paper aims to provide a remote morphometric object authentication protocol dedicated to anti-counterfeiting applications. The security model is presented. The suggested scheme is based on an Elliptic Curve Cryptography (ECC) encryption adding a mechanism to control integrity at the verification stage. The main new point is a Private nformation Retrieval scheme in the protocol to assure the privacy constraint useful in many applications.

The work in this paper is a follow-up to an article that appeared in the proceedings of the SPIE: Defense Sensing and Security 2009 conference, vol 7344, by the same authors, and in which a procedure to remotely authenticate objects in a secure manner for anti-counterfeiting purposes is given. In this document, we propose a new procedure to accomplish the same task while eliminating major computation problems. Specifically, we are able to lower the size of the random numbers that need to be chosen by the reader. This is done via the use of a standardized encryption scheme and a private information retrieval scheme. Elliptic curve methods are still used here to lower cryptographic key lengths.

Both the previously mentioned paper and this one describe cryptographic protocols that remotely authenticate an object O using its morphometrics, an analog for the biometrics of an individual. A trusted authority AS (e.g. the manufacturer) attributes a unique system-dependant ID to O which it prints on O, and extracts from O a reference morphometric bitstring f that is stored in a database DB at an index easily derived from ID. The object is then released. To remotely authenticate O in a hostile environment, an entity reads ID on O and extracts from O a new morphometric template f' by using an optical reader R. This reader then connects to the server AS allowing a comparison of f and f', and a decision is taken based on how close these two bitstrings are.

Both protocols provide message integrity against all outside attackers, and confidentiality against all outside attackers and certain inside attackers. This is proven true in a theorical security model based on mathematical assumptions made on the considered adversaries.

8063-47, Session 2

Maximizing gain to time-cost of human-machine interactive decision-making under asymmetrical time constraints

H. Sasaki, Ritsumeikan Univ. (Japan) and Keio Univ. (Japan)

The continued growth of time-critical mobile/image processing demands real-time solutions supporting human-machine interactive decision-making.

Its typical devices are body scanners and strike weapons.

Those devices are designed to make decisions without human interruption but sometimes implemented with a process of human decision-making for safety reasons.

That time-critical and interactive process should take into account time-cost, i.e. the value of time it takes to select proper actions.

A typical approach to the problem of time-cost is found in stopping criteria which are based on certain heuristics derived from empirical studies of human behaviors.

The approach of heuristics however lacks its rational representation of time-cost but just applies a psychological anchor of human behaviors or the finding in a process of trial and error as a reliable or reasonable solution.

Our approach to the problem of time-cost is its explicit representation as measured in terms of gain or outcome obtained in decision-making.

The gain-based representation of time-cost allows no reference to external circumstances beyond internal factors of decision-making.

Our arithmetic representation of time-cost locates two points maximizing gain to time-cost under asymmetrical time constraints.

Those points accelerate decision-making by 1.5 times rather than the solutions derived from heuristics though human-machine interaction is inevitably accompanied with some delay between events and actions by humans.

We build a non-linear model of human-machine interaction reflecting delay of human response to events.

We operate a computer simulation of our approach based on the model that leads to significant improvements in the stopping criteria for time-critical decision-making.

8063-10, Session 3

Smart compression using high-dimensional imagery

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

We present a method for the disadvantaged user (Warfighter remotely carrying low bandwidth devices), featuring “smart” compression of high dimensional imagery from passive hyperspectral (HS) sensors. As noted, bandwidth demand in current battlegrounds continues to increase owing to the rapid advances in sensory technology; it now can provide enormous quantities of data to support intelligence analysis. This is particularly true for HS sensors, since a data cube usually requires greater than an order of magnitude memory space compared to broadband imagery of the same scene. HS imagery provides both spatial and spectral information, where different materials (e.g., motor vehicle paints, vegetation) produce different spectral responses. These differences are exploited through target and anomaly detection algorithms. The proposed method uses the application of anomaly detection closer to the sources, transmitting only the essential information (spectral anomalies) to the user for further analysis. The method's uniqueness relies on a random-sampling, binomial distribution model of a parallel process designed to mitigate the likelihood that samples of targets (specific materials) are erroneously used as non-target spectral references for testing. The model's single free parameter is invariant to target scale, target shape, and number of targets in the scene. The detection scheme has many advantages over existing anomaly detectors, including (i) no prior imagery segmentation requirement, (ii) little sensitivity to its free parameter, and (iii) no prior knowledge of targets' spatial scales. We show that the proposed method is suitable for smart compression and that experimentation results are promising for a variety of difficult scenarios.

8063-11, Session 3

Multitemplate image matching using alpha-rooted biquaternion phase correlation with application to logo recognition

S. P. DelMarco, BAE Systems (United States)

Hypercomplex approaches are seeing increased application to signal and image processing problems. The use of multi-component hypercomplex numbers, such as quaternions, enables the simultaneous co-processing of multiple signal or image components. This joint processing capability can provide improved exploitation of the information contained in the data, thereby leading to improved performance in detection and recognition problems. In this paper, we apply hypercomplex processing techniques to the logo image recognition problem. Specifically, we develop an image matcher by generalizing classical phase correlation to the biquaternion case. We further incorporate biquaternion Fourier domain alpha-rooting enhancement to create Alpha-Rooted Biquaternion Phase Correlation (ARBPC). We present the mathematical properties which justify use of ARBPC as an image matcher. We present numerical performance results of a logo verification problem using real-world logo data, demonstrating the performance improvement obtained using the hypercomplex approach. We compare results of the hypercomplex approach to standard multi-template matching approaches.

8063-12, Session 3

Parallel design patterns for a low-power, software defined compressed video encoder

M. W. Bruns, M. A. Hunt, Coherent Logix, Inc. (United States); N. R. Gunupudi, S. Sonachalam, Parallel Prisms (United States)

Video compression algorithms such as H.264 or MPEG-2 include much potential for parallel processing that is not always exploited by the technology of a particular implementation. Consumer mobile encoding devices often achieve real-time performance and low power consumption through parallel processing in Application Specific Integrated Circuit (ASIC) technology, but many other applications require a software defined encoder. High quality compression features needed for some applications such as 10 bit sample depth or 4:2:2 chroma format often go beyond the capability of a typical consumer electronics device. An application may also need to efficiently combine compression with other functions such as noise reduction, image stabilization, real time clocks, GPS data, mission/ESD/user data or software defined radio in a low power, field upgradable implementation.

Low power, software defined encoders may be implemented using a massively parallel processor array with 100 or more cores and distributed memory. The large number of processing elements allow the silicon device to operate more efficiently than conventional DSP or CPU technology. A dataflow programming methodology may be used to express all of the encoding processes including motion compensation, transform and quantization, and entropy coding. This is a declarative programming paradigm in which the parallelism of the compression algorithm is expressed as a hierarchical graph of tasks with message communication. Data parallel and task parallel design patterns are supported without the need for explicit global synchronization control.

An example is described of an H.264 encoder developed for a commercially available, massively parallel processor device.

8063-13, Session 3

A fast, efficiency-preserving system for simultaneous compression and encryption

R. Metzler, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

Mounting data traffic over information networks such as the Internet is adversely effecting the cost and expediency of data files. To mitigate this traffic, data compression is used to accurately represent files within the fewest bits possible. However, many organizations provide content to a select user database and must secure this content against unwanted eavesdroppers. Thus, for many applications - e.g., media distribution, confidential transmission, video surveillance, and other military and medical applications - files must be encrypted before they are transmitted. Because encryption hides the redundancies within a data set, compression after encryption is not effective, and a file cannot be sent efficiently. We present a coding solution which simultaneously compresses and encrypts digital data through implementation of a key-dependent compression algorithm. This algorithm minimizes computational cost and provides a theoretically secure encryption without compromising the optimal compression ratio.

8063-14, Session 4

Real-time and location-secured multifactor biometrics for mCommerce authentication

T. Kuseler, H. Al-Assam, I. A. Lami, S. A. Jassim, Univ. of Buckingham (United Kingdom)

Secure connectivity between mobile devices and financial/commercial providers is mature, and so is the security of biometric authentication for mCommerce. However, the current techniques are open for hacking, false/misrepresentation, replay and other attacks because of the lack of real-time and current-precise-location authentication in the biometric process. This paper proposes a new technique that includes freshly-generated real-time personal biometric data and present-position of the mobile device used to perform the mCommerce to form a one-time multi-factor biometric representation to authenticate the transaction. A fresh GPS fix generates the “time and location” to stamp the biometric data capture to produce a single multi-factor biometric representation on the mobile device. The authenticator, then, independently & at that instant, collects the mobile device “time and location” from the cellular network so to compare with the received information, together with the user’s stored biometric information.

8063-15, Session 4

Block error correction codes for face recognition

W. R. Hussein, H. Sellahewa, S. A. Jassim, Univ. of Buckingham (United Kingdom)

Face recognition is one the most desirable biometric-based authentication scheme to control access to sensitive information/ locations and as a proof identity to claim entitlement to services. The aim of this paper is to develop block-based mechanisms, to reduce recognition errors that result from varying illumination conditions with emphasis on using different types of error correction codes. We investigate the modelling of error patterns in different image subdivisions as a result of differences in illumination conditions, and we use appropriate error correction codes to deal with the corresponding distortion. We test our proposed schemes using Extended Yale-B Face Database, which consists of face images belonging to 5 illumination subsets depending to the direction of light source from the camera. In our experiments each image is divided into four horizontal regions as following: region1 above the eyebrows, region2 eyebrows and eyes, region3 nose region and region4 mouth and chin region. By estimating statistical parameters for errors in each region we select suitable error correction codes that yields improved recognition accuracy for that particular region in comparison to applying error correction codes on the entire image. Discrete Wavelet Transform (DWT) is used for face feature extraction, followed by local/global binarization. Subdividing each of four regions into local blocks is also considered. This paper designed to performance of a face identification scheme.

8063-16, Session 4

Estimation of the head pose based on monocular images

Y. Yari, J. Scharcanski, Univ. Federal do Rio Grande do Sul (Brazil)

Head pose estimation is understood as detecting the head orientation in 3D space with respect to a reference. The head pose and the head movements can provide some information about the person and his/her actions, which is important in surveillance applications. Some authors have suggested to estimate the head pose in video sequences by tracking the head orientation in 3D, and some other authors proposed to estimate the head pose working directly with 3D scans of a head. However, monocular head pose estimation still is challenging. This paper presents a new method to compute the head pose in monocular images by comparing the positions of specific facial features with the positions of these facial features in multiple instances of a prior 3D face model. Given an image containing a face, we locate facial features such as nose, eyes, and mouth. Then these 2D feature locations are used as references in the comparison with the corresponding feature locations in multiple instances of our 3D face model, projected on the 2D image space. To estimate the depth of these feature points, we use the 3D spatial constraints imposed by our face model (e.g. eyes are at a certain depth with respect to the nose, and so on). The head pose is estimated by minimizing the comparison error between the face feature locations in the image and in a given instance of the face model. Our preliminary experimental results are encouraging, and suggest that our approach potentially can provide accurate results.

8063-17, Session 4

A design of smart robot for human identification

Z. Zhou, E. Y. Du, Indiana Univ.-Purdue Univ. Indianapolis (United States); E. J. Delp III, Purdue Univ. (United States)

Humans have always dreamed to have human-like robots. However, one of the biggest challenges is for a robot to perform accurate human identification in real-life scenarios. In robot vision, the acquired data is often noisy with low resolution and significant motion/blurry effects. Existing identification algorithms are either not sophisticated enough to work on real-life scenarios, or are too complicated to performe in real-time. In this paper, we design a smart robot for human identification that can recognize people accurately using on-board processors. In this paper, we propose a multimodal non-cooperative biometrics system

including face, iris and sclera to increase the recognition accuracy of our proposed robot.

8063-18, Session 4

A new approach for willingness test in biometric systems

K. Yang, E. Y. Du, Indiana Univ.-Purdue Univ. Indianapolis (United States)

Biometrics identifies/verifies a person using his/her physiological or behavioral characteristics. It is becoming an important ally for law enforcement and homeland security. However, there are some safety and privacy concerns: biometric based systems can be accessed when users are under threat, reluctant or even unconscious states. In this paper, we build a robot which can identify a person and detect his/her willingness. Our experimental results show that the new approach can enhance the security by checking the consent signature while achieving very high recognition accuracy.

8063-19, Session 4

Unsupervised tattoo segmentation combining bottom-up and top-down cues

J. D. Allen, Harris Corp. (United States)

Tattoo segmentation is significantly different from traditional semantic object segmentation in spatial distribution, the shape of each component and varying background. A tattoo with unknown number of components with arbitrary spatial distribution and irregular shapes is difficult to be distinguished from the varying background via any prior on location or shape of tattoo. Thus we have developed an unsupervised segmentation framework for finding tattoos in an image. Our basic idea is split-merge: split each tattoo image into clusters through a bottom-up process, learn to merge the clusters containing skin and then distinguish tattoo from the other skin via top-down prior in the image itself. In the bottom-up process, we begin by applying an initial clustering process on the gray-scale distribution of the image so as to obtain an initial segmentation. The pixels with intensity values between either two closest local minima of such distribution are labeled as a cluster. In the top-down process, given two properties of tattoo image, a sample patch in the center of image is sampled for obtaining prior knowledge for skin and tattoo. With such priors, clusters covering the major area of the sample patch are merged together as skin and tattoo while excluding the background. Tattoo segmentation with unknown number of clusters is therefore transferred to a skin-tattoo binary segmentation. A traditional kmeans algorithm (k=2) is applied for distinguishing tattoo from skin via one of the properties of tattoo image above. We have applied our segmentation algorithm on a tattoo dataset and the results have shown that our tattoo segmentation system is efficient, promising and suitable for further tattoo classification.

8063-20, Session 5

iPhone forensics: an overview

T. Höne, R. Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of this article is to give an state of the art overview on some useful tools for forensic investigation of iPhone 3G and iPhone 4.

It is demonstrated how important data stored in the iPhone are investigated.

Different cases of investigations are presented that are well-suited for a forensics lab work.

8063-21, Session 5

Automated detection of semagram-laden images using adpative neural networks

P. Cerkez, DCS Corp. (United States)

Digital steganography is gaining wide acceptance in the world of electronic copyright stamping. 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 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 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 be will discussed. This presentation is a follow up to last year's and provides the results of our research experiments.

8063-22, Session 5

Rapid prototyping of an automated video surveillance system: a hardware-software co-design approach

H. T. Ngo, R. N. Rakvic, R. P. Broussard, R. W. Ives, U.S. Naval Academy (United States)

Automated video surveillance is a rapidly evolving area in which hardware components are controlled by system intelligence rather than manual intervention. These systems allow more efficient and effective surveillance monitoring by employing intelligent video processing algorithms. As with many image processing applications, there is a need for high performance systems to support real-time automated video surveillance. In recent years, new generations of FPGAs with their inherently parallel digital signal processing (DSP) blocks, large number of embedded memory blocks and registers, and high-speed memory and storage interfaces have provided an attractive solution for video processing applications.

Developing video processing systems based on FPGA technology also has challenges such as implementing efficient memory and storage device controllers, interfacing with different video formats and lengthy debug and verification process. In this work, a hardware-software co-design approach is proposed to effectively utilize FPGA features for a real-time prototype of an automated video surveillance system. Time-critical steps of the video surveillance algorithm are designed and implemented in the FPGA's logic elements to maximize parallel processing. Other non time-critical tasks are achieved by executing a high level language program on an embedded Nios II processor. Pre-tested and verified video and interface functions from a standard video framework are utilized to significantly reduce development and verification time. Custom and parallel processing modules are integrated into the video processing chain by Altera's Avalon Streaming (Avalon-ST) video protocol. Other data control interfaces are achieved by connecting hardware controllers to a Nios II processor using Altera's Avalon Memory Mapped protocol.

8063-23, Session 5

System approach to steganalysis

J. D. Allen, Harris Corp. (United States)

We propose a system approach to steganalysis for reliably detecting steganographic objects among large number of images, where most of them do not contain stego messages. The system consists of a cascade of classifiers, where the classifiers in the early stage are designed to filter out non-stego images based on real world constraints and the classifiers in the late stage are designed to detect specific features of steganographic routines. As images taken by various cameras often have an associated meta data file (e.g., exif data), we use the verifiable attributes to check if they have been tampered. Verifiable attributes include the camera type, compression, white balance setting, and so on. For example, based on the camera type, we can check if the quantization table of a JPEG image has been modified; based on the white balance setting, we can check if the image satisfies the white balance constraints; if the editing software is specified, it can be used to check whether the editings are from standard image editing routines. These constraints give rise to classifiers that can detect modified images, which will be candidates to targeted steganalysis algorithms. The proposed approach allows us to maximally utilize the available constraints and lead to robust detection performance. Experimental results using images from flickr.com demonstrate the potential of the proposed approach.

8063-24, Session 5

Forensic investigation of mobile phones

S. Luttenberger, R. Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of this article is to show the usefulness of certain open source tools as well as commercial forensic tools for forensic investigation of modern mobile phones.

It is demonstrated how important data stored in the mobile device are investigated. Different scenarios of investigations are presented that are well-suited for a forensics lab work.

8063-25, Session 5

Video object trajectory perturbation-based data hiding

A. Cay, Old Dominion Univ. (United States)

A new steganographic algorithm for hiding data in the motion trajectories of Video Objects (VOs) is presented. First, a set of primitives (object's bounding-box coordinates and its centroid) are used to define a VO. The centroid of VO is tracked in each frame and its coordinate is stored in a trajectory vector. The proposed algorithm is quantization based in which the data are embedded in the VO object trajectory by presenting a relationship between the hidden and the trajectory data in the form of a motion drift or perturbation. To preserve semantic meaning of the motion the smoothness of the object motion is used as a constraint to determine the degree of trajectory perturbation. The perturbation resulting from quantization based embedding algorithm is implemented by motion compensating the pixels in the VO bounding box. Assessment of the steganographic algorithm is done by both subjective judgments based on the perceived quality of the perturbed video sequence and by some commonly used statistical steganalysis metrics. Both subjective assessments and statistical measures indicate visual and statistical invisibility of the proposed method.

8063-26, Session 5

On the novel space-time duality language of the latency information theory revolution, part I: the time-dislocation of the information-space uncertainty outputs of sources

E. H. Feria, College of Staten Island (United States)

The latency information theory (LIT) revolution is a nascent universal guidance theory for efficient system designs. The LIT revolution consists of four design quadrants, each discussed in detail in this four paper series. As design enablers LIT uses: 1) the universal guidance theory for communication source designs offered by information-theory; 2) certainty-motion-physics addressing the space-dislocation (SD) of the latency-time (LT) certainty matter or energy inputs of movers; 3) uncertainty-retention-physics addressing the time dislocation (TD) of the information-space (IS) uncertainty matter or energy outputs of retainers; 4) the thermodynamics of matter or energy; and 5) the structural-physical LT-certainty/IS-uncertainty dualities of communication and observation systems. In this paper the space-time duality language of the LIT revolution is reviewed for the time-dislocation of the information-space uncertainty matter or energy outputs of communication sources, and is illustrated with a simple engineering example. In particular, the bit-rate in bits/sec units of a source is defined as the product of TD-frequency (in bit-TD cycles per sec where bit-TD denotes the time duration of a bit) and TD-wavelength (in communicated bits per bit-TD cycle). It is then noted that for constant bit-TD and constant bit-effort the communicated source bit-rate unavoidably decreases as the bit to noise effort ratio decreases. Effort in SI Pa.sec units is the TD uncertainty-retention-physics dual of SD certainty-motion-physics work in SI N.m units.

8063-27, Session 6

Palmprint identification using FRIT

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The fundamental issue in palmprint verification is finding a proper feature descriptor and representation network to represent its overall structure and its line patterns. Physiological structure of palmprint consists of different types of features including principal lines, wrinkles and creases, and principal lines composed of heart line, head line and life line. In palmprint verification and identification, locations of these physiological features are important for individual. These principal lines and their shapes change little over time. It has been estimated that the wrinkles are much thinner than the principal lines and much more irregular. Palmprint verification and identification systems are proved to be a unique, reliable and robust biometric characteristic with high recognition accuracy. Quest for more reliable biometric systems with accurate performance, palmprint systems are attracted much public attention. Due to several advantages, such as non-intrusiveness, low-resolution imaging, user-friendly, low price palmprint devices and setup, stable and distinct features made palmprint systems more usable to users.

We propose a palmprint identification system using Finite Ridgelet Transform (FRIT) and Bayesian classifier. Prior to feature characterization, ROI (region of interest) is extracted from palmprint image with some standard palmprint localization algorithm and further FRIT is applied to ROI palm image. Since, wavelets are applied for denoising and compact approximations of images containing zero dimensional (point) singularities and wavelets are not able to isolate the smoothness along edges that occurs in images because lack of directionality. These shortcomings of wavelets are further addressed by the finite ridgelet transforms and they extend the functionality of wavelets to higher singularities. In this respect, palm image contains three principal lines and the texture of palmprint is more a like fingerprint image. Therefore to extract a set of more distinctive features from palmprint image, FRIT is found to be an effective method than wavelets. Finally, palmprints are

classified using Bayesian classifier. The proposed system is evaluated and tested with CASIA and IIT Kanpur palmprint databases. The experimental results are found to be encouraging and demonstrate the robust performance while the proposed system is compared with other existing systems.

8063-28, Session 6

A secure wavelet-based isometric projection for face recognition

H. Al-Assam, H. Sellahewa, S. Jassim, Univ. of Buckingham (United Kingdom)

Biometric systems such as face recognition must address four key challenges: efficiency, robustness, accuracy and security. Isometric projection has been proposed as a robust dimension reduction technique for a number of applications, but it is computationally demanding when applied to high dimensional spaces such as the space of face images. On the other hand, wavelet transforms have shown to provide an efficient tool for facial feature representation and face recognition with significant reduction in dimension. In this paper, we propose a hybrid approach that combines the efficiency and robustness of wavelet transforms with isometric projections for face features extraction in the transformed domain to be used for recognition. We shall compare the recognition accuracy of our approach with the accuracy of other commonly used projection techniques in the wavelet domain such as PCA and LDA. The security of biometric templates is addressed by adopting a novel lightweight random projection technique as an add-on subsystem. The results are based on experiments conducted on publicly available benchmark face databases.

8063-29, Session 6

A three-factor challenge/response approach for remote biometric authentication

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Although biometric authentication is known to be more reliable than traditional authentication schemes, it becomes vulnerable when it comes to remote biometric authentication over untrusted networks. This paper proposes a novel biometric-based challenge-response approach to be used for remote authentication between two parties A and B over open networks. In the proposed approach, a biometric system A challenges its client B who wants to authenticate his/her self to the system by sending a one-time public random challenge. The client B responses by employing the random challenge along with secret information obtained from a password and a token to produce a one-time cancellable representation of his freshly captured biometric sample. The one-time biometric representation, which is based on multi-factor, is then sent back to A. Here, we argue that eavesdropping of the one-time random challenge and/or the resulting one-time biometric representation does not compromise the security of the system, and leaks no information about the original biometric data. In addition to securing biometric templates, the proposed protocol offers a practical solution for the replay attack on biometric systems. We shall illustrate the effectiveness of the proposed approach by experimental results based on two biometric modalities: fingerprint and face biometrics. Security analysis shows the viability of the proposed approach to be used in real life applications.

8063-30, Session 6

Palmprint verification using Lagrangian decomposition and invariant interest points

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In the proposed palmprint verification system, we extract region of interest (ROI) from wide palm texture as square region and after that, we apply SIFT feature extraction technique on palmprint images, where only the ROI is considered for invariant SIFT keypoints extraction. Lagrangian decomposition is used for palm graph matching drawn on the extracted SIFT features. Each SIFT keypoint is considered as node or vertex of palm graph and the relation between pair of vertices is considered as edge. The palm graph matching is formulated as follows. Two palm graphs are given for the reference palm and probe palm. Now, finding a permutation matrix between two graphs is important to minimize the distance between two palm graphs. The obtained permutation matrix is a zero-one matrix whose rows and columns sum to one. Permutation matrix constraints are formulated quite naturally in the framework of deterministic annealing. The row or column constraints are winner-take-alls (WTAs). The graph matching distance allows us to express the combination of the distance measure and the permutation matrix constraint using Lagrange parameters. Finally, identity is established between target palm graph and probe palm graph. The experimental results computed on CASIA and IITK palmprint databases show the effectiveness and robustness of the proposed palmprint verification system while SIFT operator is used for feature extraction.

8063-31, Poster Session

SIFT-based feature level fusion of face, palmprint and fingerprint biometrics using log polar transform

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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.

8063-32, Poster Session

PreNotiS: a case study of a mobile disaster informatics framework

D. Akopian, M. Chan, A. Kumar, The Univ. of Texas at San Antonio (United States)

Disaster Informatics is the scientific discipline in the use of information and technology for the provision and preparation of crisis mitigation and handling. Event reporting aids in effective and expeditious quarantine, isolation and emergency evacuation as part of response and recovery phases of disasters and other emergencies.

The design of PreNotiS was designated to be in unison to the objectives of satisfying the current lack in many event reporting and disaster informatics systems. The underscore of this letter is to propose PreNotiS as a provision of trusted proxies of information sourcing to be integral to the disaster informatics framework.

The PreNotiS system had undergone a reconstruction for multiple-user scenario. To cater for multiple-users scenario it behooves a different architecture with different flow logic. This is also an enhancement over the previous protocol in terms of enhanced speed and economy. To promote loose coupling among subsystems, PreNotiS has evolved into a Model-View-Controller architectural pattern via Incremental Prototyping with Object-Orientation. The MVC specifies how all subsystems and how they interact with each other.

The enhanced PreNotiS was tested with a Test Suite which facilitates in the assurance of robustness in field operations. Similar self-test modules were inbuilt in the dual purposes of ascertaining the sanity of the system, as well as to alert for timely rectifications heightens the high assurance of system serviceability before the critical moment at the call of disasters.

8063-33, Poster Session

An interpolation filter based on wavelet polynomial threshold operators

D. Akopian, M. Chan, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

The heightening of processor computational power has made numerous robust and computationally complex algorithms possible for high image resolution interpolation with low feature corruption pertaining to edges and contours distortion. While in the conventional practice, common low computation methods, such as bilinear and bicubic interpolation, are used in the field. While more computational power required algorithms to improve the regularity of object boundaries in the generated images are in extant, the resolution of the recovered image is however limited.

Here, the paper presents the use of Polynomial Threshold Operators as a Wavelet-Denoising Interpolation Filter. Instead of finding the balancing act in trade-offs with the likelihood of systematically biased estimates in soft thresholding and poorer denoising performance of hard thresholding estimates.

8063-34, Poster Session

An image similarity measure using enhanced human visual system characteristics

S. C. Nercessian, K. A. Panetta, Tufts Univ. (United States); S. S. Agaian, The Univ. of Texas at San Antonio (United States)

Image similarity measures are crucial for image denoising, compression, and other image processing applications which require comparison to an ideal reference image to quantitatively assess algorithm performance. The Structural Similarity index (SSIM) is motivated by the fact that the human visual system is adapted to extract local structural information. It has shown to correlate with subjective human evaluations better than standard error metrics such as the mean squared error (MSE). Consequently, variants of the SSIM index such as the Gradient Structural Similarity index (GSSIM), the 4-component SSIM (4-SSIM) and 4-component GSSIM (4-GSSIM) are based on the fact that the human visual system is particularly sensitive to edges, and incorporate the image gradient information into the quality assessment process. These variants have yielded improved performance relative to the SSIM index particularly when quantitatively assessing blurry or noisy distortion types. In this paper, we propose a new measure which leveraging on the benefits of the proposed image similarity measures and enhances the gradient information used for quality assessment, thereby increasing the correlation of the objective evaluation with subjective human opinions. An analysis of the proposed image similarity measure using the LIVE database of distorted images and their corresponding subjective evaluations of visual quality illustrate the improved performance of the proposed metric.

8063-35, Poster Session

Remote laboratory architecture for radio-communications

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Today's graduating electrical engineers need marketable skills based on hands-on experimenting with electronic devices in design laboratories. Hands-on experiments help to efficiently digest theoretical concepts and relate those to practical tasks. However, dramatically increasing number of students, the shortage of costly equipment and human resources for laboratory maintenance and assistance decrease the implementation capacity of the hands-on laboratories.

Over the past decade, with the continued development of information technology the Internet has become a common media to enhance education. Apparently, Internet-based remote laboratories can resolve many constrains in providing hands-on training as can be used at flexible times and sharing the same equipment between different students. Thus they can serve as viable alternatives to the traditional hands-on laboratories. Such labs minimize expenses and will eventually provide limitless access to available experimentation resources. Unfortunately not all hands-on experiments can be implemented in remote settings - only PC-controlled parameters and characteristics can be changed for the studies which constraints the applicability of the concept e.g. in radio-communications.

This article describes a remote hands-on experimentation laboratory being developed at the University of Texas at San Antonio. It includes experiments in modulation, networking and applications. The core component is the remote lab architecture and server management system which are adapted to use various familiar networking media used by modern students, such as chat rooms and video streaming. These labs are being offered as training modules in a regular radio-communications class, and the paper presents survey results for assessing student satisfaction with the proposed concept.

8063-36, Poster Session

Image sequence enhancement based on alpha trimmed mean and histogram equalization

J. R. Figueroa, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

In this paper, we present a novel method for global image enhancement on image sequences. Unlike other forms of global image enhancement that use only information from a single slice, this algorithm utilizes information from neighboring slices in order to enhance details and edges in the current slice. In addition, we use a noise removal method that incorporates inverse histogram equalization to the alpha trimmed mean image. This is done by segmentation and histogram equalization in order to normalize the noise signal and using an alpha trimmed mean filtering technique to the segmented images. Computer simulation demonstrates the effectiveness of the developed algorithms. The performance of the algorithm is compared with other state of the art enhancement techniques and evaluated using a statistical image quality evaluation method.

8063-37, Poster Session

Empirical mode decomposition-based contrast enhancement for color images

S. Bakhtiari, S. S. Agaian, M. Jamshidi, The Univ. of Texas at San Antonio (United States)

Lighting in the images captured by an optical camera plays a key role in narrowing the dynamic range of the images. Improper or insufficient illumination results in a dark image, a very bright image or an image with varying brightness in different regions. Consequently, the details of the picture can be invisible in the original image. In this paper, we present an algorithm based on Empirical Mode Decomposition (EMD) to adjust the lighting and stretch the contrast in color images. In the proposed method the luminance channel of the color signal is decomposed into distinct frequency components called Intrinsic Mode Functions (IMFs) by EMD technique. Combination of chromaticity and enhanced luminance will generate an image with a higher contrast and uniform illumination. EMD is a fully data driven technique and has proved to be particularly efficient for non-linear and non-stationary signals. Hence, it demonstrates a higher performance compared to the other methods in real applications.

8063-38, Poster Session

Novel local enhancement algorithm with 3D weighted median filters for image sequences

S. S. Agaian, E. Silva, J. R. Figueroa, The Univ. of Texas at San Antonio (United States)

In this study, we consider a novel 3D local image enhancement algorithm for image sequences extended from a 2D algorithm presented in previous work. The algorithm separates high frequency components of an image via a cascaded unsharp masking technique which are then enhanced using a modified adaptive contrast enhancement algorithm. The local image enhancement algorithm is modified by incorporating a 3D weighted mean filtering approach to the adaptive contrast enhancement algorithm. Experimental results from enhancing a sequence of two-photon excited fluorescence microscopy images in the MATLAB environment are then compared to the original images as well as other enhancement methods. An image processing scheme, which also includes a global image enhancement algorithm, for two-photon excited fluorescence microscopy images will be implemented and utilized as a comparison tool to evaluate the performance of the local image enhancement algorithm.

8063-39, Poster Session

A polynomial threshold wavelet denoising approach for 3D biomedical applications

D. Akopian, M. Chan, S. G. Sathyanarayana, S. S. Agaian, The Univ. of Texas at San Antonio (United States)

This paper demonstrates Wavelet-Denoising Approach Using Polynomial Threshold Operators in 3-dimensional applications. The primary goal of this project is to compare the efficiency of different denoising algorithms on 3D biomedical images using 3D wavelet transform.

The principle mechanism of denoising is the mitigation of Gaussian noise of different variances using polynomial thresholding. This involves adaptively parameterization of operators to include classical soft- and hard-thresholding such that the algorithm may attain higher degrees of freedom for optimalnoise suppression while preserving the signal details.

The soft thresholding operator has a tendency of systematically biased estimates. While as, the less biased hard thresholding estimates has poorer denoising performance. While these two classical operators have inherent trade-offs, other state-of-the-art threshold operators suggested have not broughtabout much more significant improvements.Our approach is to apply a parameterized threshold and optimally choose the parameters for high performance noise suppression depending on the nature of the images and noise. Comparative studies are performed and improvement figures are presented in the paper.

8063-40, Poster Session

Comparative study of color image enhancement techniques

J. Xia, K. A. Panetta, Tufts Univ. (United States); S. S. Agaian, The Univ. of Texas at San Antonio (United States)

The goal of image enhancement techniques is to improve the characteristic or visual quality of an image for specific criteria [1]. A majority of techniques so far have focused on the enhancement of gray level images in both spatial domain and transform domain, which include adaptive histogram equalization, unsharp masking, contrast variance enhancement, homomorphic filtering and alpha rooting etc [2-4]. These methods have also been adapted for color image enhancement. However, for enhancing color images, we have taken into account also the chromatic information as well. In many such algorithms the RGB color coordinates are transformed into a different space such as HSV, YCbCr etc., where chromatic components are more uncorrelated from the achromatic component to avoid color distortion problem. There are also a few work reported in the RGB space. For example, retinex theory leads to excellent quality of the enhanced images and techniques reported using equalization of the 3-D histograms in the RGB space [5].

This paper presents a comprehensive review study of color image enhancement technique. We have compared four representative color image enhancement algorithms, which are Multiscale Retinex with Color Restoration (MSRCR) proposed by Rahman Jobson and Woodell [6], a retinex based adaptive filter algorithm proposed by Meylan and Süsstrunk [7], scaling DCT coefficients algorithm proposed by Mukherijee and Mitra [8] and our logarithmic transform histogram shifting algorithm which is based on altering the transform coefficient histograms through shifting and mapping. Optimal parameter selection based on image quality measurement [8] is also discussed in this algorithm. Computer simulations and analysis are provided to compare the enhancement performance of these algorithms. Also color space selection has been examined and a new color space based on the improved Principle Component Analysis has been introduced [9]. By analyzing the results we are able to determine which color space is best suited for each algorithm.

8063-41, Poster Session

Using fuzzy data mining to diagnose patients' degrees of melancholia

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Sufferers of chronic depression normally have noticeable negative emotion in communication. This study proposes to use fuzzy data mining algorithm to find association rules among keywords segmented from patients' daily voice/text messages to assist psychiatrists extract useful information before outpatient service. Patients of melancholia can use devices such as mobile phones to record their own emotion anytime and anywhere and then uploading the recorded files to the back-end server for analysis. The analysis results can be used for psychiatrists to diagnose patients' degrees of melancholia.

Two major modules are proposed in this study. One module is designed for automatic segmentation of keywords and the other is created for automatic analysis of patients' emotion.

In Chinese there is no apparent separation between words that result in the segmented keywords might show the antonym to the meaning in a sentence from automatic emotion analysis system. Identifying the true meaning of segmented words is an important issue. For example, adding the Chinese character "bu" (means "no" in English) to the compound Chinese characters "gaoxing" (happy) means unhappiness. In case a module segments the phrase "bugaoxing" (unhappy) to two parts, "bu" and "gaoxing", the results from emotion detection is happiness rather

than unhappiness. This paper resolves the problems by using fuzzy data mining to discover association rules among segmented words. For example, if the degree of “little interest or pleasure in doing things” is high and the degree of “feeling down, depressed or hopeless” is medium, then the degree of “feeling tired or having little energy” is high.

The other module is proposed to automatically analyze patients’ emotion from their uploaded voice/text files. Fuzzy data mining strategy is applied to detect words that are seldom spoken in the communications. Some emotional words such as suicide or death that patients spoke rarely may become the most critical keywords. The critical information may assist psychiatrists to diagnose a patient’s degree of melancholia. Accordingly, computational intelligence can be used for psychiatrists to diagnose patients’ melancholia in the early stage.

8063-42, Poster Session

Detection of modified matrix encoding using compressed sensing

J. D. Allen, Harris Corp. (United States)

In this paper we propose a compressed sensing based on approach for intrinsic steganalysis to detect MME stego messages. Compressed sensing is a recently proposed mathematical framework to represent an image (in general, a signal) using a sparse representation relative to an overcomplete dictionary by minimizing the l1-norm of resulting coefficients. Here we first learn a dictionary from a training set so that the performance will be optimized using the KSVD algorithm; since JPEG images are processed by 8x8 blocks, the training examples are 8x8 patches, rather than the entire images and this increases the generalization of compressed sensing. For each 8x8 block, we compute its sparse representation using OMP (orthogonal matching pursuit) algorithm. Using computed sparse representations, we train a support vector machine (SVM) to classify 8x8 blocks into stego and non-stego classes. Then given an input image, we first divide it into 8x8 blocks. For each 8x8 block, we compute its sparse representation and classify it using the trained SVM. After all the 8x8 blocks are classified, the entire image is classified based on the majority rule of 8x8 block classification results. This allows us to achieve a robust decision even when 8x8 blocks can be classified only with relatively low accuracy. We have tested the proposed algorithm on two datasets (Corel-1000 dataset and a remote sensing image dataset) and have achieved 100% accuracy on classifying images, even though the accuracy of classifying 8x8 blocks is only 80.89%.

8063-43, Poster Session

On the novel space-time duality language of the latency information theory revolution, part II: the space-dislocation of the latency-time certainty inputs of movers

E. H. Feria, College of Staten Island (United States)

In this second paper the space-time duality language of the LIT revolution for the space dislocation (SD) of the latency time (LT) certainty matter or energy inputs of communication movers is reviewed and illustrated with a moving vehicle where any of its wheels is the SD dual of a time-dislocated (TD) bit. While the reciprocal of the duration of the bit, i.e., bit-TD, determines the TD-frequency used in finding the communication source bit-rate, the distance traveled by a full wheel revolution, i.e., wheel-SD, determines the SD-wavelength used to find the wheel-speed in SI m/sec units. The wheel-speed of the communication mover is defined as the product of SD-wavelength (in meters per SD-wheel cycle) and SD-frequency (in wheel-SD cycles per communication sec). It is then noted that for constant wheel-SD and constant wheel-work the wheel-speed unavoidably decreases as the wheel to friction work ratio decreases. Work in SI N.m units is the SD certainty-motion-physics dual of TD uncertainty-retention-physics effort in SI Pa.sec units.

8063-44, Poster Session

On the novel space-time duality language of the latency information theory revolution, part III: the time-dislocation of the information-space uncertainty outputs of retainers

E. H. Feria, College of Staten Island (United States)

In this third paper the space-time duality language of the LIT revolution for the time dislocation (TD) of the information space (IS) uncertainty matter or energy inputs of observation retainers is reviewed and illustrated with a retaining membrane where any of its pores is the TD dual of a space-dislocated (SD) wheel. While the distance traveled by a wheel revolution, i.e., wheel-SD, determines the SD-wavelength used in finding the communication mover wheel-speed, the time duration of matter or energy retention of a pore, i.e., pore-TD, determines the TD-weavelength used to find the pore-pace in SI sec/m3 units. The pore-pace of the observation retainer is defined as the product of the TD-weavelength (in secs per pore-TD cycle) and TD-fix (in pore-TD cycles per observation m3). It is then noted that for constant bore-TD and constant bor-effort the pore-pace unavoidably decreases as the pore to noise effort ratio decreases. TD-weavelength is the uncertainty-retention-physics dual of the certainty-motion-physics SD-wavelength. TD-fix is the uncertainty-retention-physics dual of the certainty-motion-physics SD-frequency. Effort in SI Pa.sec units is the TD uncertainty-retention-physics dual of SD certainty-motion-physics work in SI N.m units.

8063-45, Poster Session

On the novel space-time duality language of the latency information theory revolution, part IV: the space-dislocation of the latency-time certainty inputs of processors

E. H. Feria, College of Staten Island (United States)

In this fourth and last paper of this series the space-time duality language of the LIT revolution for the space dislocation (TD) of the latency time (LT) certainty matter or energy inputs of observation processors is reviewed and illustrated with a processing full adder where any of its binary operators (bors in short) is the SD dual of a time-dislocated (TD) bit. While the reciprocal of the duration of a bit, i.e., bit-TD, determines the TD-frequency used in finding the communication source bit-rate, the space dislocation of matter or energy in a bor, i.e., bor-SD, determines the SD-weavelength used to find the bor-rate in bors/m3. The pore-pace of the observation processor is defined as the product of the SD-weavelength (in bors per bor-SD cycle) and SD-fix (in bor-SD cycles per observation m3). It is then noted that for constant bor-TD and constant bor-effort the bor-pace unavoidably decreases as the bor to noise effort ratio decreases. SD-weavelength is the processor dual of the source TD-wavelength. SD-fix is the processor dual of the source TD-frequency. Effort in SI Pa.sec units is the TD uncertainty-retention-physics dual of SD certainty-motion-physics work in SI N.m units.

8063-46, Poster Session

A new approach for automatic human deceit detection

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Accurate detection of deceit or truth from human subjects can be a difficult task. While humans have an ability to recognize a small portion of deceitful interactions through facial cues, body language, and vocal tones, this ability to recognize deceit is very limited to the human’s ability to recognize, and correctly interpret these behavioral signals. In this research, we propose using a new computer vision system to extract

the facial features, along with audio vocal data, to perform deception detection of human subjects. The computer vision system will detect deceit using facial cues including eye movement, facial expressions, body language, and vocal tones. Using video or still facial images, the characteristic features of deceitful behavior will be analyzed to produce deceit detection components for computer vision systems. The proposed system can work with a robot to accomplish more complicated tasks.

8063-48, Poster Session

Possibilities of forensic investigation of CD, DVD and Blu-ray disc

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The aim of this article is to show the possibilities of the forensic investigation of CD, DVD and Blu-ray disc.

To that, an overview of the methodologies in computer forensics is presented.

After a presentation of the possibilities of identification found in the specifications mentioned, they are examined by using freely available and commercial software.

It is demonstrated how important forensic information can be investigated and obtained, in particular the serial number of the burner who created the optical disc.

8063-49, Poster Session

Speed up face recognition with the use of limited physiological characteristics and SURF

D. R. Kisku, Asansol Engineering College (India); P. Gupta, Indian Institute of Technology Kanpur (India); J. K. Sing, Jadavpur Univ. (India); A. Rattani, Univ. degli Studi di Cagliari (Italy); C. J. Hwang, Texas State Univ. San Marcos (United States)

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. SURF is based on sums of 2D Haar wavelet responses and makes an efficient use of integral images. As basic image features it uses a Haar wavelet approximation of the determinant of Hessian blob detector.

Differences in facial expression, head pose, illumination, and partly occlusion may result to variations of facial characteristics and attributes. To capture the face variations, face characteristics of dynamic and static parts are further fused by concatenation with the detected SURF interest points extracted from localized mouth, eyes and nose facial parts. The proposed technique has made an attempt to handle this problem. It first detects and extracts automatically some salient facial parts such as eyes, mouth and nose with the help of some existing algorithms. Scale and rotation Invariant SURF feature descriptor is used on each of these facial parts to determine interest points and finally fusion of SURF interest points are performed. For Matching between two faces is done by considering some distance metric with the pair of corresponding fused feature vectors. These matching scores obtained from verification module is then further characterized by Doddington's user-dependent matcher reliability method. The relevance of individual matchers towards more efficient and robust performance is determined by wolf and lamb factors. It has been estimated that, both these factors can decrease the performance of any biometric system by accepting more and more imposters as false accept. In Doddington's concept, for user weighting, the users who can imitated labeled as lambs, i.e., imposters can provide biometric cues that are similar to that of lambs. Wolves on the other hand can successfully imitate some other users. The proposed techniques are evaluated against three face databases, namely, FERET, ORL, BANCA and IITK face databases.

In this paper, an efficient and robust face recognition technique by considering facial landmarks and using the SURF feature descriptor has been proposed. During the face recognition process, the human faces are characterized on the basis of local salient landmark features. It has been determined that when the face matching accomplishes with the whole face region, the global features (whole face) are easy to capture and they are generally less discriminative than localized features. In the proposed face recognition method, local facial landmarks are considered for further processing. The optimal face representation using SURF descriptor on local landmarks then allows matching the localized facial features efficiently.

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8064-01, Session 1

Image fusion for remote sensing using fast, large-scale neuroscience models

S. P. Brumby, Los Alamos National Lab. (United States)

Primate visual cortex consists of several billion cortical neurons organized in a hierarchy of modules that determine what and where objects are in the visual field. The human eye contains ~6 million retinal cone cells, delivering ~10^15 pixels/year, which is a million times the size of datasets typically used to train computer-vision systems. The visual system provides the archetypal fusion architecture, fusing high spatial resolution panchromatic, with lower spatial resolution spectral and faster temporal resolution imagery. Exploring the behavior of neuroscience models in response to vast amounts of imagery requires high performance codes that are real-time as well as full-scale. To reach these processing goals, we are leveraging the revolution in computing technology driven by the entertainment/games industry. These systems use cluster-on-a-chip designs, e.g., a single NVIDIA Fermi GPU chip has 448 scalar processing cores, providing raw computing power equivalent to mouse cortex for <$1,000. This type of computing will soon be universal.

We present results with our large-scale neuroscience models for feature detection with satellite imagery and aerial video. We describe a model using a biologically inspired artificial neural network architecture and learning rules to build sparse scene representations over an adaptive redundant dictionary, fusing data from high spatial resolution panchromatic and lower spatial resolution spectral imagery. Our results suggest that visual cortex models are a promising approach to these hard visual pattern recognition problems.

8064-02, Session 1

The continuum fusion theory of signal detection, with an application to multimodal fusion

A. P. Schaum, U.S. Naval Research Lab. (United States)

For nearly a century one type of target detection algorithm, the generalized likelihood ratio (GLR) test, has been the inference method of choice for solving non-Bayesian problems defined by parametric models. These models generate composite hypothesis (CH) tests, which entail deterministic parameters with unknown values. GLR solutions to CH problems have appeared in thousands of technical papers and underpin the signal processing logic in many autonomous systems for cueing and detection.

Continuum Fusion (CF) methods expand the solution set for CH testing problems. CF produces new detectors by integrating an infinity of optimal algorithms, each corresponding to a different parameter value. This paper explains the principles of the new methodology, and shows how to apply it to a prototypical model of multi-modal fusion. The model is as simple as possible, while still generating a CH problem. It involves two scalar signals and one unknown parameter value, the cross-modal target correlation. Despite its simplicity, the problem is nearly unsolvable in closed form with the conventional GLR method.

The flexibility in design afforded by the fusion methodology is exercised in solving the bi-modal problem to produce a new CF flavor. Called fixed-intercept fusion, this variant is solved in closed form and is shown to constitute a good approximation to the GLR solution. Subtleties in the derivation that are not uncommon to CF methods are explicated. Also discussed are easily constructed derivatives of the basic solution, which are appropriate to natural variants of the bi-modal model.

8064-03, Session 1

Probabilistic inference for battle damage assessment using physics-based models

Y. Shin, Applied Research Associates, Inc. (United States)

A timely and accurate battle damage assessment (BDA) of a target after the strikes has been a challenge for the success of military operations. We developed a probabilistic inference system using physics-based damage models for near real-time target battle damage assessment (BDA). It provides a sensor exploitation and decision support system that helps field commanders quickly perform BDA of ground mobile targets and/or hard and deeply buried targets. A probabilistic inference for BDA is conducted using a Bayesian Belief Network (BBN) in which the state of target damage, damage observables, and sensor observations are uncertain variables. The probabilistic relationships between the variables are provided by integrating a stochastic simulation of physics-based weapon-target interaction models, damage observables models, and sensor observation models. Battle damage is estimated by computing the posterior distribution of target damage variables given observation of sensor variables in the BBN. This system, for the first time, provides on-going near-real time feedback on the status of enemy target, enabling field commanders to achieve their objectives with fewer weapons and casualties. Its technical approach is centered on: (1) rapid extraction of trans-strike weapon impact and target response observables from imaging sensors; (2) development of a response surface model for physics-based weapon-target interaction analysis under uncertainties (3) development of BBN for a weapon-target specific BDA by performing stochastic analysis of physics-based model (4) inference of likely target damage states corresponding to the observation of multiple sensors. Two nominal examples are presented to demonstrate the approach and the accuracy and robustness of probabilistic BDA inference system are discussed.

8064-04, Session 1

Wavelet-based fusion of overhead imagery and digital surface models

A. M. Thomas, J. M. Burkhart, Georgia Tech Research Institute (United States)

High resolution Digital Surface Maps, such as those created from SAR data or LiDAR data, are fused at the feature level with overhead multi-spectral imagery in order to improve object classification. Conventional imaging object classification systems have the problem that they require large amounts of training data to account for all the variations in perspective and even then they are not robust to illumination variations. Purely spectral methods exploit material properties from a single pixel but don’t take advantage of the spatial structure. Purely, 3D geometric data doesn’t capture the important spectral material characteristics. Our approach is to combine the 3D geometric data and the spectral data at the feature level to obtain multimodal features which better distinguish object classes and increase the robustness of classification to variation in collection conditions. This approach also allows for the fusion of data from multiple perspectives with reduced data alignment errors. This is achieved by utilizing a redundant Gabor wavelet representation in a manner that generalizes models of the visual cortex.

8064-05, Session 2

Feature-aided Monte Carlo probabilistic data association filter for ballistic missile tracking

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The problem of ballistic missile tracking using multiple sensors in the presence of clutter is investigated. We propose to use sequential Monte Carlo methods, i.e., particle filters, aided with amplitude information (AI) in a probabilistic data association (PDA) framework in order to improve the tracking performance of a single target in clutter when severe nonlinearities exist in the system. We call this approach “Monte Carlo probabilistic data association filter with amplitude information (MCPDAF-AI)”. Furthermore, we formulate a realistic problem in the sense that we use simulated radar cross section (RCS) data for a missile warhead and a cylinder chaff using Lucernhammer, a state of the art electromagnetic signature prediction software, to model target and clutter amplitude returns as additional amplitude features which help to improve data association and tracking performance. A performance comparison is carried out between a single sensor case and a multiple sensor case where the information from multiple sensors is fused to improve the tracking performance. We also compare the traditional extended Kalman filter (EKF) and the proposed particle filter which has a significantly higher computational complexity. The results show that, when only one sensor is used, the MCPDAF performs significantly better than the EKF in terms of tracking accuracy under severe nonlinear conditions. However, when the number of sensors is increased, even under severe nonlinear conditions, the EKF performs as well as the MCPDAF. Our results indicate that fusing information from multiple sensors can mitigate the effects of severe nonlinearities in the tracking system.

8064-06, Session 2

Architectures, algorithms, and applications using Bayesian networks

T. Kingsbury, General Dynamics Advanced Information Systems (United States)

A Bayesian network is a tree structure where each branch represents a classification candidate. The leaves of the tree represent observable target features such as frequency or length. An optimized tree groups similar features together, e.g. frequency and pulse width, while collecting dissimilar or disparate information, e.g. spectral and kinematics, all within the same unifying structure. A vehicular track then is a subset of the a priori and contains only feasible branches. The algorithm for updating the confidence of each feasible candidate according to Bayes' rule is embedded in each track, as is the ability of a track to learn, apply a priori probability distributions, switch among modes, switch among kinematics models, apply tracking history to classification and apply classification history to tracking, and support multi-sensor correlation and fusion. GD-AIS fields this technology in the Surface Electronic Warfare Improvement Program (SEWIP).

8064-07, Session 2

Fusion of hyperspectral and ladar data for autonomous target detection

A. V. Kanaev, T. J. Walls, U.S. Naval Research Lab. (United States)

Robust fusion of data from disparate sensor modalities can provide improved target detection performance over those attainable with the individual sensors. In particular, detection of low-radiance manmade objects or objects under shadow obscuration in hyperspectral imagery (HSI) with acceptable false alarm rates has proven especially challenging. We have developed a fusion algorithm for enabling detection of difficult targets when the HSI data is simultaneously collected with ladar data. Initial detections are obtained by applying a sub-space RX (SSRX) algorithm to the HSI data. In parallel, ladar-derived digital elevation map (DEM) is segmented and coordinates of objects within a specific elevation range and size are returned to the HSI processor for their spectral signature extraction. Each extracted signature that has not been already detected by SSRX is used in secondary HSI detection employing the adaptive cosine estimator (ACE) algorithm. We show that spatial distribution of ACE score allows for confident discrimination between background elevations and manmade objects. Key to cross-characterization of the data is the accurate co-alignment of the image data. We have also developed an algorithm for automatic co-registration of ladar and HSI imagery, based on the maximization of mutual information, which can provide accurate, sub-pixel registration even in the case when the imaging geometries for the two sensors differ. Details of both algorithms will be presented and results from application to field data will be discussed.

8064-08, Session 3

A relaxed fusion of information from real and synthetic images to predict complex behavior

D. M. Lyons, Fordham Univ. (United States); D. P. Benjamin, Pace Univ. (United States)

An important component of cognitive robotics is the ability to mentally simulate physical processes and to compare the expected results with the information reported by a robot's sensors. In previous work, we have proposed ADAPT, a Cognitive Architecture that views perception as top-down and goal-oriented, so that perception becomes part of the problem solving process. We have described an architecture for the perceptive and world modelling components of ADAPT and reported on experimental results using this architecture to perceive events in a complex, real-world scenario. A key part of that architecture is the Match-Mediated Difference (MMD) operation, an approach to fusing sensory data and synthetic predictions at the image level.

The MMD operation insists that simulated and predicted scenes are similar in terms of the appearance of the objects in the scene. This constrains the simulator to try to shape and color the components of the synthetic world as close to those in the real, sensed world as possible. If a robot is traversing an urban disaster site and predicts that a nearby column of masonry is leaning dangerously enough that it may collapse, there is no reason to ask that the simulator be able to color and shape the chunks of masonry in the collapsed wall.

In this paper we propose an extended MMD operation that relaxes the constraint that real and synthetic scenes contain objects of similar appearance. It allows the real and synthetic scenes to differ in some feature but not in others. In tracking a rolling ball through various collisions, some features, such as shape, need to be the same; some features such as velocity need to be close; and, other features such as color and texture can be entirely different. This allows the robot to concentrate only on the key features in problem, even we argue to the level of producing a 'cartoon-like' simulation similar to Cohen's 'Wubbles.'

We report experimental results for the extended MMD operation (EMMD) for the ball tracking example showing the generaliztion from our previous results.

8064-09, Session 3

Inner rehearsal modeling for cognitive robotics

J. J. Braun, K. Bergen, T. J. Dasey, MIT Lincoln Lab. (United States)

Return to Contents

Algorithmic approaches that model cognitive processes believed to occur in animals or humans may constitute one of the most promising paths to autonomous intelligent systems and in particular to autonomous robots. One of the aspects of our current Cognitive Robotics research effort involves the modeling of a cognitive process referred to as inner rehearsal. Behavioral and brain imaging studies suggest that certain overt actions, e.g., motor actions, are preceded by rehearsal-type neuronal activity.

In this paper, we discuss an inner-rehearsal model we developed in the context of a relatively complex task, namely a search in an unknown labyrinth-like environment, conceptually representative of what might be required of an autonomous search-and-rescue robot searching for disaster survivors trapped under rubble. It is assumed that the robot must operate autonomously, without any external communications, and that the environment's topology or map is not available a priori. Furthermore, the victim's location is not known until the robot reaches the victim's immediate vicinity. The robot makes use of sensory cues from multiple sensors, currently simulated at a high level. Those sensory cues represent acoustical and visual sensory channels, constituting a simulated interpretation of the robot's front field of vision contents and a rough direction to the noise source attributable to the trapped survivor.

The specifics of the developed inner-rehearsal model, integration of multisensory cues, and computational experiments with the inner rehearsal model, are discussed. The results showing the behavior of the simulated robot using the proposed inner-rehearsal model are discussed. While their context is representative of a robotic search-and-rescue application, the core contribution of this work is in exploring techniques that exploit cognitive-science and neuroscience insights towards artificial cognition for robotics and autonomous systems.

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8064-10, Session 3

The perception problem in robotics

T. D. Kelley, U.S. Army Research Lab. (United States)

Why is there a perception problem in robotics? Given the increases in the speed of computer hardware and technology, why haven't there been commensurate advances in computer vision technology which would enable a robot to respond appropriately to its environment? Perhaps the algorithms are not appropriate for the problem. In the field of Artificial Intelligence (AI) the computer vision problem was first assumed to be easy, and supposedly more difficult challenges were tackled first (problem solving, decision making). As it turned out, problem solving and decision making were handled relatively easily by symbolic manipulations, however, the perception of the real world turned out to be much more difficult. What are the algorithms that have been used for perception in robotics and why do they sometimes fail at reproducing human-like behavior? How can we learn from biological systems which, through evolution, have made great advances in solving problems of perception and classification?

8064-11, Session 3

A motion writing based on perceptograms and its use in motor skill transfer

A. Stoica, Jet Propulsion Lab. (United States)

The paper introduces a cognitive framework in which concepts are represented as perceptograms (a perception-induced representation) and ideograms (compositions of perceptograms making an idea). The paper illustrates how perceptograms are derived (perception) and manipulated reasoning/thought). It applies this framework to the problem of transferring cognitive/motor skills from teachers to apprentices, specifically to transfer from humans to humanoid robots or between various humanoids, more general between somehow similar body shape and mobility set but not identical dimensions, etc. In this context a Motion Writing (of the same set of Sutton's DanceWriting) is developed, consisting of perceptograms that are simplified, skeleton-derived body postures. Teaching of a skill consists on the presentation of a sequence of body posture -inspired characters. The main advantages the system has is that meaning is recognizable from the perceptogram sequence, and robots of similar body shape would be able to interpret/imitate/reproduce without much prior knowledge. This comes to fill a gap in representations for motor skills transfer, between these types of robots, of similar shape but different dimensions, for which a description of how to perform a task can not be done accurately neither in end effector coordinates, nor in joint coordinates.

8064-12, Session 4

A hidden Markov model for multimodal biometrics score fusion

Y. Zheng, Alcorn State Univ. (United States)

There are strong evidences of that multimodal biometric score fusion can significantly improve human identification performance. Score level fusion usually involves score normalization, score fusion, and fusion decision. There are several types of score fusion methods, direct combination of fusion scores, classifier-based fusion, and density-based fusion. The real applications of DOD and federal agencies require achieving greater reliability in determining or verifying person's identity. The goal of this research is to improve the accuracy and robustness of human identification by using multimodal biometrics score fusion. The accuracy means the genuine accept rate (GAR) under low false accept rate (FAR), whereas the robustness means the reliable GAR when using poor data from uncooperative subject and/or from noisy environments. We propose a hidden Markov model (HMM) for multiple score fusion, where the biometric scores include multimodal scores and multi-matcher scores. The feature densities under each state (i.e., emission probabilities) of a HHM model are estimated by using Gaussian mixture model (GMM). The proposed HMM model for multiple score fusion is anticipated to be accurate for identification, flexible with biometrics, and robust to noisy data. We will test the proposed HMM method on the NIST-BSSR1 multimodal database and on our own face database. We will report the HMM performance compared to other methods.

8064-13, Session 4

INFORM Lab: a testbed for high-level information fusion and resource management

P. Valin, A. Guitouni, E. Bossé, Defence Research and Development Canada (Canada); H. W. Wehn, J. Happe, MacDonald, Dettwiler and Associates Ltd. (Canada)

Defence R&D Canada Valcartier and MacDonald Dettwiler have brought together a team of researchers from industry, government, and academia in order to create an advanced simulation testbed for the purpose of evaluating the effectiveness of Network Enabled Operations in a Coastal Wide Area Surveillance situation. This INFORM Lab testbed allows experimenting with high-level distributed information fusion, dynamic resource management and configuration management, given multiple constraints on the resources and their communications networks.
This paper describes the architecture of INFORM Lab, the essential concepts of goals and situation evidence, a selected set of algorithms for distributed information fusion and dynamic resource management, as well as auto-configurable information fusion architectures. The testbed provides general services which include a multi-layer plug-and-play architecture, and a general multi-agent framework based on John Boyd's Observe-Orient-Decide-Act loop. The testbed's performance is demonstrated on 2 types of Coastal Wide Area Surveillance scenarios/vignettes for 1) a cooperative search-and-rescue effort, and 2) a non-cooperative smuggling scenario involving many target ships and various methods of deceit. For each mission, an appropriate subset of Canadian airborne platforms (Maritime Patrol Aircraft, helicopters, Unmanned

Aerial Vehicles) and naval platforms (frigates) are dispatched to collect situation evidence, which is fused, and then used to modify the platform trajectories for the most efficient collection of further situation evidence. These platforms are fusion nodes which obey a Command and Control node hierarchy. Finally further planned enhancements to INFORM Lab are outlined.

8064-14, Session 4

Multisensor remote sensing information fusion for urban area classification and change detection

G. Palubinskas, A. Makarau, P. Reinartz, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Information extraction from multi-sensor remote sensing imagery is an important and challenging task for many applications such as urban area mapping and change detection. Especially for optical and radar data fusion a special acquisition (orthogonal) geometry is of great importance in order to minimize displacements due an inaccuracy of Digital Elevation Model used for data orthorectification and existence of unknown 3D structures in a scene. Final data spatial alignment is performed by recently proposed co-registration method based on a Mutual Information measure. For a combination of features originating from different sources, which are quite often non-commensurable, we propose an information fusion framework called INFOFUSE consisting of three main processing steps: feature fission (feature extraction for complete description of a scene), unsupervised clustering (complexity reduction and feature conversion to a common dictionary) and supervised classification realized by Bayesian/Neural networks. An example of urban area classification is presented for the orthogonal acquisition of space borne very high resolution WorldView-2 and TerraSAR-X imagery over Munich city, South Germany. Comparison with other well known methods such as Maximum Likelihood and Support Vector Machine classifiers is performed. Experimental results confirm our approach and show a great potential also for other applications such as change detection.

8064-15, Session 4

Metrics for the selection of frequency bands from hyperspectral data for image fusion and sensor development

J. E. Fulton, Jr., Naval Surface Warfare Ctr. Crane Div. (United States)

The application of imagers in security is to provide a clear warning of potential threats to the end users. Hyperspectral imagers (HSI) are not used in security applications due to the high cost and the need for extensive processing. The continuum of frequency bands represented in a HSI data cube contains a rich set of information. For specific applications, there is enough data in a subset of the total number of frequency bands available to detect a specific threat, thus reducing the cost and processing requirements. The Security Sensors Branch of the Naval Surface Warfare Center, Crane Division’s Electro-Optics Technology Division is proposing a set of metrics for the selection of multiple frequency bands from the total a HSI range. The selected frequency bands are fused into a final image. The metric includes objective and subjective evaluations of the input images and final fused image. The process of assigning the metric allows the selection of pertinent frequency bands to be assembled into application specific multi-spectral imagers. The selection criteria create a basis set of frequencies to be used in a fieldable, threat specific, affordable imager.

8064-16, Session 5

Fusion of chemical, biological, and meteorological observations for agent source term estimation and hazard refinement

P. E. Bieringer, National Ctr. for Atmospheric Research (United States)

Chemical and biological (CB) agent detection and effective use of these observations in hazard assessment models are key elements of our nation’s CB defense program that seeks to ensure that Department of Defense (DoD) operations are minimally affected by a CB attack. Accurate hazard assessments rely heavily on the source term parameters necessary to characterize the release in the transport and dispersion (T&D) simulation. Unfortunately, these source parameters are often not known and based on rudimentary assumptions. In this presentation we will describe an algorithm that utilizes variational data assimilation techniques to fuse CB and meteorological observations to characterize agent release source parameters and provide a refined hazard assessment. The underlying algorithm consists of a combination of modeling systems, including the Second order Closure Integrated PUFF model (SCIPUFF), its corresponding Source Term Estimation (STE) model, a hybrid Lagrangian-Eulerian Plume Model (LEPM), its formal adjoint, and the software infrastructure necessary to link them. SCIPUFF and its STE model are used to calculate a “first guess” source estimate. The LEPM and corresponding adjoint are then used to iteratively refine this release source estimate using variational data assimilation techniques. This algorithm has undergone preliminary testing using virtual “single realization” plume release data sets from the Virtual THreat Response Emulation and Analysis Testbed (VTHREAT) and data from the FUSION Field Trials 2007 (FFT07). The end-to-end prototype of this system that has been developed to illustrate its use within the United States (US) Joint Effects Model (JEM) will be demonstrated.

8064-17, Session 5

Implementation and testing of a sensor-netting algorithm for early warning and high confidence C/B threat detection

T. C. Gruber, Jr., L. B. Grim, R. A. Fauth, B. M. Tercha, MESH, Inc. (United States)

Large networks of disparate chemical/biological (C/B) sensors, MET sensors, and intelligence, surveillance, and reconnaissance (ISR) sensors reporting to various command/display locations can lead to conflicting threat information, questions of alarm confidence, and a confused situational awareness. Sensor netting algorithms (SNA) are being developed to resolve these conflicts and to report high confidence consensus threat map data products on a common operating picture (COP) display. A data fusion algorithm design was completed in a Phase I SBIR effort and development continues in the Phase II SBIR effort. The initial implementation and testing of the algorithm has produced some performance results. The algorithm accepts point and/or standoff sensor data, and event detection data (e.g., the location of an explosion) from various ISR sensors (e.g., acoustic, infrared cameras, etc.). These input data are preprocessed to assign estimated uncertainty to each incoming piece of data. The data are then sent to a weighted tomography process to obtain a consensus threat map, including estimated threat concentration level uncertainty. The threat map is then tested for consistency and the overall confidence for the map result is estimated. The map and confidence results are displayed on a COP. The benefits of a modular implementation of the algorithm and comparisons of fused / un-fused data results will be presented. The metrics for judging the sensor-netting algorithm performance are warning time, threat map accuracy (as compared to ground truth), false alarm rate, and false alarm rate v. reported threat confidence level.

8064-18, Session 5

Fusion of disparate spectra for chemical identification

C. P. Minor, Nova Research, Inc. (United States); K. Johnson, H. Brooke, U.S. Naval Research Lab. (United States)

Currently there is no systematic framework for characterizing fused, multisensory systems, and therefore the comparison of multiple independent systems is difficult without extensive field-testing. Development of a framework would allow for theoretical comparisons and enable more rapid prototyping of fused sensor systems, guidance for design from existing sensor components, and more effective engineering of new sensors optimized for use in fused sensor systems. Recent research at NRL has focused on characterizing Fourier transform infrared spectroscopy (FTIR) and mass spectrometry data for fused, multisensor applications to enhance chemical detection and discrimination in the presence of complex interfering backgrounds. An information theoretic approach has been used to elucidate the information content available from spectral data, quantify the ability of these sensing techniques to distinguish chemicals, and determine their susceptibility to noise and resolution limitations. The approach has also been applied to feature extraction and data fusion techniques on these data. Results characterizing the effectiveness of a fused multisensor system combining FTIR and mass spectrometry are presented.

8064-19, Session 6

Learned fusion operators based on matrix completion

C. F. Hester, K. K. Dobson, U.S. Army Aviation and Missile Command (United States)

The efficient and timely management of imagery captured in the battlefield requires methods capable of searching the voluminous databases and extracting highly symbolic concepts. When processing images, a semantic and definition gap exists between machine representations and the user's language. Based on matrix completion techniques, we present a fusion operator that fuses imagery and the semantic field elements provided by user inputs and post analysis. Specifically, an information matrix is formed from imagery and written reports and documents. From this matrix an image operator is derived for the extraction/prediction of information from future imagery. Single and multiple modality data are considered.

8064-20, Session 6

Mask pyramid methodology for enhanced localization in image fusion and enhancement

D. C. Zhang, G. S. van der Wal, S. Chai, D. Berends, A. A. Sufi, G. Buchanan, M. Piacentino, P. J. Burt, Sarnoff Corp. (United States)

Image fusion is a process that combines regions of images from different sources into a single fused image based on a salience selection rule for each region. In this paper, we proposed an algorithmic approach using a mask pyramid to better localize the selection process. A mask pyramid operates in different scales of the image to improve the fused image quality beyond a global selection rule. The proposed approach offers a generic methodology for applications in image enhancement, high dynamic range compression, depth of field extension, and image blending. The mask pyramid can also be encoded for intelligent analysis of source imagery. Several examples of this mask pyramid method are provided to demonstrate its performance in a variety of applications. A new embedded system architecture that builds upon the Acadia® II Vision Processor is proposed.

8064-21, Session 6

GStreamer as a framework for image processing applications in image fusion

S. D. Burks, J. M. Doe, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Multiple source band image fusion can sometimes be a multi-step process thatconsists of several intermediate image processing steps. Typically, each of these steps are required to be in a particular arrangement in order to produce a unique output image. For instance, if two source images each have a local area processing and then are combined using a wavelet fusion algorithm, the resulting image will be different than if these two processing steps were reversed. GStreamer is an open source, cross platform multimedia framework, and using this framework, engineers at NVESD have produced a software package that allows for real time manipulation of processing steps for rapid prototyping in image fusion. Each step is implemented as a discrete element that can be added and removed at any point in the processing pipeline.

8064-22, Session 6

Ultrasonic flaw imaging exploiting multipath information

X. Shen, Shanghai Institute of Technology (China) and Villanova Univ. (United States); Y. D. Zhang, R. Demirli, M. G. Amin, Villanova Univ. (United States)

Ultrasonic imaging using sensor arrays is a powerful nondestructive testing (NDT) tool that assesses material conditions and helps detect, localize, and classify flaws inside a structure. In this paper, we propose the exploitation of multipath signals that yields extended virtual array apertures to enhance imaging capability beyond the limitation of traditional multisensor approaches. The key concept examined here is the utilization of higher-order reflections of the direct path ultrasonic signal from the material boundaries. The waveforms observed at the physical as well as virtual sensors result in expanded data sets for fusion processing with different aspect angles. As a result, the exploitation of multipath information is found to address several key and unique issues observed in ultrasonic imaging. (1) Utilization of virtual sensors significantly extends the array aperture for image enhancement. (2) Ultrasonic images usually only have a narrow angle of view because of the narrow beamwidth of ultrasound transducers. Multipath signals extend the angle of view for improved visibility and array design flexibility. (3) Ultrasonic signals experience difficulty in penetrating a flaw, thus the aspect angle of the observation is limited unless access to other sides is available. The significant extension of the aperture makes it possible to yield flaw observation from multiple aspect angles. We analytically demonstrate that data fusion of physical and virtual sensor array data significantly improves the detection and localization performance, and this claim is supported by simulations as well as experimental studies.

8064-23, Session 6

A classification-based image fusion scheme using wavelet transform

X. Luo, J. Zhang, BeiHang Univ. (China); Q. Dai, Tsinghua Univ. (China)

With today's advances in imaging sensor application, it is impossible to generate an image that includes all salient features using only one sensor. Thus, fusing multiple images is still important to produce a more comprehensive synthetic image for a scene. However, an image fusion method does not suit all fusion cases of different images in practice, such as multi-focus images, medical images, or visual-infrared images. In this paper, we propose an image fusion scheme based on wavelet transform

to satisfy different fusion applications as much as possible, which mainly depends on the classification of low-frequency coefficients.

The proposed scheme aims at a universal image fusion method for various images. The main advantage of this method lies in the analysis of different source images to assign appropriate fusion rules for the coefficients. Hence, the input images are firstly decomposed into wavelet domain. Considering the approximate characteristic of low-frequency and the detailed characteristic of high-frequency, the different low-frequency coefficients of different input images are discriminated with different fusion rules based on the classification of structure similarity. On the other hand, the high-frequency coefficients are fused via assimilation method in terms of edges. Finally, the fused image can be reconstructed via wavelet inverse transform.

The proposed scheme achieves robust performances for different kinds of input images through classifications fusing of low-frequency wavelet coefficients. Moreover, the fusion processing for the high-frequency coefficients is resistant to noise. We believe that the proposed scheme can be employed to many applications. Some simulation results demonstrate its effectiveness.

8064-24, Session 7

Songs of cyberspace: an update on sonifications of network traffic to support situational awareness

M. Ballora, N. A. Giacobe, D. L. Hall, The Pennsylvania State Univ. (United States)

Building on our previous work, we extend sonification techniques to other common network security data. In this current work, we now examine packet flow and the creation of socket connections between a requestor's IP address and port number with the server's IP address and port number, mixing and matching these four values with a mixing board-like interface. We have found that patterns associated with intrusion attempts such as port scans and denial of service attacks easy for an analyst to interpret audibly against the background of normal network traffic. These base case proofs-of-concept provide the potential promise of future development of tools to aid in cognition, support in the development of situational awareness and reduce information overload commonly associated with network security analysts. An octaphonic audio rendering system allows improved flexibility, offering capabilities such as representing geographical coordinates by stereo pan location, or improving intelligibility by separating renderings of different information over different audio channels so that they are easier to track when played simultaneously. Systems such as the one presented here could be used to augment visualization techniques to potentially provide better cognitive refinement capabilities for data fusion systems, especially when multiple sources of data at various levels of refinement are presented to the human analyst.

8064-25, Session 7

Secure data aggregation in WSN-based border surveillance systems

S. Ozdemir, Gazi Univ. (Turkey)

Heterogeneous wireless sensor network (HWSN) based border surveillance systems are composed of several types of sensors such as video, temperature, seismic, and sound sensors. The data collected in these networks are analyzed by data aggregators or a central base station to determine illegal activities inside the border region. Due to high security requirements, secure data aggregation is vital for mission critical HWSNs. However, because of the multiple sensor types that generate different types of data, performing secure data aggregation in HWSN based border surveillance systems is not a trivial task. In this paper, a secure data aggregation protocol that allows aggregation of multiple data types in HWSN based border surveillance systems. The novel idea behind the paper is that the proposed concealed data aggregation protocol is able to aggregate different sensor data types into a single data packet. In addition, the base station is able to obtain each different data type separately when it decrypts the aggregated data. For example, in the proposed scheme, a photo sensor's data and a temperature sensor's data can be securely aggregated into a single data packet and the base station is able to extract the photo sensor's data and temperature sensor's data separately. The proposed protocol relies on an elliptic key cryptography based privacy homomorphic encryption scheme which is suitable for resource constrained sensor nodes. The performance analysis and simulation results show that the proposed scheme reduces the amount of data transmission in the network while preserving the data confidentiality during data aggregation.

8064-26, Session 7

Multisource information fusion for logistics

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Current Army logistical systems and databases contain massive amounts of data that need an effective method to extract actionable information. The databases do not contain root cause and case-based analysis needed to diagnose or predict breakdowns. A system is needed to find data from as many sources as possible, process it in an integrated fashion, and disseminate information products on the readiness of the fleet vehicles. 21st Century Systems, Inc. introduces the Agent-Enabled Logistics Enterprise Intelligence System (AELEIS), designed as a tool to assist logistics analysts with assessing the availability and prognostics of assets in the logistics pipeline. AELEIS extracts data from multiple, heterogeneous data sets. This data is then aggregated and mined for data trends. Finally, data reasoning tools and prognostics tools evaluate the data for relevance and potential issues. Multiple types of data mining tools may be employed to extract the data and an information reasoning capability determines what tools are needed to apply them to extract information. This can be visualized as a push-pull system where data trends fire a reasoning engine to search for corroborating evidence and then integrate the data into actionable information. The architecture decides on what reasoning engine to use (i.e., it may start with a rule-based method, but, if needed, go to condition based reasoning, and even a model-based reasoning engine for certain types of equipment). Initial results show that AELEIS is able to indicate to the user of potential fault conditions and root-cause information mined from a database.