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Space, and Security

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8704-1, Session 1

Epitaxially passivated mesa-isolated InGaAs photodetectors

John F. Klem, Jin K. Kim, Michael J. Cich, Samuel D. Hawkins, Darin Leonhardt, Torben R. Fortune, Wesley T. Coon, Sandia National Labs. (United States)

Achieving low dark current in InGaAs photodiodes is dependent on passivation of device sidewalls, which otherwise exhibit high conductance. Typically, high-performance devices are fabricated using heterostructures with no exposed InGaAs surfaces, while contacts are formed through implant or diffusion processes. We have fabricated low-dark-current InGaAs photodetectors utilizing an epitaxial structure incorporating an InAlGaAs passivation layer and a simple mesa isolation process, and requiring no implant or diffusion steps. At 295 K, areal and perimeter dark current contributions are typically 15 nA/cm2 and 10 pA/cm, respectively, in devices with large aspect ratios biased at -0.1 V. Full responsivity is achieved even at zero bias in these devices. These results are comparable to state-of-the-art devices fabricated by other processes.

Devices were modeled using a commercial drift-diffusion simulator. Good fits to reverse dark current-voltage measurements were obtained using a model that included both bulk and interfacial generation mechanisms. With small reverse bias, dark current is consistent with generation at the interface between the absorber and underlying layers. A large increase in dark current is associated with depletion near the InAlGaAs/absorber interface, while small increases in current at large reverse bias suggest long Shockley-Read-Hall lifetimes in the absorber. Forward biasing of these devices results in efficient injection of minority carrier holes into the absorber region, mimicking photogeneration, while providing a method to estimate hole diffusion length and predict the performance of illuminated detector arrays.

8704-2, Session 1

SWIR InGaAs focal plane arrays in France

Anne Rouvié, Odile Huet, Sébastien Hamard, Jean-Patrick Truffer, Maxime Pozzi, Jean Decobert, Eric M. Costard, Alcatel-Thales III-V Lab. (France); Michel Zecri, Patrick Maillart, Yann Reibel, Alexandra Pécheur, SOFRADIR (France)

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

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

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

More recently, III-VLab is developing in close collaboration with SOFRADIR the next SWIR InGaAS product generation like VGA formats in both 25µm and 15µm pitch.

In this paper, we present the last developments achieved in France and the foreseen road map for decreasing the pitch of the arrays as well.

8704-3, Session 1

A low-noise, extended dynamic range 1.3 Megapixel InGaAs array

Wim Vereecken, Urbain Van Bogget, Thierry Colin, Rosa M. Vinelli, Xenics NV (Belgium); Patrick J. Merken, Xenics NV (Belgium) and Royal Military Academy (Belgium); Jan P. Vermeiren, Xenics NV (Belgium)

Xenics has designed and manufactured a 1280*1024 pixel, 17 µm pitch InGaAs array for SWIR imaging in the [0.9 – 1.7 µm] range. It will report on the first characterisation results of the device.

As usual for this type of room temperature operated SWIR image sensors, the detector interface is based on a CTIA stage, yielding excellent linearity, a low detector bias and hence a low and stable dark current combined with low image lag. The charge to voltage conversion factor is 53 µV/e-.

The pixel interface scheme contains a CDS circuit in order to reduce the kTC noise and common mode effects. The noise is expected to be below 30 e-rms in linear mode, resulting in a dynamic range > 60 dB. Additionally the linear dynamic range is complemented with a high dynamic range logarithmic response with a saturation level > 5 nA/pixel.

The information in the pixel matrix can be read via 2, 4 or 8 outputs, yielding a maximum full frame rate between 50 and 200 Hz. Each output is operating at 40 MHz pixel rate. The outputs are differential with a common mode voltage of 1.5 V and an adjustable output swing of 2 Vptp. Nevertheless the power dissipation shall be below 400-600 mW.

8704-4, Session 1

Low-power advancements for a 1.3 Mpixel SWIR imaging platform

Michael Delamere, Robert Rozploch, Jonathan Nazemi, Andrew Eckhardt, UTC Aerospace Systems (United States)

No abstract available.

8704-5, Session 1

Eye-safe active Vis SWIR imaging for highly portable tactical applications

Andrew Hood, David Follman, Paula Heu, Jonathan C. Geske, Chad Wang, Falgun D. Patel, Peter Dalmatoff, Fedor Talantov, FLIR Electro-Optical Components (United States)

A recent emphasis on low light, passive SWIR imaging has driven the advancement of sensor technology, resulting in reduced detector dark current and ROIC read noise. However, there are often imaging scenarios where passive SWIR imaging can be challenging, require significant SWaP, or even be completely impossible. In this paper we present FLIR Electro Optical Components' system level approach to SWIR imaging that provides benefits of reduced SWaP and enhanced operational capabilities. This includes an un cooled or TEC-stabilized advanced, low power VGA SWIR sensor with a 15 um pitch coupled with an eye safe, high power, low-speckle SWIR illuminator with adaptable divergence angles for search and identification tasks. We will present system level performance comparisons of these ensembles compared to those of passive, TEC-cooled systems. The comparison will outline the advantages of an eye safe, active SWIR solution for highly versatile, portable applications.

8704-6, Session 1

IR CMOS: infrared enhanced silicon imager

Martin U. Pralle, James E. Carey III, Homayoon Haddad, SiOnyx Inc. (United States)

SiOnyx has developed visible and infrared CMOS image sensors and cameras leveraging a proprietary ultrafast laser semiconductor process technology. This technology demonstrates 10 fold improvements in infrared sensitivity over incumbent imaging technology while maintaining complete compatibility with standard CMOS image sensor process flows. Furthermore, these sensitivity enhancements are achieved on a focal plane with state of the art noise performance of 2 electrons/pixel. By capturing light in the visible regime as well as infrared light from the night glow, this sensor technology provide imaging in daytime through twilight and into nighttime conditions. The measured 10x quantum efficiency at the critical 1064 nm YAG laser node enables see spot imaging capabilities in a variety of ambient conditions. The spectral sensitivity is from 400 to 1200 nm. Imaging performance metrics will be discussed.

Demonstrated performance characteristics:

Pixel size : 5.6 & 10 um

Array size: SVGA, 720P and SXGA

Frame rate: 60 Hz

Read noise: 2 ele/pixel

Spectral sensitivity: 400 to 1200 nm (with 10x QE at 1064nm)

Daytime imaging: color (Bayer pattern)

Nighttime imaging: down below ? moon conditions

1064nm laser imaging: below 10 uJ in room light conditions

8704-7, Session 2

High-performance IR detector modules for Army applications *(Invited Paper)*

Holger Lutz, Rainer Breiter, Stefan Rutzinger, Timo Schallenberg, Joachim C. Wendler, Johann Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

Since many years AIM delivers IR-modules for army applications like pilotage, weapon sights, UAVs or vehicle platforms. State-of-the-art 640x512, 15µm pitch detector modules are in production in manifold configurations optimized for specific key requirements on system level. This is possible due to a modular design, which is best suited to meet the diversity of system needs in army applications. Examples are optimization of detector-dewar length for gimbal applications, size weight and power reduction for UAVs or lifetime enhancement for vehicle platforms.

In 2012 AIM presented first prototypes of megapixel detectors (1280x1024, 15µm pitch) for both spectral bands MWIR and LWIR. These large format detector arrays fulfill the demand for higher spatial resolution, which is requested for applications like rotorcraft pilotage, persistent surveillance or tasks like determination of threat level in personnel targets. Recently, a new tactical dewar has been developed for the 1280x1024 detector arrays. It is designed to withstand environmental stresses and, at the same time, to quest for a compact overall package. Furthermore, the idea of a modular design will be even more emphasized. Integration of different cooler types, like AIM's SX095 or rotary integral, will be possible without modification of the dewar.

The paper will present development status of large format IR-modules at AIM as well as performance data and configuration considerations with respect to army applications.

8704-8, Session 2

High-performance and long-range cooled IR technologies in France *(Invited Paper)*

Yann Reibel, Thibault Augey, Sebastien Verdet, David Billon-Lanfrey, SOFRADIR (France); Gérard L. Destéfanis, CEA-LETI-Minatec (France); Eric M. Costard, Alexandru Nedelcu, SOFRADIR (France); Laurent Mollard, Francois Marion, Nicolas Baier, CEA-LETI (France); Olivier Gravrand, CEA-LETI-Minatec (France)

Cooled IR technologies that offer high performances are at the top of DEFIR's priority list.

We have been pursuing further infrared developments on future MWIR detectors, such as the VGA format HOT detector that operates at 150K and the 10µm pitch IR detector which gives us a leading position in innovation In the same time Scorpio LW expands Sofradir's line of small pixel pitch TV format IR detectors from the mid-wavelength to the long-wavelength, broadening the performance attributes of its long wave IR product line.

Finally, our dual band MW-LW QWIP detectors (25µm, 384×288 pixels) benefit to tactical platforms giving an all-weather performance and increasing flexibility in the presence of battlefield obscurants.

These detectors are designed for long-range surveillance equipment, commander or gunner sights, ground-to-ground missile launchers and other applications that require higher resolution and sensitivity to improve reconnaissance and target identification. This paper discusses the system level performance in each detector type.

8704-9, Session 2

Advantages of SWIR-VIS detection means for self-protection suites *(Invited Paper)*

Gil A. Tidhar, Elta Systems Ltd. (Israel)

Optical detection means are required for immediate detection of and direction finding towards launch events of projectiles, rockets, guided missiles and other types of threats. Their operation requires high probability of detection, very low false alarm rate and simple installation of ground vehicles operating in military type scenarios and conditions. H/W complexity and performance gaps have limited wide proliferation of such means to date. We indicate how multi-band low cost and low complexity SWIR-NIR-VIS detection means may provide for an optimal technical solution - with large probability and range of detection, low false alarm rate even when operating in dense man-made interfering environment with simple and rugged design.

8704-10, Session 2

Wide field-of-view dual-band multispectral muzzle flash detection *(Invited Paper)*

Joseph R. Montoya, U.S. Army Research Lab. (United States); Lawrence A. Taplin, FluxData, Inc. (United States); Jorge Melchor Jr., U.S. Army Research Lab. (United States); Pano Spiliotis, FluxData, Inc. (United States)

Sensor technologies are undergoing revolutionary advances, as seen in the rapid growth of multispectral methodologies. Increases in spatial, spectral, and temporal resolution, and in breadth of spectral coverage, render feasible sensors that function with unprecedented performance. A system was developed that addresses many of the key hardware requirements for a practical dual-band multispectral acquisition system, including wide field of view and spectral/temporal shift between dual bands. The system was designed using a novel dichroic beam splitter and dual band-pass filter configuration that creates two side-by-side

images of a scene on a single sensor. A high-speed CMOS sensor was used to simultaneously capture data from the entire scene in both spectral bands using a short focal-length lens that provided a wide field-of-view. The beam-splitter components were arranged such that the two images were maintained in optical alignment and real-time intra-band processing could be carried using only simple arithmetic on the image halves. An experiment related to limitations of the system to address multispectral detection requirements was done. This characterized the system's low spectral variation across its wide field of view. This report will provide lessons learned on the general limitation of key hardware components required for multispectral muzzle flash detection, using the system as a hardware example combined with simulated multispectral muzzle flash and background signatures.

8704-11, Session 3

OTHELLO: a novel SWIR dual-band detection system and its applications *(Invited Paper)*

Gil A. Tidhar, Elta Systems Ltd. (Israel)

A fourth generation of SWIR based optical detection and warning means is presented as the EL/O – 5220 OTHELLO passive Optical Threat Locator, which detects and precisely finds directions towards a source of battle tank gun fire and missile (e.g. Anti-Tank Guided Missiles (ATGMs) Rocket Propelled Grenades (RPGs)) launch events in the battlefield.

OTHELLO hardware is described followed by an explanation of some inherent advantages of SWIR imagers as building blocks for optical detection systems mounted on ground military vehicles at harsh and demanding operating conditions. Finally we describe possible application of OTHELLO with radar systems.

8704-12, Session 3

A miniature ruggedised fast frame rate infrared sensor module for hostile fire detection and industrial applications *(Invited Paper)*

Richard M. Ash, Andrew P. Ashcroft, Peter M. Thorne, Lee Richardson, David Isgar, David Jeckells, Martin Stevens, Asim Malik, Tim Davey, SELEX Galileo Infrared Ltd. (United Kingdom)

A highly ruggedised infra-red sensor assembly has been developed which is suitable for a variety of fast framing (1000 fps) applications in hostile fire detection and in commercial/industrial metrology. The sensor has a 384x384 element array and offers high operability in either mid-wave or long-wave IR applications. The paper will report design concepts and performance data.

8704-13, Session 3

Protecting SWIR cameras from laser threats *(Invited Paper)*

Ariela Donval, Tali Fisher, Ofir Lipman, Moshe Oron, KiloLambda Technologies, Ltd. (Israel)

SWIR cameras offer the advantage of higher resolution and smaller optical systems than conventional mid and far infrared optical systems. With the ability of seeing at low illumination conditions at the near infrared region, it can provide the detection of covert lasers. The ability of laser detection introduces the risk of sensor damage when the laser power is above a certain threat level. Smart protection is therefore needed, that is transparent for low laser intensities and limit or block the high laser intensities, and is effective over a wide band of wavelengths.

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

8704-14, Session 3

A modular packaging approach for upgrading tanks with thermal imagers *(Invited Paper)*

Mario O. Münzberg, Bertram Achtner, Jörg Fritze, Dirk Weisser, Markus Welk, Cassidian Optronics GmbH (Germany)

The thermal imager ATTICA was designed to fit into the thermal sights of the new German Infantry tank PUMA. The very flexible approach for the optical concept, using different folding mirrors allows to meet the different available space requirements for thermal sights also of other tanks like the main battle tank Leopard 2 and the infantry fighting vehicle Marder. These tanks are going to be upgraded in near future. The flexible concepts of the thermal imager optics is realized by appropriate location of lenses, mirrors and micro scanner. The mechanical packing solutions for the different space volumes of the commander periscope and the gunner sights of the vehicles are presented and discussed.

8704-15, Session 3

Challenges and requirements for future vehicle mounted infrared sensors *(Invited Paper)*

John L. Miller, FLIR Systems, Inc. (United States)

Requirements such as FOV, frame rate, data latency and sensitivity and challenges for vehicle mounted Infrared Sensors will be detailed and analyzed, especially as imagers evolve to High definition Format. The impact of HD formats and data rates will be presented. Lessons Learned from integrations of infrared sensors on armored vehicles, unarmored military vehicles and commercial automobiles will be discussed. Comparisons between sensors for driving and those for situation awareness, targeting and other functions will be presented. Conclusions will be drawn regarding future applications and installations.

8704-16, Session 4

Development of a panoramic third generation IRST: initial study and experimental work *(Invited Paper)*

Gianni Barani, SELEX Galileo S.p.A. (Italy); Cristian Luison, Altran Italy S.p.A. (Italy); Monica Olivieri, SELEX Galileo S.p.A. (Italy); Alessandro Rossi, Marco Diani, Univ. di Pisa (Italy); Nicola Acito, Accademia Navale di Livorno (Italy)

The paper introduces the analysis carried out by SelexGalileo for the development of a third generation IRST system based on large format MWIR sensors, separable in blue and red bands. In the feasibility study, physical constraints have been evaluated relying to different optics and scanning options.

The analysis has led to consider a solution in which three or four heads are employed to cover 360° with a resolution better than 0.3 mrad, with a frame-rate of 10 Hz. Each head has a staring IR detector on which an optomechanical device steers the incoming radiation. For the purpose of furnishing a panoramic view of each scanned FOR, two critical aspects have been discussed: (i) the setting of an adequate scanning mechanism to assure an overall system frame-rate of 10 Hz and (ii) the stitching of the collected images while maintaining the bit-depth so as to avoid abrupt changes of SNR at the seams between two subsequent images.

To address the issue of stitching IR images sensed on a maritime scenario, an acquisition system composed of two MWIR cameras has been assembled and mounted on a rotating platform. This set up allows the synchronous acquisition of images from the two cameras. A measurement campaign has been held on board ship to address the stitching of images collected in different operating conditions. Critical aspects concerning both the optics configuration and the scanning system are discussed as well as the software processing developed for the composition of plain panoramic images.

8704-17, Session 4

Sea Spotter - A fully staring naval IRST system *(Invited Paper)*

Michael Y. Engel, Amir Navot, Izhak Saban, Yaakov Engel, Eyal Arad, Nir Shahar, Rafael Advanced Defense Systems Ltd. (Israel)

Infrared sensor technology, high performance computing hardware and advanced detection and tracking algorithms have enabled a new generation of infrared warning systems for navy surface vessels. In this paper we describe SEASPOTTER - a new third-generation naval IRST system, which is unique in offering a fully staring electro-optical imaging head. Starting from naval IRST operational requirements, for both blue water and littoral scenarios, we describe the considerations and constraints that led us to the optical configuration of the sensor head and the supporting hardware. The second part of the paper is dedicated to the target acquisition methodology, including the use of originally developed machine learning technology for target acquisition and tracking.

8704-18, Session 4

Hyperspectral reconnaissance in urban environment *(Invited Paper)*

Ingmar G. Renhorn, Maria Axelsson, Swedish Defence Research Agency (Sweden); Koen W. Benoist, TNO Defence, Security and Safety (Netherlands); Dirk Borghys, Royal Belgian Military Academy (Belgium); Yann G. Boucher, Xavier Briottet, ONERA (France); Rob J. Dekker, TNO Defence, Security and Safety (Netherlands); Alwin Dimmeler, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Ola Friman, Swedish Defence Research Agency (Sweden); Ingebjørg Kåsen, Norwegian Defence Research Establishment (Norway); Maria Lomoro, Ctr. Interforze Studi per le Applicazioni Militari (Italy); Thomas O. Opsahl, Norwegian Defence Research Establishment (Norway); Mark van Persie, National Aerospace Lab. NLR (Netherlands); Salvatore Resta, Ctr. Interforze Studi per le Applicazioni Militari (Italy); Hendrik Schilling, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Piet B. W. Schwering, TNO Defence, Security and Safety (Netherlands); Michal Shimoni, Royal Belgian Military Academy (Belgium)

For hyperspectral imagery sensors, the signal processing includes atmospheric characterisation and correction, spectral properties retrievals, feature extraction based on physics and phenomenology for the purpose of detection and classification algorithms development. High resolution sensor data are used for classification and identification. Processing for trafficability, mission planning and mapping, detections of IEDs, change detection, tracking and rediscovery of vehicles, detection of people and vehicles in hide is in progress. The purpose of the effort is to explore and develop the potential benefit of combined high spatial and spectral resolution airborne imagery for several defence applications in the urban areas.

8704-19, Session 4

A review of the latest developments of MCT infrared technology from visible to VLWIR for space applications at Sofradir *(Invited Paper)*

Philippe Chorier, Patricia Pidancier, Nicolas Jamin, Bruno Fièque, Cédric Leroy, SOFRADIR (France)

For the last ten years, Sofradir space activity has grown and strengthened relying on 25 years of experience in development and production of 2nd and 3rd generation MCT infrared detectors. Based on this experience, Sofradir is conducting major space programs covering all the wavelength range from visible to VLWIR as Sentinel projects in the frame of the GMES program or MTG detectors development and manufacturing for the future European meteorological satellites of third generation. Thus Sofradir is conducting new developments of MCT infrared detectors such as :

- a new generation of SWIR hyperspectral detectors with a format of 1024x1024 / 15 µm pitch
- optimization of MCT performances for VLWIR spectral range aiming at new sounding missions
- developments of new infrared detectors for MTG program

In this paper, a review of the main space programs conducted by Sofradir is presented. A particular emphasis is made on the last developments concerning a new generation of visible – SWIR large format detector with low pixel pitch (1024x1024 / 15 µm pitch), last results regarding MCT VLWIR technology for sounding applications and new MCT infrared detectors for earth observation.

8704-20, Session 5

Miniaturized day/night sight in Soldato Futuro program

Alberto Landini, Altran Italy S.p.A. (Italy); Alessandro Cocchi, Stefano Puntri, Mirela Cojocaru, SELEX Galileo S.p.A. (Italy); Mauro Sardelli, Selex ES S.p.A. (Italy)

The market of the sights for the 5.56 mm assault rifles is dominated by mainly three types of systems: TWS (Thermal Weapon Sight), the Pocket Scope with Weapon Mount and the Clip-on.

The latter are designed primarily for special forces and snipers use, while the TWS design is triggered mainly by the DRI (Detection, Recognition, Identification) requirements. The Pocket Scope design is focused on respecting the SWaP (Size, Weight and Power dissipation) requirements.

Compared to the TWS systems, for the last two years there was a significant technological growth of the Pocket Scope/Weapon Mount solutions, concentrated on the compression of the overall dimensions.

The trend for the assault rifles is the use of small size/light weight (SWaP) IR sights, suitable mainly for close combat operations but also for extraordinary use as pocket scopes – handheld or helmet mounted. The latest developments made by Selex Galileo S.p.A. are responding precisely to the above-mentioned trend, through a miniaturized Day/Night sight embedding state-of-the art sensors and using standard protocols (USB 2.0, Bluetooth 4.0) for interfacing with PDAs, Wearable computers, etc., while maintaining the “shoot around the corner” capability.

Indeed, inside the miniaturized Day/Night sight architecture, a wireless link using Bluetooth technology has been implemented to transmit the video streaming of the rifle sight to an helmet mounted display. The video of the rifle sight is transmitted only to the eye-piece of the soldier shouldering the rifle.

8704-21, Session 5

Next-generation cooled long-range thermal sights with minimum size, weight, and power

Rainer Breiter, Tobias Ihle, Joachim C. Wendler, Ingo Rühlich, Johann Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

Situational awareness and precise targeting at day, night and severe weather conditions are key elements for mission success in asymmetric warfare. To support these capabilities for the dismounted soldier, AIM has developed a family of stand-alone thermal weapon sights 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 design driver for these sights is a long ID range >1500m for the NATO standard target to cover the operational range of a platoon with the engagement range of .50 cal rifles, 40mm AGLs or for reconnaissance tasks. The most recent sight WBZG has just entered into serial production for the IdZ Enhanced System of the German army with additional capabilities like a wireless data link to the soldier backbone computer.

Minimum size, weight and power (SWaP) are most critical requirements for the dismounted soldiers' equipment and sometimes push a decision towards uncooled equipment with marginal performance referring to the outstanding challenges in current asymmetric warfare, e.g. the capability to distinguish between combatants and non-combatants in adequate ranges.

To provide the uncompromised e/o performance with SWaP parameters close to uncooled, AIM has developed a new thermal weapon sight based on high operating temperature (HOT) MCT MWIR FPAs together with a new low power single piston stirling cooler. The core of the sight is put as a clip-on in front of the rifle scope, eye pieces for stand-alone targeting with e.g. AGLs or a bi ocular version for relaxed surveillance are available.

The paper will present details of the technologies applied for such long range cooled sights with size, weight and power close to uncooled.

8704-22, Session 5

Infrared signature reduction of military and law enforcement uniforms

Than Emery, Milliken & Company (United States); Rene Schwarz, SSZ Camouflage Technology AG (Switzerland)

Uniform fabric is treated as part of the manufacturing process with a fine coating containing low emissive properties. This results in low-emissive surfaces with significant reduction of the thermal IR signature.

The fabric can be printed and finished using standard industrial textile production methods.

Fabric maintains breathing and evaporation qualities and does not limit soldiers in their action in any way.

Fire Resistant fabric properties can be included as in regular FR clothing.

8704-23, Session 5

Aural stealth of portable HOT infrared imager

Alexander Veprik, RICOR-Cryogenic & Vacuum Systems (Israel)

Improving SWAP indices and cooldown times of the integral rotary cryogenic coolers of the future HOT infrared imagers will primarily rely on increasing driving speed during boosted cooldown and temperature control operational phases.

The immediate penalty is the increased vibration export resulting from intensification of piston side slaps and micro collisions occurring in the numerous clearances inherent for the crank-slide linkages as typically used to transform rotary motion of the driver into the linear reciprocation of compression and expansion pistons.

In a typical design of a portable infrared imager, the Integrated Detector-Dewar-Cooler Assembly (IDDCA) is directly mounted upon the metal enclosure accommodating optical train and serving as the optical bench and heat sink. Excitation of structural resonances in such enclosures results in excessive noise generation compromising the aural stealth, especially during the cooldown (boost) phase of operation.

Reducing/preloading the above clearances in the mechanical linkages, is not always feasible and leads to the increased manufacturing costs, mechanical complexity, added weight and size, power consumption and negatively affects the life expectancy.

The paper presents the complex approach to a design of aural non-detectable infrared imagers, relying on for mounting IDDCA upon the imager enclosure using silent pad. The author reports on the development of improved silent pad capable of serving wide range of high-speed rotary integral coolers. In particular

The demonstration imager relying on Ricor K562S cryocooler meets the most stringent requirement to 10 meters aural non-detectability distance (per MIL-STD 1474D, Level II) even during boost cooldown phase of operation.

8704-24, Session 6

High-performance bias-selectable dual-band mid-/long-wavelength infrared photodetectors and focal plane arrays based on InAs/GaSb Type-II superlattices *(Invited Paper)*

Manijeh Razeghi, Abbas Haddadi, Anh Minh Hoang, Guanxi A. Chen, Northwestern Univ. (United States)

High performance dual-band infrared imaging is a very powerful tool for different military applications, such as tracking and reconnaissance missions, and civilian safety. In this paper, we report demonstration of high-performance mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) dual-band photodetector and focal plane array (FPA) based on InAs/GaSb Type-II superlattices. At 150K, the MWIR channel, with a 4.83 μm cut-off wavelength, exhibits a quantum efficiency of 52% and the specific detectivitity of 8.8×1011 Jones, with a differential resistance-area product of 802 Ωcm2 at zero bias (R0A). At 77K, the LWIR channel, with an 11 μm cut-off wavelength, exhibits a quantum efficiency of 50% and the specific detectivity of 7×1011 Jones. Under back-side illumination, a temperature evolution study of the MWIR detector's electro-optical performance found the 300K background-limit to be achieved below operating temperatures of 160K for a 50% cut-off wavelength of 5.2μm, and the measured current reached the system limit of 0.1pA at 110K for 30μm pixel-sized diodes.

A highly selective dual-band MWIR/LWIR co-located FPA with 3μm active region thickness per channel was demonstrated. It can perform imaging under high operating temperatures (HOT) for the MWIR band. Excellent imagery from the dual-band imager exemplifying pixel coincidence is shown.

The authors would like to acknowledge support and encouragement of Dr. Fenner Milton, Dr. Meimei Tidrow, Dr. Joseph Pellegrino, and Dr. Bill Clark from the U.S. Army NVESD.

8704-26, Session 6

Thiol passivation of MWIR Type II superlattice photodetectors

Omer Salihoglu, Abdullah Muti, Atilla Aydinli, Bilkent Univ. (Turkey)

Poor passivation on photodetectors can result in catastrophic failure of the device. Abrupt termination of mesa side walls during pixel definition generates dangling bonds that lead to inversion layers and surface traps leading to surface leakage currents that short circuit diode action. Good

passivation, therefore, is critical in the fabrication of high performance devices. Silicondioxide has been the main stay of passivation for commercial photodetectors, deposited at high temperatures and high RF powers using plasma deposition techniques. In photodetectors based on III-V compounds, sulphur passivation has been shown to replace oxygen and saturate the dangling bonds. Despite its effectiveness, it degrades over time. More effort is required to create passivation layers which eliminate surface leakage current.

In this work, we propose the use of sulphur based octadecanethiol (ODT), CH3(CH2)17SH, as a passivation layer for the InAs/GaSb superlattice photodetectors that acts as a self assembled monolayer (SAM). ODT SAMs consist of a chain of 18 carbon atoms with a sulphur atom at its head. ODT Thiol coating is a simple process that consist of dipping the sample into the solution for a prescribed time. Excellent electrical performance of diodes tested confirm the effectiveness of the sulphur head stabilized by the intermolecular interaction due to van der Walls forces between the long chains of ODT SAM which results in highly stable ultrathin hydrocarbon layers without long term degradation.

8704-28, Session 6

Defects and noise in Type-II superlattice infrared detectors

Martin Walther, Andreas Wörl, Volker Daumer, Robert H. Rehm, Lutz Kirste, Frank Rutz, Johannes Schmitz, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); Ralf Scheibner, Johann Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

InAs/GaSb short-period superlattices (SL) have been proven to be well suited for high performance infrared imaging system for the MWIR and LWIR spectral range. Mono- and bi-spectral focal plane arrays (FPA) with excellent infrared imaging properties have been demonstrated. To further improve the performance of those detectors, a detailed knowledge of different defect generation mechanisms during the fabrication process as well as related noise properties is mandatory.

To examine defects in InAs/GaSb Type II superlattices, GaSb substrates and epitaxial InAs/GaSb layers were analyzed by synchrotron white beam X-ray topography (SWBXRT) to characterize the distribution of threading dislocations. Those measurements are compared with wet chemical etch pit density measurements on GaSb substrates and on epitaxial layer structures. The technique uses a wet chemical etch process to decorate threading dislocations and an automated optical analyzing system for mapping the defect distribution.

Dark current and noise measurements on LWIR and MWIR diode structures at 77 K have been carried out with a measurement setup to investigate noise properties of single detector elements. Both for MWIR and LWIR detectors we observe a generation-recombination limited dark current behavior without contributions by surface leakage currents. In the white noise part of the noise spectrum, the extracted diode noise closely matches the theoretically expected shot noise behavior for diodes reaching the bulk dark current limit.

8704-29, Session 6

Time-resolved photoluminescence spectroscopy of minority carrier lifetime in Type-II superlattice infrared detector materials

Blair C. Connelly, Grace D. Metcalfe, Paul H. Shen, Michael Wraback, U.S. Army Research Lab. (United States)

Time-resolved photoluminescence (TRPL) spectroscopy is used to study the minority carrier lifetime in type-II superlattice (T2SL) infrared detector materials to investigate the recombination mechanisms and trap states that currently limit their performance. Time-domain measurements of the photoluminescence signal demonstrate multiple exponential decays, which provide information on background carriers, acceptor states and trap states. The temperature dependence of the lifetime is used to determine the contributions of different recombination mechanisms to the observed carrier lifetime. T2SLs are expected to exhibit lower Auger recombination rates than HgCdTe detectors and possess a smaller thermal generation rate than QWIP detectors. In practice, TRPL measurements have shown that InAs/Ga(1-x)In(x)Sb T2SLs are dominated by non-radiative Shockley-Read-Hall (SRH) recombination, resulting in short minority carrier lifetimes (10's of nanoseconds at 77 K). The trap energy and density are obtained from TRPL measurements on n-type InAs/Ga(1-x)In(x)Sb T2SLs, where trap saturation is observed under sufficiently high injection levels over a range of temperatures. Measurements of "Ga free" InAs/InAs(1-x)Sb(x) T2SLs exhibit contributions from both radiative and non-radiative (both SRH and Auger) recombination, with radiative recombination dominating at low temperatures. This material demonstrates an order-of-magnitude improvement in carrier lifetime, which is attributed to the reduction of non-radiative recombination centers from the superlattice with the elimination of Ga. This result suggests that the SRH trap(s) limiting the carrier lifetime of InAs/Ga(1-x)In(x)Sb T2SLs is native to the Ga(1-x)In(x)Sb layer.

8704-30, Session 6

Designs and characteristics of infrared nBn photodectors based on InAs/InAsSb type-II superlattices

Zhao-Yu He, Oray O. Cellek, Shi Liu, Ha Sul Kim, Jin Fan, Zhiyuan Lin, Yong-Hang Zhang, Arizona State Univ. (United States)

Antimony-based type-II superlattice (T2SL) is strong alternative to HgCdTe for IR detector applications in both MWIR and LWIR range. Recently, a major breakthrough on minority carrier lifetime greater than 500 ns for long-wave Ga-free InAs/InAsSb T2SLs has been reported, which is more than one order of magnitude longer than that of InAs/GaSb T2SL, indicating potentially better photodetector performance and higher operating temperature. High performance devices require both low dark current and high quantum efficiency. Although a thicker layer offers potentially higher quantum efficiency, it also results in higher dark current. Therefore, a trade-off between low dark current and high responsivity is needed to optimize the overall device performance. To comprehensively study this issue, a series of nBn MW and LWIR photodetectors with different absorber layer thicknesses and doping concentrations have been designed, fabricated and characterized. Dark current densities as low as 5×10-4 A/cm2 have been achieved for devices with a 50% cutoff wavelength of 13.2 μm at 77 K. A theoretical model is developed to interpret the device characteristics and a good agreement has been achieved between the calculated dark currents and the experimental results. Detailed modeling results and device characteristics, such as dark current, external quantum efficiency, detectivity, and BLIP temperatures will be presented at the conference.

8704-31, Session 7

Electronic transport in InAs/GaSb type-II superlattices detector structures with reduced sidewall leakage

Gilberto A. Umana-Membreno, Hemendra Kala, The Univ. of Western Australia (Australia); Brianna Klein, Ctr. for High Technology Materials (United States); Jarek Antoszewski, The Univ. of Western Australia (Australia); Nutan Gautam, Maya N. Kutty, Elena Plis, Sanjay Krishna, Ctr. for High Technology Materials (United States); Lorenzo Faraone, The Univ. of Western Australia (Australia)

In this work, we report recent results on the characterization of vertical and longitudinal electronic transport parameters in InAs/GaSb type- II superlattices for infrared detectors. The samples studied were grown by molecular beam epitaxy (MBE) on GaSb substrates. Top and bottom heavily p-type doped layers were employed as ohmic contacts regions to a lightly doped p-type “absorber”-like superlattice region consisting of 300 superlattice periods, each defined by 14 monolayers (ML) of InAs and 7 ML of GaSb. The composition and doping of this region are similar to the absorber region of long-wave IR detectors in this material system [1,2]. Vertical electronic transport characterization was performed on circular geometry test-structures, in a configuration similar to standard normal incidence single pixel photodiodes, which were realized employing wet chemical etching to minimize the influence sidewall leakage currents. Longitudinal transport parameters were obtained employing a greek-cross Van-der-Pauw test-structures fabricated on the same wafer die. Magnetic-field dependent geometrical magnetoresistance, for the vertical configuration, and resistivity and Hall-effect measurements were measured from 80 to 300K, at magnetic field intensities up to 12 Tesla, which were analyzed using a high-resolution mobility spectrum technique.

[1] A. Rogalski, Opto-Elect. Rev. 16, pp. 458–482, 2008.

[2] B. Klein, E. Plis, M. N. Kutty, N. Gautam, A. Albrecht, S. Myers, and S. Krishna, J. Phys. D 44(7), p. 075102, 2011.

8704-32, Session 7

Low-frequency noise behaviour of MWIR Type-II InAs/GaSb superlattice photodiodes

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We describe the noise characteristics of InAs/GaSb superlattice (SL) Mid-Wavelength Infrared (MWIR) photodiodes addressing the influence of unpassivated sample and also SiO2 and Si3N4 passivated samples for reverse bias condition. These samples were realized by molecular beam epitaxy (MBE) on an n-type (001) GaSb substrate. The noise measurements exhibited a frequency dependent plateau for unpassivated as well as Si3N4 passivated samples whereas low noise suppression with a noise current reduction of more than one order of magnitude was observed for SiO2 passivation. For reverse bias values below -0.15 V, the classical Schottky- noise calculation alone did not appear to describe the noise mechanism in a SL noise behavior, which shows a divergence between theoretically and experimentally determined noise values. We find, the additional noise appears for, with and without passivation, at the surface activation energy of < 60 meV and is inversely proportional to the reverse bias. It is believed to be caused by the surface states which depend on the reverse bias. By taking into account of activation energies, the re-calculated noise results showed good agreement to experimental data. Moreover, the calculated D* at the -0,1V bias and 79K for unpassivated, Si3N4 and SiO2 passivated samples are 1.1x1011, 2.8x1010 and 1.2x1013 Johnes, respectively.

8704-33, Session 7

High-performance MWIR type-II superlattice detectors

Henk Martijn, Carl Asplund, Rickard Marcks von Würtemberg, Hedda Malm, IRnova AB (Sweden)

A VGA format type-II superlattice focal plane array (FPA) for the mid-wave infrared (MWIR) atmospheric window has been designed, manufactured and characterized. This FPA will be used in an IDCA (Integrated Dewar Cooler Assembly) with low weight, size and power. The detector material is based on a heterojunction structure with a barrier that effectively decreases the Shockley-Read-Hall based component of the dark current. A very effective passivation method has been used which successfully inhibits all surface leakage currents. The barrier structure has a 50 % cutoff at 5 µm and 65 % quantum efficiency without antireflective coating. The dark current density is 3×10-6 A/cm2 at -0.05 V bias and 120 K. The optical cavity of the detector has been optimized for maximum capture of available light in the MWIR window. A focal plane array with 640 by 512 pixels and 15 µm pitch was processed based on this barrier structure. High-quality imagery in a system with high F-number will be presented.

8704-35, Session 7

Infrared photodetectors and emitters with InAsSb bulk active region

Ding Wang, Youxi Lin, Dmitry Donetsky, Leon Shterengas, Gela Kipshidze, Gregory Belenky, Stony Brook Univ. (United States); Stefan P. Svensson, Wendy L. Sarney, U.S. Army Research Lab. (United States)

Mid-wave and long-wave infrared barrier photodetectors and emitters with the bulk InAsSb active regions with 20% and 44% Sb grown by MBE on metamorphic buffers have been demonstrated.

The photodetectors were grown with 1-micron-thick undoped active regions and AlInAsSb barriers. The devices with a mesa diameter in the range from 200 to 400 um were fabricated by dry etching followed by silicon nitride passivation. Operating at 80 K without reverse bias, the uncoated devices showed the quantum efficiency of 40 % at the wavelength of 5 micron and differential resistance area product RoA of 60 Ohm cm^2. At T = 13 K RoA was 125 kOhm cm^2.

As LED, the devices of similar design showed the 80K output power levels of 90 uW and 8 uW at the peak wavelengths of 5 and 8 micron, respectively.

8704-36, Session 7

Multiwafer production of epitaxy-ready 4” GaSb: substrate performance assessments pre- and post-epitaxial growth

Mark J. Furlong, Rebecca J. Martinez, Sasson Amirhaghi, Andrew Mowbray, Brian Smith, Wafer Technology Ltd. (United Kingdom); Dmitri Loubychev, Joel M. Fastenau, Amy W. K. Liu, IQE Inc. (United States)

In this paper we describe the volume production of 4” GaSb substrates suitable for the epitaxial growth of GaSb based infrared detector structures. Using a modified version of the Czochralski (Cz) technique, large diameter (4”-5”) GaSb mono-crystals have been grown that demonstrate very low levels of dislocation density, as measured by etch pit density assessments, optical defect recognition microscopy and X-Ray Diffraction (XRD). This work also describes our latest work on surface finishing and the outputs from a new larger format (20 x3” or 10 x4”) substrate polishing platform will be described. The surface quality of 4” GaSb substrates will be determined by optical profilometry, Nomarski optical microscopy and spectroscopic ellipsometry (SE). SEMI/ASTM standard flatness assessments of multi-wafer polished 4” GaSb substrates will also be presented. The structural properties of MBE grown GaSb detector structures will be assessed by high-resolution X-Ray diffraction. The surface quality of GaSb epiwafer surfaces will be determined by Atomic Force Microscopy (AFM).

With a 4” GaSb manufacturing capability established, we will comment on the future outlook for the production of larger substrate volumes and make comparisons with the quantities of other materials used in the fabrication of infrared detector devices.

8704-37, Session 7

MBE growth of Sb-based nBn photodetectors on large diameter GaAs substrates

Dmitri Lubyshev, Joel M. Fastenau, Yueming Qiu, Amy W. K. Liu, IQE Inc. (United States); Edwin J Koerperick, Jonathon T Olesberg, Dennis Norton Jr., ASL Analytical (United States); Nikolai N Faleev, Christiana B Honsberg, Arizona State University (United States)

The GaSb-based family of materials and heterostructures provides rich bandgap engineering possibilities for a variety of infrared (IR) applications. Mid-wave and long-wave IR photodetectors are progressing toward commercial manufacturing applications, but to succeed they must move from research laboratory settings to general semiconductor production and they require larger diameter substrates than the current standard 2-inch and 3-inch GaSb. Substrate vendors are beginning production of 4-inch GaSb, but another alternative is growth on 6-inch GaAs substrates with appropriate metamorphic buffer layers.

We have grown generic MWIR nBn photodetectors on large diameter, 6-inch GaAs substrates by molecular beam epitaxy. Multiple metamorphic buffer architectures, including bulk GaSb nucleation, AlAsSb superlattices, and graded GaAsSb and AlInSb ternary alloys, were employed to bridge the 7.8% mismatch gap from the GaAs substrates to the GaSb-based epilayers at 6.1 Å lattice-constant and beyond. Reaching ~6.2 Å extends the nBn cutoff wavelength from 4.2 to >5 µm, thus broadening the application space. The metamorphic nBn epiwafers demonstrated unique surface morphologies and crystal properties, as revealed by AFM, XRD, and cross-section TEM. Different relaxation mechanisms were observed for different buffer architectures, with GaSb nucleation leading to a more island-like surface morphology while graded ternary buffers resulted in cross-hatched surface morphology. Low root-mean-square roughness values of 5-20 Å were obtained, and cross-wafer optical and structural measurements showed excellent epilayer uniformity, with PL wavelength variation <0.1 µm. This work demonstrates a promising path to satisfy the increasing demand for even larger area focal plane array detectors in a commercial production environment.

8704-38, Session 8

Wavelength selective wideband uncooled infrared sensor using a two-dimensional plasmonic absorber

Shinpei Ogawa, Mitsubishi Electric Corp. (Japan); Junya Komoda, Kyohei Masuda, Masafumi Kimata, Ritsumeikan Univ. (Japan)

A wavelength selective wideband uncooled infrared (IR) sensor at middle-wavelength and long-wavelength infrared (MWIR and LWIR) region has been developed using two-dimensional plasmonic absorber (2D PLA). 2D PLA is the Au-based 2D periodic hole-array structure, where the photon can be manipulated by its surface plasmon-like mode. The numerical investigations demonstrate that the wavelength of the absorption can be mainly controlled by the surface period and the slight influence of the depth and diameter. A microelectromechanical systems-based uncooled IR sensor with 2D PLA was fabricated through a complementary metal oxide semiconductor (CMOS) and a micromachining technique. 2D PLA was formed by Au layer sputtered on the perforated SiO2. However, the backside of SiO2 absorbs the incident light scattered on the cavity walls under 2D PLA, which produces additional absorption peak at LWIR. The Al layer was introduced to the backside of the 2D PLA in order to reflect the scattering light and prevent the absorption of SiO2. The measurement of the spectral responsivities shows that the selective enhancement of responsivity was achieved over both MWIR and LWIR, where the wavelength of the responsivity peak coincided with the period of the 2D PLA. The results obtained here are the direct evidence that a wideband wavelength selective IR sensor was realized only by the surface structure of 2D PLA without vertical control. It indicates that a pixel array where each pixel has a different detection wavelength would be developed for multi-color imaging by a standard CMOS and a micromachining technique.

8704-39, Session 8

Three Dimensional Dual-band Stacked Microbolometer Design using resistive dipoles and slots

Hoo Kim, Dean P. Neikirk, The Univ. of Texas at Austin (United States)

A dual-band microbolometer with separate absorption of each wavelength band would be desirable for multispectral applications. In addition, a three dimensional (3D) stacked structure would be advantageous for size and integration in focal plane arrays. We present designs for a 3D stacked dual-band microbolometer based of the in-band and out-of-band reflection and transmission characteristics of resistive dipoles and slots. The mechanism of individual absorption in each layer of a dual-band microbolometer is analyzed and simulated to allow the resistive slot layer to efficiently absorb the LWIR band while a superposed resistive dipole layer absorbs the MWIR band. The top dipole layer is designed to have peak absorption at 5 µm, with a second underlying slot layer and mirror layer designed to have peak absorption at 10 µm. Between the top and bottom layers and mirror are λ/4 air gaps. Optimal sheet resistances for each layer's absorption is found from simulation. The resistive dipole layer is used as a top layer because of its out-of-band transmission characteristic so that other wavelengths of the incident radiation can reach the bottom layer. The resistive slot layer is used as the bottom layer because of its out-of-band reflection characteristic works as a mirror to the top layer. This combination of two different types of layers provides highly efficient wavelength selective absorption, yielding calculated power absorption efficiency of nearly 100 % for both LWIR and MWIR bands.

8704-40, Session 8

Vertically Integrated Pixel Microbolometers for IR Imaging Using High Resistivity VOx

Hitesh A. Basantani, Hang-Beum Shin, Thomas N. Jackson, Mark W. Horn, The Pennsylvania State Univ. (United States)

Uncooled IR bolometers form an integral part of thermal imaging cameras. Vanadium oxide material currently used for IR imaging has a resistivity between 0.1 and 1 ohm-cm and a TCR between -1.4%K-1 to -2.4%K-1. Higher TCR materials are desired, however, such materials inevitably have higher resistivity and therefore higher electrical resistance in a lateral resistor configuration. A high resistance leads to an increase in the Johnson-Nyquist noise of the bias-induced current, thereby limiting the performance of bolometers using high resistivity material. In this work, we propose the use of temperature dependent through-film conductivity as an alternate pixel structure design with lower Johnson noise when compared with the conventional lateral pixel design. Biased Target Ion Beam Deposition was used to deposit high resistivity vanadium oxide thin-films (~100 nm thick). Electrical characterization of lateral resistor structures showed resistivities ranging from 1.2 x 10^4 ohm-cm to 2 x 10^4 ohm-cm, TCR varying from -3.4%K-1 to -4.4%K-1, Johnson noise (pixel resistance of 300KΩ) of 4.7 to 6µV/√Hz and 1/f noise (normalized Hooge's parameter (α/n)) of 5 x 10-18 to 1 x 10-16 cm-3. In contrast, the through-film resistor structures showed significantly higher resistivities at 9 x 10^4 Ohm-cm to 1.55 x 10^5 Ohm-cm, TCR similar to lateral resistive structure between -3.4%K-1 to -4.5%K-1, immeasurably low Johnson noise (pixel resistance of 48KΩ) and normalized Hooge's parameter ranging from 1x10-18 to 1x10-21 cm-3. These results indicate the possible use of through-film resistors as an alternative to the conventional lateral-resistor design currently used in uncooled imaging microbolometers.

8704-41, Session 8

High-performance LWIR microbolometer with Si/SiGe quantum well thermistor and wafer level packaging

Audun Roer, Sensonor Technologies AS (Norway)

An uncooled microbolometer with peak responsivity in the long wave infrared region of the electromagnetic radiation is developed at Sensonor. It is a 384 x 288 focal plane array with a pixel pitch of 25µm, based on monocrystalline Si/SiGe quantum wells as IR sensitive material.

The high sensitivity (TCR) and low 1/f noise are the main performance characteristics of the product. The frame rate is maximum 60Hz and the output interface is digital (LVDS).

The quantum well thermistor material is transferred to the read-out integrated circuit (ROIC) by wafer bonding. The ROIC wafer containing the released pixels is bonded in vacuum with a silicon cap wafer, providing hermetic encapsulation at low cost. The resulting wafer stack is mounted in a standard ceramic package.

In this paper the architecture of the pixels and the ROIC, the wafer packaging and the electro-optical measurement results are presented.

8704-42, Session 9

Memorial Tribute for Paul Kruse

Marion B. Reine, Photon Detector Physics, LLC (United States)

No Abstract Available.

8704-43, Session 9

Uncooled infrared detector with 12um pixel pitch video graphics array

Tsutomu Endoh, NEC Corp. (Japan)

We have developed an uncooled infrared detector with 12um pixel pitch VGA.

Reduction of pixel size is cost-effective for thermal imaging cameras as well as reducing size, weight, and power (SWaP) of them.

But reduction of pixel size causes decrease of signal to noise ratio (SNR).

To improve the SNR with 12um pixel pitch, we have developed highly sensitive bolometer material, thermal isolated structure for the pixel and newly designed read-out IC (ROIC).

The bolometer material has been improved by using vanadium niobium oxide.

As a result, we have achieved temperature coefficient of resistance (TCR) -3.6%/K, which is 2 times higher than the conventional bolometer.

For thermal isolated structure, we have used triple level sacrificial layer to achieved thermal conductance (Gth) 6nW/K, which is 2 times higher than the conventional structure.

As the imaging area is reduced by the pixel size, the uniformity of pixel can be improved. This enables to remove the non-uniformity correction circuit in the ROIC, which is effective for low power and low noise.

Furthermore, in order to facilitate the infrared detector use, on-chip ADC with 14bit

pipeline, 13.5MHz and 0.2W, has been developed.

The performance of the 12um pixel pitch 640 x 480 VGA will be discussed.

8704-44, Session 9

Large-format 17µm high-end VOx µ-bolometer infrared detector

Udi Mizrahi, Shimon Elkind, Aviho Giladi, Yoav Hirsh, Michael Labilov, Igor Pivnik, Niv Shiloah, Mchael T. Singer, SCD Semiconductor Devices (Israel); Avi Tuito, Michael Ben-Ezra, SIBAT (Israel); Naamah Argaman, Itay Shtrichman, SCD (Israel)

Long range sights and targeting systems require a combination of high spatial resolution, low temporal NETD, and wide field of view. For practical electro-optical systems it is hard to support these constraints simultaneously. Moreover, achieving these needs using the relatively low-cost Uncooled µ-Bolometer technology is a major challenge in the design and implementation of both the bolometer pixel and the Readout Integrated Circuit (ROIC).

In this work we present measured results from a new, large format (1024×768) detector array, with 17µm pitch. This detector meets the demands of a typical armored vehicle sight with its high resolution and large format, together with low NETD of better than 35mK (at F/1, 30Hz). We estimate a Recognition Range for a NATO target of better than 4 km at all relevant atmospheric conditions, which is better than standard 2nd generation scanning array cooled detector. A new design of the detector package enables improved stability of the Non-Uniformity Correction (NUC) to environmental temperature drifts.

8704-45, Session 9

Temperature stability improvement of a QVGA uncooled infrared radiation FPA

Koichi Ishii, Hiroto Honda, Hideyuki Funaki, Ikuo Fujiwara, Keita Sasaki, Hitoshi Yagi, Kazuhiro Suzuki, Honam Kwon, Masaki Atsuta, Toshiba Corp. (Japan)

We have developed the low-cost uncooled infrared radiation focal plane array (FPA) requiring no thermoelectric cooler (TEC), which has the 320 x 240 detection pixels with 22 um pitch. The silicon single-crystal series p-n junction diodes and the low-noise readout circuit on a same SOI wafer fabricated by 0.13 um CMOS technology were utilized for IR detection. The temperature dependencies in the readout circuit were eliminated by correlated double sampling (CDS) operation with reference pixel which is insensitive to infrared radiation.

For greater temperature stability, we improved the reference pixel and the readout circuit. Although the reference pixels should be completely insensitive to IR radiation, prior reference pixels showed significant sensitivity. The improved reference pixel was formed by partially releasing with bulk-micromachining and it was verified to be insensitive to IR radiation by an object of more than 200 degrees. The readout circuit had a differential amplifier instead of a single transistor amplifier and an analog digital converter (ADC). In each potion, CDS was operated respectively for reducing temperature dependencies. The first CDS operation was used for eliminating the pixel output variation and the second operation was used for canceling the variation of the differential amplifier. The output variation of the circuit was reduced to less than 1/20 compared with the prior circuit.

With these improvements, the sensitivity variation of the FPA was improved to be within 10 percents in the range of -30 degrees to 80 degrees and noise equivalent temperature difference (NETD) of 40 mK was achieved.

8704-46, Session 9

BAE Systems' 17mm LWIR camera core for civil, commercial, and military applications

Jeffrey H. Lee, BAE Systems OASYS, LLC (United States)

BAE Systems' uncooled foundry is now running its 17m pixel pitch Long Wave Infrared (LWIR) Sensor based on Vanadium Oxide (VOx) Bolometers in full rate production at its Night Vision Sensors facility in Lexington, MA. The camera core is optimized for size weight and power while maintaining focal plan performance and compatibility with a diversity of video interfaces. The focal planes run in 30Hz and 60Hz progressive modes at a VGA (640x480) resolution. The camera core consumes very little power with an all-digital video and control interface. The camera core is available with system specific interface boards which enable combinations of interfaces ranging from Cameralink to analog RS170 in addition to micro display drivers. Its software and firmware are fully upgradable through its USB 2.0 port. The USB port also gives users access to its internal frame capture memory of up to 100 lossless images. The mechanical package of the camera core with the baseline interface board, is packed into 1.67 in3 [1.24" x 1.305" x 1.03" - L x W x H] and weighs just under 1.4 oz.

For the IR Sensors and Systems Track

This abstract has been submitted to SPIE for consideration of being presented at the 2013 Defense and Securities Conference. Any further distribution or use must be approved by BAE Systems

8704-47, Session 9

Low-cost uncooled VOx infrared camera development

Chuan C. Li, DRS Technologies, Inc. (United States)

This paper will discuss the most recent uncooled VOx microbolometer infrared detector and camera developments at DRS. Major development activities including integrated camera system design, design-to-cost methodology and advanced manufacturing technologies aiming at reducing the camera size, weight, power and productioin costs will be discussed and some preliminary results will be presented

8704-48, Session 9

Uncooled detector development at Raytheon

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

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

8704-99, Session 9

80x80 VPD PbSe: the first uncooled MWIR FPA monolithically integrated with a Si-CMOS ROIC

Germán Vergara, Rodrigo Linares-Herrero, Raul Gutierrez Alvarez, Carlos Fernandez-Montojo, Luis J. Gómez, Victor Villamayor, Arturo Baldasano-Ramirez, Maria Teresa Montojo Supervielle, New Infrared Technologies, Ltd. (Spain)

In the work it is presented a breakthrough in the field of low cost uncooled infrared detectors: an 80x80 MWIR FPA of VPD PbSe. The device is the result of depositing by thermal evaporation the active material (a thin layer of polycrystalline PbSe) directly on the corresponding Si-CMOS circuitry processed on 8" Si wafers. After depositing, the material is submitted to a specific sensitization process. The new device represents a milestone in the road towards affordable uncooled MWIR imagers.

Due to fundamental reasons, low cost uncooled IR imagers have poor performances in terms of velocity of response and high frame rates. The new detector presented in this work fills the gap. The device is able to provide MWIR images to rates as high as 2 KHz-full frame, in real uncooled operation, more than 1 order of magnitude above the existing standard low cost uncooled technologies. For the first time affordable infrared imagery will fulfill the requirements demanded for the study of dynamic processes and the detection of fast events. As remarkable fact, the technology opens the MWIR band to SWaP concept.

8704-50, Session 10

Low SWaP MWIR detector based on XBn focal plane array *(Invited Paper)*

Philip Klipstein, Daniel Aronov, Eyal Berkowicz, Yossi Cohen, Rami Fraenkel, Alex Glozman, Yoav Gross, Steve Grossman, Olga Klin, Inna Lukomsky, Tuvy Markovitz, Lior Shkedy, Itay Shtrichman, Noam Snapi, Michael Yassen, Eliezer Weiss, SCD Semiconductor Devices (Israel); Avi Tuito, SIBAT (Israel); Michael Ben-Ezra, IMOD (Israel)

Over the past few years, we have developed a new type of High Operating Temperature (HOT) photon detector at SCD, which operates in the upper MWIR window of the atmosphere (3.4-4.2 micron). This window is generally more transparent than the lower MWIR window (4.4-4.9 micron), especially for mid and long range applications. The detector has an InAsSb active layer, and is based on the new "XBn" device concept. We have analyzed various electro-optical systems at different atmospheric temperatures, based on XBn-InAsSb operating at 150K and epi-InSb at 95K, respectively, and find that the typical recognition ranges of both detector technologies are similar. Therefore, for very many applications there is no disadvantage to using XBn-InAsSb instead of InSb. On the other hand XBn technology confers many advantages, particularly in low Size, Weight and Power (SWaP) and in high reliability of the cooler and Integrated Detector Cooler Assembly (IDCA). In this work we present a new IDCA, designed for 150K operation. The 15 micron pitch 640x512 digital FPA is housed in a robust, light-weight, miniaturised Dewar, attached to Ricor's K562S Stirling cycle cooler. The complete IDCA has a diameter of 28 mm, length of 80 mm and weight of < 300 gm. The total IDCA power consumption is ~ 3W at a 60Hz frame rate, including an external miniature proximity card attached to the outside of the Dewar. We will describe some of the key performance parameters of the new detector, including its NETD, RNU and operability, pixel cross-talk, and early stage yield results from our production line.

8704-51, Session 10

Quantum-engineered mid-infrared type-II InAs/GaSb superlattice photodetectors for high-temperature operation

Zhaobing Tian, Theodore Schuler-Sandy, The Univ. of New Mexico (United States); Stephen A. Myers, Brianna Klein, Elena Plis, Sanjay Krishna, Ctr. for High Technology Materials (United States)

Over the last several years, owing to the material improvement and the implementation of advanced device architectures, antimony-based type-II superlattice (SL) infrared (IR) photodetectors and their focal plane arrays (FPAs) have made significant progress. Here we present our effort towards the development of high operating temperature

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SL photodetectors, which utilizes a interband cascade scheme with discrete InAs/GaSb SL absorbers, sandwiched between election and hole barriers. This low-noise architecture, has enabled background-limited operation above 170 K (BLIP, 300 K, 2π field-of-view), as well as above room temperature response in Mid-IR. The detector yields a dark current density of 2.1×10-7 A/cm2(1.4×10-3 A/cm2) at -5 mV, and a Johnson-limited D* of 1.4×1011 cmHz1/2/W (1.2×109 cmHz1/2/W) at 150 K (room temperature), respectively. In this presentation, we will discuss the operation principles of the cascade structure, and our most recent progresses of mid-wave infrared photodetectors toward high temperature operation.

8704-52, Session 10

Fabrication of high-operating temperature (HOT), visible to MWIR, nCBn photon-trap detector arrays

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We describe our recent efforts in developing visible to mid-wave (0.5 μm to 5.0 μm) broadband photon-trap InAsSb-based infrared detectors grown on GaAs substrates operating at high temperature (150-200K) with low dark current and high quantum efficiency. Utilizing an InAsSb absorber on GaAs substrates instead of an HgCdTe absorber will enable low-cost fabrication of large-format, high operating temperature focal plane arrays. We have utilized a novel detector design based-on pyramidal photon trapping InAsSb structures in conjunction with compound barrier-based device architecture to suppress both G-R dark current, as well as diffusion current through absorber volume reduction. Our optical simulation show that our engineered pyramid structures minimize the surface reflection compared to conventional diode structures acting as a broadband anti-reflective coating (AR). In addition, it exhibits > 70-80% absorption over the entire 0.5 μm to 5.0 μm spectral range while providing up to 3x reduction in absorber volume.

Lattice-mismatched InAs0.82Sb0.18 with 5.25 μm cutoff at 200K was grown on GaAs substrates. 128x128/60um detector arrays that consist of bulk absorber as well as photon-trap pyramid structures were fabricated to compare the detector performance. The measured dark current density for the diodes with the pyramidal absorber was 3x lower that for the conventional diode with the bulk absorber, which is consistent with the volume reduction due to the creation of the pyramidal absorber topology. We have achieved high D* (> 1.0 x 1010 cm √Hz/W) and maintain high (> 80 %) internal quantum-efficiency over the desired band at 200K.

8704-53, Session 10

MWIR InAsSb barrier detector data and analysis

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The AWARE Broadband program requires photon trap detector architecture to achieve pioneering performance of MWIR detectors at 200 K. One of the ambitious requirements is to obtain high (> 80 %) quantum efficiency over the broad 0.5 um to 5.0 um spectral range while maintaining high D* (> 1.0E11 cm √Hz/W) in the 3.0 um to 5.0 um spectral range. Electromagnetic simulations show that using pyramids as photon trapping structures minimizes the reflection and maximizes absorption to > 90 % over the entire 0.5 um to 5.0 um spectral range. InAs1-xSbx as the absorber layer with a cutoff wavelength ~ 5.1 um at 200 K has been grown on GaAs and photon trap barrier detectors and barrier detectors without pyramids have been fabricated in a 1024 x 1024 format on an 18 um pitch. A 1024 x 1024 ROIC on an 18 um pitch designed to interface with the barrier detector arrays have also been fabricated.

MWIR III-V nBn detectors in a 1024 x 1024 format were hybridized to fanouts to permit direct measurement of the electrical and optical properties of detectors without going through an ROIC. Multiple 18 um x 18 um detectors were tied together in parallel by connecting the Indium bump of each detector to a single large metal pad on the fanout. The dark current density at -1 V bias for a 64 x 64 and 6 x 6 array of detectors, each of which are tied together in parallel is ~ 1E-3 A/cm^2 at 200 K and 5E-6 A/cm^2 at 150 K. The 4096 and 36 18 um x 18 um detectors both have similar Jdark vs Vd characteristics, demonstrating high operability and uniformity of the detectors in the array. The external QE measured using a narrow band filter centered at ~ 4 um had values in the 65 – 70 % range. Since the detectors were illuminated through a GaAs substrate which has a reflectance of 29%, the internal QE is greater than 90 %. Also measured is the QE at 150 K for a 1024 x 1024 detector array hybridized to a ROIC. QE measured at the FPA (detector hybridized to a ROIC) level matches the QE measured on detectors that were measured directly through a fanout chip. Additional response and noise measurements are being conducted and that data will also be presented.

8704-54, Session 10

High-performance bias-selectable dual-band short-/mid-wavelength infrared photodetectors and focal plane arrays based on InAs/GaSb/AlSb Type-II superlattices *(Invited Paper)*

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Active and passive imaging in a single photodetector based on the combination of short-wavelength and mid-wavelength infrared (SWIR/MWIR) detection is highly needed in a number of tracking and reconnaissance missions. We report the demonstration of high-performance bias-selectable dual-band short-/mid-wavelength infrared photodetectors and focal plane arrays (FPAs) based on InAs/GaSb/AlSb type-II superlattices (T2SLs) with designed cut-off wavelengths of 2.2 and 4.5μm at 150K. At 150 K, the short-wavelength channel exhibited a quantum efficiency of 55%, and a dark current density of 1.0×10-9 A/cm2 at -50 mV bias voltage, providing an associated shot noise detectivity of 3.0×1013 Jones. The mid-wavelength channel exhibited a quantum efficiency of 33% and a dark current density of 2.6×10-5 A/cm2at 300 mV bias voltage, resulting in a detectivity of 4.0×1011 Jones. The operations of the both absorber channels are selectable by changing the polarity of applied bias voltage.

Using the same detector design, a dual-band SWIR/MWIR FPA capable of active and passive imaging was demonstrated. A bi-layer etch-stop scheme is introduced for back-side illuminated detectors which enhanced the external quantum efficiency both in the SWIR and MWIR spectral regions. Excellent imagery from the dual-band imager exemplifying pixel coincidence is shown.

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8704-55, Session 10

Modeling of InAsSb/AlAsSb nBn HOT detector's performance limit *(Invited Paper)*

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InAsSb with cut-off wavelength covering 3-12 m IR range has provided alternative to HgCdTe alloy as for as IR detection systems are concerned. There has been enormous progress in development of the InAsSb focal plane arrays (FPA) and strained superlattices (SL). The higher operation temperature (HOT) conditions were successfully achieved with AIIIBV unipolar barrier structures, where InAsSb/AlAsSb system plays dominant role.

The performance of medium wavelength infrared (MWIR) InAsSb-based nBn detectors, called also "bariodes", is examined theoretically taking into account thermal generation governed by the Auger and radiative mechanisms. In our model, the heterojunction barrier-active region (absorber) was assumed to be decisive as the contributing dark current mechanism limiting nBn's detector performance. Since there is no depletion layer in the active layer of such devices, the generation-recombination and trap assisted tunneling mechanisms are suppressed leading to lower dark currents in bariode detectors in comparison with standard diodes.

Detailed analysis of the detector's performance (such as dark current, RA product, and detectivity) versus bias voltage, operating temperatures, and structural parameters are performed pointing out optimal working conditions. The theoretical predictions of bariode parameters are compared with experimental data published in the literature. Finally, the InAsSb nBn performance is compared with standard p-on-n InAsSb photodiodes and HgCdTe nBn detectors operated at room temperature with the same bandgap wavelength.

8704-56, Session 10

Numerical simulation of lateral collection and crosstalk in back-illuminated InAs nBn detector arrays

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This paper will present recent results from our three-dimensional finite-element numerical simulations of back-illuminated InAs nBn infrared detector arrays. These simulations have led to several important results. First, these simulations have helped us to better understand the dark current and photocurrent mechanisms that operate in this fundamentally new type of semiconductor quantum detector, and have led us to some simple analytical expressions that describe the I(V) curves and quantum efficiency versus bias voltage for an "ideal" nBn detector in which the dark current is due only to diffusion current from the absorber and collector layers. We validated these analytical expressions by comparing them against the numerical simulations. Second, these simulations have revealed a new lateral transport mechanism based on "trapping" of minority photocarriers (holes) in a p-type barrier layer, which explain the anomalously long lateral collection lengths (hundreds of µm) for photocarriers measured in InAs and InAsSb nBn detectors with p-type barrier layers that have been reported by two groups. Third, these simulations have allowed us to calculate the I(V) curves, quantum efficiency and crosstalk in a 3x3 back-illuminated InAs nBn array with 15x15 μm^2 pixels, with a variety of mesa sizes and diffusion lengths in the absorber layer. We believe that these 3D numerical simulations play a critical role in understanding the basic physical mechanisms that govern the behavior and performance of nBn detectors and arrays.

8704-133, Session 10

Design and performance evaluation of high-aspect ratio mesa delineated HgCdTe mid-wavelength detectors for high-operating temperatures

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Raytheon Vision Systems (RVS) is evaluating the performance optimization of molecular beam epitaxy (MBE) grown mid-wavelength infrared (MWIR) HgCdTe-on-Silicon double layer heterojunction (DLHJ) and triple layer heterojunction (TLHJ) detector designs for high operating temperature performance (~ 200 K). RVS has been using high-aspect ratio, deep dry-etching to form a photonic crystal for 3D photon trapping in the single-color DLHJ HgCdTe detector absorber to achieve a reduction in active detector and junction volume, and associated dark current, while also maintaining high quantum efficiency (QE). This approach has now been extended to dual-band TLHJ HgCdTe detectors where a broadband MWIR detector with two discrete spectral bands can be realized using a back-to-back photodiode detector architecture and performance optimization for high operating temperature performance can be focused on the longer wavelength spectral band. Conventional deposition techniques for CdTe passivation are challenging for small pixel geometries, high-aspect ratios, and advanced detector designs such as those necessary for 3D photon trapping with increased p-n junction perimeter to surface area ratios. To address this, atomic layer deposition (ALD) of CdTe with metal organic chemical vapor deposition (MOCVD) is being evaluated to conformally coat the sidewalls of deep dry-etched devices.

This paper will describe two-dimensional TCAD semiconductor device simulations performed by RVS to evaluate critical detector design parameters and performance at high operating temperature for DLHJ and TLHJ HgCdTe detector architectures with and without 3D photon trapping designs, and report on recent experimental results for these detectors. Results will also be reported for the evaluation of ALD deposition of CdTe on high-aspect ratio dry-etched mesa sidewalls and the application of this technique in the fabrication of DLHJ MWIR HgCdTe detectors.

8704-58, Session 11

Nickel-oxide film as an AR coating of Si window for IR sensor packaging

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Infrared (IR) transparent window is necessary to the IR sensor package. Most commonly used materials for IR transparent window are Ge (germanium) and Si (silicon). Ge has an excellent optical properties but it has a disadvantage of an expensive price. Si has a merits of inexpensive cost and CMOS process compatibility but it has a lower transmittance in the range of LWIR (long wavelength IR) region (8~12um) than Ge. Therefore, anti-reflection (AR) coating is necessary to increase the transmittance of Si as an IR transparent window in the LWIR region.

In this paper, we design the simple single layer AR coating. Among the various materials, nickel oxide was selected as an AR coating material due to its suitable optical properties and simple process. Nickel oxide film was deposited onto the double side polished (100) orientation CZ (Czochralski) Si wafer by reactive rf sputtering with Ni target in an environment of Ar and O2 mixed gas. FT-IR was used to measure the transmittance of the samples in the LWIR region. After the nickel oxide film was sputtered onto the double side of the silicon wafer, the measured transmittance of the Si wafer was increased over 20% in the LWIR region than that of uncoated Si wafer. Additionally, annealing effect on the transmittance of the Si wafer with nickel oxide coating was studied. With increasing the annealing temperature from 300°C to 500°C, additional increase of transmittance was achieved.

8704-59, Session 11

High-resistant multispectral optical coatings for infrared applications

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Infrared optics which are built into optical systems for outdoor applications are required to transmit high-quality images and signals with long-time stability. It must do so despite harsh environmental conditions and process-induced impacts on optical components and their coatings. DLC – also referred to as "hard carbon" IR coatings – represent the state-of-the-art in optical systems of thermo-sensor-based monitoring plants for industrial, civil and military applications. They can be manufactured on such materials as silicon or germanium. This can be achieved, in the simplest case, through adaptation of refractive indexes (single-layer coating). This coating is industry standard.

The newly developed Hybrid-DLC coating unites lasting resistance with the strongly improved transmittance of a dielectric coating (Fig.1). This enables the capability to selectively manufacture customized IR windows of highest durability and lowest residual spectral reflection. A sophisticated design and production process makes it possible to minimize internal coating tensions and, hence, warrant the durability and adhesive power in accordance with such established testing standards as TS 1888 (Windscreen-Wiper Test) or MIL.

In addition, these spectral properties can be achieved in two separate wavelength ranges (e.g. MWIR and LWIR). Multispectral coatings of this type provide users of coatings with new solutions in design and application. By way of example, Fig. 2 shows a multispectral Hybrid-DLC coating with optimized transmittance as a dual band coating with the properties of e.g. a transmission >85% for 3-5 µm a transmission of >90% for 8-11,5µm.

Therefore, an optical element that has been used to provide protection only with a narrow AR window is now a multifunctional tool including protection, a wide AR window and a dual-band filter coating which leads to less optical components in the lens system and therefore saving optical design space and weight.

The new approach in multifunctional and resistant optical elements requires much more a sophisticated coatings set-up. While the standard DLC coatings consists of one single layer is the stack of single layers for the Hybrid-DLC with up to 50 layers on each optical surface.

The state of the art of durable infrared coatings with coating designs and internal coating tension is described in this paper together with projections into the future.

8704-60, Session 11

Dual- and triple-band AR coatings for IR systems

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Abstract: Dual-band infrared camera systems allow viewing and comparison of the 3-5µ and 8-12µ spectrum regions, improve visibility at sunrise/sunset and help distinguish between targets and decoys. They also enhance the ability to defeat many IR countermeasures such as smoke, camouflage and flares. As dual band 3rd generation FLIR systems progress, we introduce coatings for these systems. This paper describes advanced dual band coatings for the 3-5µ and 8-12µ spectrum regions, with reference to single band coatings. Theoretical and measured designs are shown for ZnSe, ZnS, Ge, & IG-6 substrates. Triple band AR coatings with additional transmittance at 1.06µ are also demonstrated.

8704-61, Session 11

New solutions and technologies for uncooled infrared imaging

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The military uncooled infrared market is driven by the continued cost reduction of the focal plane arrays whilst maintaining high standards of sensitivity and steering towards smaller pixel sizes.

Two approaches can come into play: the bottom up option consists in allocating improvements to each contributor and the top down proccess rather rely on an overall optimization of the complete image channel.

The University of Rennes I with Thales Angénieux alongside has been working over the past decade through French government fundings, on low cost alternatives of infrared materials based upon chalcogenide glasses.

A special care has been laid on the enhancement of their mechanical properties and their ability to be molded according to complex shapes.

New manufacturing means developments capable of better yields for the raw materials will be addressed, too.

Beyond the mere lenses budget cuts, a wavefront coding process can ease a global optimization.

This technic gives a way of relaxing optical constraints or upgrading thermal device performances through an increase of the focus depthes and desensitization against temperature drifts: it combines image processing and the use of smart optical components. Thales achievements in such topics will be enlightened and the trade-off between image quality correction levels and low consumption/ real time processings, as might be required in hand-free night vision devices, will be emphasized.

It is worth mentioning that both approaches are deeply leaning on each other.

8704-62, Session 11

A practical approach to LWIR wafer-based optics for thermal imaging systems

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The development and implementation of wafer level packaging for commercial microbolometers has opened the pathway towards full wafer-based thermal imaging systems. The next challenge in development is moving from discrete element LWIR imaging systems to a wafer based optical system, similar to lens assemblies found in cell phone cameras. This paper will compare a typical high volume thermal imaging design manufactured from discrete lens elements to a similar design optimized for manufacture through a wafer based approach. We will explore both performance and cost trade offs as well as review the manufacturability of all designs.

8704-63, Session 11

Dewar-level integrated MWIR wavefront sensor for high-sensitivity optical quality control

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Recent developments in the Mid Wave InfraRed (MWIR) optical domain were made on materials, optical design and manufacturing. They answer increasing demands for more compact, less temperature dependent optical systems with increased optical performances and complexity (multi- or hyper- spectral imagery). At the same time, the characterization of these components has become strategic and requires solutions with higher performance.

The optical quality of such devices is measured by wavefront sensing techniques. PHASICS previously developed wavefront sensors based on Quadri-Wave Lateral Shearing Interferometry (QWLSI) using broadband microbolometers cameras for infrared measurements. However they suffer from reduced light sensitivity in the MWIR domain, which limits their use with broadband sources such as black bodies. To meet metrology demands, we developed an innovative wavefront sensor. This instrument combines the metrological qualities of QWLSI with the radiometric performances of a last generation detection block (Infrared Detector Dewar Cooler Assembly, IDDCA) with a quantum infrared focal plane array (IRFPA) of HgCdTe technology.

The key component of QWLSI is a specific diffractive grating placed a few millimeters from the focal plane array. This requirement implies that this optics should be integrated inside the IDDCA. To achieve this, we take advantage of the experience acquired from recent developments with optics integrated in IDDCA. Thanks to this approach, we developed a high spatial resolution MWIR wavefront sensor (160x128 points) with a high sensitivity for accurate measurements under low-flux conditions.

This paper will present the instrument technological solutions, the development key steps and experimental results on various metrology applications.

8704-64, Session 11

Cryogenic wafer-level MWIR camera: laboratory demonstration

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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. This miniaturization will become feasible with the integration of optical functions in the detector area. In the field of cooled infrared imaging systems, the detector is positioned in a Dewar and the constraints on the size and weight of such integrated optics are so demanding that downscaled versions of traditional systems with a single optical axis are reaching their limits because of a loss of resolved points in the final image.

In the field of infrared, we take advantage of the progress in micro-optics to design a multichannel cooled infrared camera directly integrated on the detector. This wafer-level camera uses state of art microlenses with a high sag height. This optical system has a field of view of 120°. The additional mass of the optics is sufficiently small to be compatible with the cryogenic environment of the Dewar. The performance of this camera will be discussed. Its characterization has been carried out in terms of the modulation transfer function and the noise equivalent temperature difference (NETD). The optical system is limited by the diffraction. By cooling the optics, we achieve a very low NETD equal to 15 mK compared with traditional infrared cameras. A postprocessing algorithm that aims at reconstructing a well-sampled image from the set of undersampled raw subimages produced by the camera is proposed and validated on experimental images.

8704-66, Session 11

New multiband IR imaging optics

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Materials are needed for multiband IR imaging applications with transparency over a broad spectral range covering SWIR, MWIR and LWIR wavelength regions. The choices are often limited to zinc sulfide (ZnS), zinc selenide (ZnSe), Germanium (Ge) and a few commercially available IR glasses. Many of these materials have fixed refractive indices and cannot be tailored for dispersion compensation over a broad spectral region as is needed for multiband achromats. We have been expanding the materials available for these applications by developing new IR glasses having broadband transmission with different refractive indices and dispersion profiles. We have also developed a rugged MILTRAN ceramic that is 3-5 times harder than ZnS and ZnSe. Using Zemax with the expanded database of these new materials, we have designed a dual band achromat with only 19 µm focal shift between MWIR and LWIR. High optical quality polishing methods for both the MILTRAN ceramics and IR glasses are being developed. The status of our current effort in developing multiband achromats will be presented.

8704-68, Session 11

Dual-band infrared picture-in-picture demonstrator

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No abstract available.

8704-132, Session 11

Challenges, constraints and results of lens design in 8-12 micron waveband for bolometer-FPAs having a pixel pitch ≤12micron

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In the 8-12 micron waveband Focal Plane Arrays (FPA) are available with a pixel pitch of 12 microns or less. High resolution FPAs with VGA and XGA resolution should become available at a reasonable price. These will require new lens designs to give the required fields of view.

The challenge for the Optical Designer is to design lenses where the pixel pitch of the detector is the same as the wavelength of the light imaged. The lens specification will need to give more thought to the resolution required by the system.

A smaller pixel pitch detectors defines a requirement for a shorter focal length to give the same field of view. This will have a number of effects upon the lens design. The geometrical aberrations decrease proportionally with the focal length. Reverse telephoto layouts become more common, particularly when the system has a shutter. The increase in pixel count will require wide field of view lenses which present particular challenges.

The impact of diffraction effects on the lens design is considerably

increased. The fast F-number causes an increase in the diffraction limit of the system, but also increases the geometric aberrations by a cube law. Therefore the balance between the diffraction limited and the aberration limited performance becomes more difficult.

The first approach of the designers is to re-use proven design originally intended for use with 17 micron detectors. Some of these designs will have adequate performance at the Nyquist limit of 12 micron detectors.

Even smaller detector pitches, such as 10 micron, will demand new approaches to Infra Red lens design. The traditional approach will quickly increase the number of elements to 3 or more. This could lead to the lenses with medium fields of view driving the system cost. It will become necessary for a close cooperation between the camera developer and lens designer to explore alternate approaches such as wavefront coding in order to reach the most cost effective solution.

8704-67, Session 12

Wide-angle catadioptric optics for broadband applications

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Many design approaches to color correction of infrared optics have evolved from theories presented by first-order linear equations, but that has only been half the battle. Geometric forms and glass properties have limited the development of well-corrected lenses when faced with higher order color and aberration correction. In this paper we will discuss broad spectral multi-band imaging with specific recognition in fast catadioptric wide-angle systems. The result of this work will illustrate a solution yielding a compact well-corrected lens for advanced imaging applications.

8704-69, Session 12

Optical methods for the optimization of system SWAP-C using aspheric components and advanced optical polymers

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We describe the benefits to camera system SWAP-C associated with the use of aspheric molded glasses and optical polymers in the design and manufacture of optical components and elements. Both camera objectives and display eyepieces, typical for night vision man-portable EO/IR systems, are explored. We discuss optical trade-offs, system performance, and cost reductions associated with this approach in both visible and non-visible wavebands, specifically NIR and LWIR. Example optical models are presented, studied, and traded using this approach.

8704-70, Session 12

Enhanced processability of ZrF4-BaF2-LaF3-AlF3-NaF glass in microgravity

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Fluorozirconate glasses, such as ZBLAN (ZrF4-BaF2-LaF3-AlF3-NaF), are ideally suited for Infrared (IR) optical transmission. However, crystallites formed during the fabrication processes deteriorate mechanical properties and prevent this glass from achieving its desired transmission range. The temperature at which the glass can be drawn into a fiber is known as the working range, defined as (Tx – Tg), bounded by the glass transition temperature (Tg) and the crystallization temperature (Tx). In contrast to Silica glasses, the working temperature range for ZBLAN glass is extremely narrow. Multiple ZBLAN samples were subject to a heating and quenching test apparatus on the parabolic aircraft, under a controlled 0-g and hyper-g environment and compared with 1-g ground tests. Optical microscopy examination elucidates crystal growth in ZBLAN is suppressed when processed in a microgravity environment. The crystallization temperature, Tx, at which crystals form increased, therefore, significantly broadening the working temperature range for ZBLAN.

ZBLAN samples were placed inside a single fused silica ampoule which was inserted at the end of a pushrod to place the samples inside the test apparatus. Each ampoule contained two, 2-3 mm (0.79 in - 0.11 in.) by 1.03 mm (0.041 in.) diameter samples. These samples were separated by a small piece of silica glass, of similar length but slightly larger diameter, 1.09 mm (0.043 in.). Tests were conducted to carefully characterize the temperature variation in the test apparatus. Differential Scanning Calorimetry (DSC) tests were independently conducted to verify the Tg.

8704-71, Session 12

Precise optomechanical characterization of assembled IR optics

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The imaging quality of assembled optical systems is strongly influenced by the alignment errors of the individual lenses in the assembly. Although instrumentation for characterizing centering errors for the visual spectral range existed for some time, the technology to include the LWIR (8-12µm) and the MWIR (3-5µm) spectral ranges was only recently developed. Here, we report on the development and performance of such a measurement system that is capable of fully characterizing the alignment of all individual elements of an IR lens assembly in a non-contact and non-destructive fashion.

The main component of the new instrument is an autocollimator working in the LWIR that determines the position of the center of curvature of each individual IR lens surface with respect to the instruments reference axis. This position data are used to calculate the shift and tilt of the individual lenses with respect to each other or a user-defined reference axis like e.g. the assembly housing. Finally, to complete the whole picture, the thicknesses and air gaps between individual lenses are measured with a low coherence interferometer built into the instrument. In order to obtain precise data, the instrument software takes the measured real centering error into account and directs the user to optimally align the assembly with respect of the interferometer reference axis, which then determines the position of the vertex positions along the optical axis and from these the center thicknesses of each lens and the air gaps between lenses with an accuracy below one micrometer.

8704-72, Session 13

2.2 micron, uncooled, InGaAs photodiodes, and balanced photoreceivers up to 25 GHz bandwidth

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We report lattice mismatched, uncooled, 2.2 Micron wavelength cutoff, InGaAs Photodiodes and Balanced Photoreceivers with bandwidth up to 25 GHz. The responsivity at 2.05 micron is 1.2 A/W, and the 1 dB compression, optical current handling of these photodiodes is 10 mA at 7V reverse bias. Such high current handling capacity allows these photodiodes and balanced photoreceivers to operate with a higher DC Local Oscillator (LO) power, thus, allowing more coherent gain and shot noise limited operation. The impulse response of these devices shows rise time/fall time of ~15 ps, and Full Width Half Maximum (FWHM) of

~20 ps.

The InGaAs Photodiodes are optically sensitive from 1.2 to 2.2 Micron, and can be used at both 1.55 Micron and 2.05 Micron wavelength for imaging and LIDAR applications. With the advent of 25 GHz Digital Signal Processing (DSP), Analog to Digital Converters (ADC) and Digital to Analog Converters (DAC), these high speed InGaAs Photodiodes and Balanced Photoreceivers act as a perfect front end, for very high speed imaging, as well as LIDAR systems which can be operated uncooled at 300K.

8704-73, Session 13

Development of high-sensitivity SWIR APD receivers

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Emerging short wavelength infrared (SWIR) LIDAR and long range laser rangefinder systems, require large optical aperture avalanche photodiodes (APDs) receivers with high sensitivity and bandwidth. A large optical aperture is critical to increase the optical coupling efficiency and extend the LIDAR sensing range of the above systems. In order to achieve high receiver sensitivity both APD noise and transimpedance amplifier (TIA) noise need to be reduced. Dark current and capacitance of large area APDs increase with increasing APD aperture and thus limits the sensitivity and bandwidth of receivers. Spectrolab has been developing low excess noise APDs with impact ionization engineering (I2E) designs since 2009. Spectrolab has demonstrated APDs with optical gain over 100 utilizing multiple I2E structures in the APD multiplier. These high gain I2E APDs showed an excess noise factor less than 0.15.

In this paper, Spectrolab will discuss our recent progresses in the development of large area and low excess noise of I2E APDs. The main efforts are focused on optimization of APD design and epitaxial growth. APDs with optical aperture as large as 300 microns are fabricated and fully characterized. Large-area, high sensitivity I2E APD receivers are built using low-noise TIAs and detailed characterization data will be presented at the meeting.

8704-74, Session 13

Multifunction InGaAs detector with on-chip signal processing

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Advanced electro-optical systems are designed towards a more compact, low power, and low cost solution with respect to traditional systems. Integration of several components or functionalities, such as infrared imager, laser designator, laser range finder (LRF), into one multi-function detector serves this trend. SNIR Read-Out Integrated Circuit (ROIC) incorporates this high level of signal processing and with relatively low power consumption. In this paper we present measured results from a Focal Plane Array (FPA) where the SNIR ROIC is Flip-Chip bonded to a 15µm pitch VGA InGaAs detector array. The FPA is integrated into a metallic vacuum sealed package.

We present InGaAs arrays with dark current density below 1.5nA/cm2 at 280K, Quantum Efficiency larger than 75% at 1550nm, and operability better than 99.5%. The metallic package is integrated with low power proximity electronics which delivers Camera Link output. The overall power dissipation is less than 1W, not including Thermo-Electric Cooling (TEC), which is required in some applications.

The various active and passive operation modes of this detector will be reviewed. Specifically, we concentrate on the high gain mode with low readout noise for Low Light Level imaging application, and the Asynchronous Laser Pulse Detection (ALPD) with remarkably low detection thresholds.

8704-75, Session 13

Long-range night/day human identification using active-SWIR imaging

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Positive identification of personnel from a safe distance is a long-standing need for security and defense applications. Advances in computer face recognition have made this a reliable means of identification when facial imagery of sufficient resolution is available to be matched against a database of mug shots. Long-range identification at night requires that the face be actively illuminated; however, for visible and NIR illumination, the intensity required to produce high-resolution long-range imagery typically creates an eye-safety hazard. SWIR illumination makes active-SWIR imaging a promising approach to long-range night-time identification. We will describe an active-SWIR imaging system that is being developed to covertly detect, track, zoom in on, and positively identify a human target, night or day, at hundreds of meters range. The SWIR illuminator pans, tilts, and zooms with the imager to always just fill the imager field of view. The illuminator meets Class 1 eye-safety limits (safe even with magnifying optics) at the intended target, and meets Class 1M eye-safety limits (safe to the naked eye) at point-blank range. Close-up night-time facial imagery will be presented along with experimental face recognition performance results for matching SWIR imagery to a database of visible mug shots at distance.

8704-76, Session 13

A novel optical gating method for laser gated imaging

Ofer Nesher, Ron Schneider, Eyal Zohar, Ran Ginat, Elbit Systems Ltd. (Israel)

For the past 15 years, Elbit Systems is developing time-resolved active Laser-Gated Imaging (LGI) systems for various applications. LGI systems are based on high sensitive gated sensors, synchronized to pulsed laser sources. A significant characteristic of the LGI is its ability to penetrate a disturbing media, such as rain, haze and some fog types. Elbit propriety multi-pulse per frame method, which is being implemented in LGI systems, further improves the imaging quality.

Current LGI systems are based on Image Intensifiers (II) sensors, limiting the system parameters such as spectral response, image quality, reliability and cost. A novel propriety optical gating module was developed in Elbit, untying the dependency on the II. The optical gating module is independent on the radiance wavelength and located between the system optics and the sensor. This method supports the use of conventional solid state sensors. By selecting the appropriate solid state sensor, the new LGI systems can operate at any desired wavelength.

In this paper we present the new gating method characteristics, performance and its advantages over the II gating method. The use of the gated imaging systems is described in a variety of applications, including results from latest field experiments.

8704-77, Session 14

Large format MWIR and LWIR detectors at AIM

Johann Ziegler, Holger Bitterlich, Rainer Breiter, Martin Bruder, Petra Fries, Richrad Wollrab, Joachim C. Wendler, Jan Wenisch, AIM INFRAROT-MODULE GmbH (Germany)

AIM's roadmap indicates a wide range of efforts to improve the performance and expand the capability of MCT FPA IR detectors. Emphasis is placed on MWIR and LWIR large-format FPAs, which offer superior spatial resolution required for applications such as rotorcraft pilotage, persistent surveillance or threat level determination in personnel targets. Adding to these benefits, operation in the LWIR spectral range offers superior detection in cluttered battlefield scenery and under adverse visibility conditions as well as short integration times for observation of fast-moving objects.

To put these advantages into practice, AIM is producing on the basis of its well established 640 x 512 pixel, 15 µm pitch staring detector a MWIR and LWIR 1280 x 1024 pixel design with 15 µm pitch size. Benefitting from continuous improvements of traditional liquid phase epitaxy (LPE) and n-on-p array technology, excellent electro-optical performance has been achieved for this new large format detector design. In parallel, the performance of MCT material grown by molecular beam epitaxy (MBE) on GaAs substrates, which is being developed to take advantage of 3rd generation device architecture, is evaluated for this application.

In this paper we will present AIM's MWIR and LWIR detector roadmap for different formats, pixel pitches (e.g.10µm) and operating temperatures and will report electro-optical performance and IR images of MWIR and LWIR FPAs fabricated by both LPE and MBE.

8704-78, Session 14

Megapixel array developments at Selex Galileo

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SELEX Galileo will present progress on our megapixel array development programmes and will include progress on the FALCON HD1920x1080p 12um pitch array. This device is 3-side buttable which provides a route to producing larger mosaic arrays that are affordable by using them as elements of a mosaic array assembly. Arrays have been fabricated using MCT grown by MOVPE on low cost GaAs substrates. An update on array test results will be given. Progress on mosaic assembly will be given along with detail on some of the technical challenges.

8704-79, Session 14

Recent progress in MCT detectors in France

Gérard L. Destéfanis, Olivier Gravrand, CEA-LETI-Minatec (France); Michel Vuillermet, David Billon-Lanfrey, SOFRADIR (France)

The exceptional physical properties of MCT and the maturity of the technology allows today the fabrication of more and more complex infrared FPAs with this material, keeping the highest performance.

Larger and larger arrays with smaller and smaller pitches can be achieved in a large variety of cut of wavelengths such as SWIR, MWIR, LWIR, and VLWIR (including the visible). Pitch reduction has for first consequence an increase of the resolution but is also a major element for consumption reduction.

Thanks to fundamental considerations based on minority carrier lifetime, these FPA present, on suitable technologies, lower and lower dark currents. As a consequence they can operate at larger and larger temperature reducing power consumption and making better reliability of cryogenic systems (SWAP).

New advanced functions can be addressed with more complex design of the pixel such as multicolor detection with MCT hetero-structures grown by MBE, or fast and noiseless amplification in the pixel using avalanche photodiodes (APD), or signal processing with smart read out circuit made with advanced foundries (0.18µm or less).

This paper gives an overview of the most recent developments at Sofradir and Leti joint laboratory 'DEFIR" on MCT detectors.

First a focus is made on high quality material developments than are the major key for all kind of devices: large CZT single crystals (115mm diameter), large MCT lattice matched epitaxies grown by LPE and MBE.

Then new developments on planar p on n technology are described on several bands from SWIR to VLWIR. As an illustration, detectors that operate in MWIR band (5.2µm) at high temperature (150K) with a high operability (above 99.5%).are presented, together with ultra-low dark current (0.06é/s) SWIR detectors. Other data on TV size LWIR and TV/2 size VLWIR (up to 15µm cut off) will be given in this paper.

In parallel, FPA with a pitch of 10µm were fabricated in MWIR band that present excellent performances, opening the way for more compact classical size FPAs (TV) or reasonable size very large FPAs (several millions pixels).

The fabrication of avalanche photodiodes could lead recently to the fabrication of SWIR APDs that operate at room temperature and of a high frame rate FPA (320x256 with a pitch of 30µm, 1.500frame/s) that operates at 2.5µm and presents a very low dark current and a high operability (above 99.5% for a gain of 10 at 80K).

8704-80, Session 14

Temperature dependence of 1/f noise, defects and dark current in small pitch MWIR and LWIR HDVIP® HgCdTe FPAs

Roger L. Strong, Michael A. Kinch, John M. Armstrong, DRS Sensors & Targeting Systems, Inc. (United States)

Reducing an array's pixel pitch reduces the size and weight of the focal plane array (FPA) and its associated dewar, cooler and optics. Higher operating temperatures reduce cool-down time and cooler power, enabling reduced cooler size and weight. High operating temperature small pitch (<15 um) infrared detectors are therefore highly desirable. We have characterized a large number of MWIR and LWIR FPAs as a function of temperature and cutoff wavelength to determine the impact of these parameters on the FPA's dark current, 1/f noise and defects. The 77K cutoff wavelength range for the MWIR arrays was 5.0-5.6 um, and 8.5-11 um for the LWIR arrays. DRS' HDVIP® FPAs are based on a front-side illuminated, via interconnected, cylindrical geometry, N+/N/P architecture.

The 1/f noise is manifested as a tail in the rmsnoise distribution. We have found that the model-independent skewness of the rmsnoise distribution is a highly effective tool for quantifying the magnitude of an FPA's 1/f noise.

Quartile Skewness = (Q3+Q1-2*Q2)/(Q3-Q1)

In this paper we show that a normal FPA's 1/f noise varies as ni (the intrinsic carrier concentration), in agreement with models that treat dislocations as donor pipes located within the P-volume of the unit cell. Nonstandard FPAs have been observed with systemic 1/f noise which varies as the square of ni.

8704-81, Session 14

Planar p on n LWIR and VLWIR FPA made with MCT

Nicolas Baier, Laurent Mollard, CEA-LETI (France); Olivier Gravrand, Gérard L. Destéfanis, CEA-LETI-Minatec (France); Guillaume Bourgeois, Jean-Paul Zanatta, CEA-LETI (France); Alexandre Kerlain, Laurent Rubaldo, Alain Manissadjian, SOFRADIR (France); Jean-Christophe Peyrard, Délégation Générale pour l'Armement (France)

In this paper, we report on results obtained both at CEA/LETI and SOFRADIR on p-on-n HgCdTe Infra-Red Focal Plane Arrays (IR FPAs) for the Long-wave (LW) and the Very-long-wave (VLW) spectral ranges. For many years, p-on-n arsenic-ion implanted planar technology has been developed and improved within the framework of the joint laboratory DEFIR. Compared to n-on-p, p-on-n technology presents lower dark

current and series resistance. Consequently, p-on-n photodiodes are well-adapted for very large FPAs operating either at high temperature or very low flux.

The long wave (LW) spectral ranges have been firstly addressed with TV/4, 30 µm pitch FPAs. Our results showed state-of-the-art detector performances, consistent with “Rule 07” law, a relevant indicator of the maturity of photodiode technology. The subsequent development of p-on-n imagers has produced more compact, less energy consuming systems, with a substantial resolution enhancement.

Space applications are another exciting but challenging domains, and are good candidates for the p-on-n technology. In this way, TV/4 arrays, 30 µm pixel pitch, have been manufactured for the very long wave spectral range. For this detection range, the quality of material and reliability of technology are the most critical. Detectors with different cutoff wavelength have been manufactured to aim 12.5 µm at 78K, 12.5 µm at 40K and 15 µm at 78K. Electro-optical characterizations reveal homogeneous imagers with excellent current operabilities (over 99.9% at best). The results highlight the very good quality of p-on-n technology with carrier diffusion limited dark current, fitting the “Rule 07” law, and high quantum efficiency.

8704-57, Session 15

Numerical simulation of quantum efficiency and crosstalk in IR photon-trapping structures

Jonathan Schuster, Boston Univ. (United States); Enrico Bellotti, The Boston Univ. Photonics Ctr. (United States)

The main goal of this work is to evaluate the efficiency and crosstalk of HgCdTe photon trapping structure arrays. We first solve the electromagnetic problem using the finite-difference time-domain method which yields the optical generation rate in the pillars. We then use the finite element method to perform drift diffusion simulations using this optical generation rate by simultaneously solving the carrier continuity and Poisson equations on a three-dimensional finite element grid. We then use this model to evaluate the quantum efficiency and crosstalk as a function of surface charge and surface recombination velocity.

8704-82, Session 15

Analysis of propellant combustion with real-time multispectral infrared camera

Grégory Vincent, Emilie Sakat, Sylvain Rommeluère, Charles Erades, Sidonie Lefebvre, Franck Cauty, ONERA (France); Stéphane Collin, Jean-Luc Pelouard, Lab. de Photonique et de Nanostructures (France); Riad Haïdar, ONERA (France)

Infrared spectroscopy is widely used for gas identification, because of specific spectral absorption/ emission of species in this wavelength range. Numerous spectrometers have been developed, based on different principles: Fourier Transform InfraRed (FTIR) spectrometers [FER2006, ROM2008], filtering wheels with standard infrared cameras [NAR2010], OPOs [BER2009]... Each technology has its own abilites: high or low spectral resolution, real-time acquisition, imaging ability, large or narrow operating spectral window...

In this paper, we present a real-time mid-infrared multispectral camera based on multichannels optical architecture. The system is made of a standard HgCdTe focal plane array, stacks of microlenses arrays and nanostructured spectral filters array [HAI2010, COL2010]. Experimental results are shown: spectral images of a lighter flame, of propellant combustion and of Bragg filters.

We present experimental set-up, and measurements, and we also describe an algorithm used to retrieve spectral signatures of objects. We thus demonstrate the ability of our system to record fast phenomena and to discriminate objects thanks to their spectral signature.

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8704-83, Session 16

Thermal imagers: from ancient analog video output to state-of-the-art video streaming

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In military especially in military vehicle applications, the video output of thermal imagers have been stayed constant over almost two decades. When the famous Common Modules were deployed in high numbers the thermal image at first was presented to the observer in the eye piece only. In the early 1990s TV cameras were attached and the standard output was CCIR. In the civil camera market output standards changed to digital formats a decade ago and norms were established and vanished again where video compression and digital video streaming is nowadays state-of-the-art.

The reasons why the output technique in the thermal world stayed unchanged over such a long time are: The very conservative view of the military community, long planning and turn-around times of programs and a slower growth of pixel number of thermal imagers in comparison to consumer cameras. Therefore for a long time the analogue output was satisfactory. This has changed in the meantime.

For thermal imagers with megapixel detectors the CCIR output format is not sufficient any more to handle the interface and the data rate. The paper discusses the state-of-the-art compression and streaming solutions for thermal imagers and the pros and cons with respect to military applications.

8704-84, Session 16

On-chip temporal multiplexing with a digital focal plane array

Christy Fernandez-Cull, Andrew Bolstad, Brian M. Tyrrell, MIT Lincoln Lab. (United States)

With emerging active-pixel focal planes, image plane coding strategies can be transferred to the pixel architecture. Digital-pixel focal plane array (DFPA) technology, which MIT Lincoln Laboratory has been developing for several years, is a promising enabling technology for such applications. In this work, we investigate applicability of a DFPA ROIC capable of a 1 kHz global frame rate and a much higher-rate on-chip temporal multiplexing capability, in which each pixel is modulated by a time-varying, pseudo-random, and binary-valued signal. We experimentally show that a high-resolution series of frames can be reconstructed from a low temporal resolution image with minimal loss in spatial resolution. Knowledge of the temporal code combined with a non-linear total variation regularization algorithm enables 3D (x,y,t) estimation from a 2D (x,y) temporally encoded image. This paper will focus on simulations and experimental results associated with 3D data recovery from a 2D multiplexed image.

8704-86, Session 16

Solid state temperature-dependent NUC (non-uniformity correction) in uncooled LWIR (long-wave infrared) microbolometer FPAs (focal plane arrays)

Christel-Loic Tisse, Yanpeng Cao, MTech Imaging Pte. Ltd. (Singapore)

In uncooled LWIR microbolometer imaging sensors, temperature fluctuations of the FPA result in thermal drift and gain non-uniformity, both of which generate undesirable FPN (Fixed-Pattern-Noise) that is difficult to remove using traditional, individual shutterless and TEC-less (Thermo-Electric Cooling) techniques.

We introduce a novel single-based image processing approach that marries statistical scene-based and calibration-based NUC algorithms, without relying on accurate global or local motion estimation between frames, to compensate the resulting temperature-dependent non-uniformity.

Our method exploits local spatial statistics of both the observed scene and the FPA's temperature distribution. Firstly, an empirical behavioural model is derived by calibration to characterize the spatio-temporal response of the microbolometric FPA to environmental and scene temperature variations. Secondly, under the assumption of strong spatial redundancy between adjacent pixels, we start by estimating the optimal NUC parameters within the homogenous regions of the thermal infrared image so as to locally minimize their intensity variance. We then make use of the estimated correction parameters from these regions of interest to infer the NUC profile across the entire image.

The performance and robustness of the proposed temperature-adaptive NUC method are demonstrated by showing results obtained from a 640x480 pixels uncooled microbolometer operating over an wide temperature range of < –5°C to >65°C.

8704-87, Session 16

Benefits in sensitivity and detection using oversampled imaging sensors

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Current generations of Infrared sensors can be limited by undersampling the image. This results in aliasing, loss of information, and higher missed detections and false alarms from several image data sources.

Recently, several programs have been exploring smaller pixel Infrared sensors. Cyan Systems is developing small pixel oversampling technology focused on improving the resolution and acuity of IR Focal Plane Sensors and related image processing. This new class of oversampled IR sensors will help extend the detection range, and improve acuity in turbulent and hazy conditions over larger pixel IR focal plane array sensors.

Improvements in Oversampling processing concepts will be demonstrated using simulations and sensor design.

We will show quantitative data to illustrate the improvements in resolution, NEP, detection range, and false alarm suppression of the oversampled IR sensor. Also, we will show high fidelity photon shot noise Monte Carlo modeling of the performance of the Oversampled FPA and compare key performance metrics with current generation of IRFPAs.

8704-88, Session 16

MT3250BA: a 320 x 256 - 50µm microbolometer ROIC for high-resistance detector arrays

Tayfun Akin, Middle East Technical Univ. (Turkey) and Mikro-Tasarim Ltd. (Turkey); Selim Eminoglu, Mikro-Tasarim San.ve Tic. Ltd. Sti. (Turkey)

This paper reports the development of a new microbolometer ROIC (MT3250BA) suitable for detector arrays with high pixel resistance. MT3250BA is the first microbolometer ROIC product from Mikro-Tasarim Ltd., which is a fabless IC design house specialized the development of monolithic imaging sensors and ROICs for hybrid imaging sensors. MT3250BA has a format of 320 x 256 and pixel pitch of 50 µm, developed with the system-on-chip architecture in mind, where all the timing and biasing for this ROIC are generated on-chip without requiring any external inputs. MT3250BA is a highly configurable ROIC, where many of its features can be programmed through a 3 wire serial interface allowing on-the-fly configuration of many ROIC features. MT3250BA has 2 analog video outputs that can be programmed in 2 or 1-output modes with a selectable analog reference for pseudo differential operation. Unlike other bolometer readout circuits, it performs snapshot operation allowing proper imaging operation without any motion artifact. The ROIC runs at 10MHz and supports frame rate values above 100fps in the 2-output mode. The integration time can be programmed from 0.1µs up to 100ms in steps of 0.1 µs. The ROIC uses 3.3 V supply voltage and dissipates less than 55mW in the 1-output mode. MT3250BA is fabricated using a modern mixed-signal CMOS process on 200 mm CMOS wafers, and tested parts will be available in the first quarter of 2013 either in wafer or die levels with test reports and wafer maps. A USB based compact camera electronics and imaging software is also available for quick evaluation of this new ROIC.

8704-89, Session 16

MT6415CA: a 640 x 512 - 15µm CTIA ROIC for SWIR InGaAs detector arrays

Tayfun Akin, Selim Eminoglu, Mikro-Tasarim San.ve Tic. Ltd. Sti. (Turkey)

This paper reports the development of a new low-noise CTIA ROIC (MT6415CA) suitable for SWIR InGaAs detector arrays for low-light imaging applications. MT6415CA is the second product in the MT6400 series ROICs from Mikro-Tasarim Ltd., which is a fabless IC design house specialized the development of monolithic imaging sensors and ROICs for hybrid imaging sensors. MT6421CA has a format of 640 x 512 and pixel pitch of 15 µm, developed with the system-on-chip architecture in mind, where all the timing and biasing for this ROIC are generated on-chip without requiring any external inputs. MT6415CA is a highly configurable ROIC, where many of its features can be programmed through a 3 wire serial interface allowing on-the-fly configuration of many ROIC features. It performs snapshot operation both using Integrate-Then-Read (ITR) and Integrate-While-Read (IWR) modes. The CTIA type pixel input circuitry has a dual gain mode with selectable full-well-capacity (FWC) values < 30.000 e- and > 300.000 e- in the high-gain (HG) and low-gain (LG) modes, respectively. MT6415CA has an input referred noise level of less than 15 e- rms in HG mode, suitable for very low-noise SWIR imaging applications.

8704-25, Session PThur

Impact of growth temperature on InAs/GaInSb strained layer superlattices for very long-wavelength infrared detection

Heather J. Haugan, Gail J. Brown, Air Force Research Lab. (United States); Said Elhamri, Univ. of Dayton Research Institute (United States); William C. Mitchel, Krishnamurthy Mahalingam, Mu J. Kim, Air Force Research Lab. (United States)

We report the ternary growth studies to develop Sb-based superlattice (SL) material for very long wavelength infrared detectors. We select a superlattice structure of 47.0 Å InAs/21.5 Å Ga0.75In0.25Sb that theoretically adjusted for the greatest possible detectivity and optimize a growth parameter for the best possible material quality. Since superlattice material quality is strongly related with the densities of nonradiative Shockley-Read-Hall recombination centers and the residual dopings, the impact of growth temperature (Tg) on the photoresponse (PR) intensity, the charge carrier density and mobility will be investigated using photoconductivity, temperature-dependent Hall effect measurements. Our growth process to create this SL structure produces a consistent band gap of 50±5 meV, however SL quality assessed by PR intensity is very sensitive to the Tg. For the SLs grown at 390-470 °C, a PR signal gradually increases as Tg increases from 400 to 440 °C with a maximum at 440 °C. Outside this temperature window, the SL quality deteriorates very rapidly. All SLs were residual n-type with mobility of ~10,000 V/cm2 for an optimized SL.

8704-92, Session PThur

Surface states characterization and simulation of Type-II In(Ga)Sb quantum dot structures for processing optimization of LWIR detectors

Qin Wang, Mina Rajabi, Amir Karim, Susanne Almqvist, Mietek Bakowski, Susan M. Savage, Jan Y. Andersson, Acreo AB (Sweden); Mats Göthelid, Shun Yu, Oscar Gustafsson, Mattias Hammar, Royal Institute of Technology (Sweden); Carl Asplund, IRnova AB (Switzerland)

Long-wave infrared (LWIR) imaging enables a variety of commercial and defense applications. However surface leakage currents arising from the LWIR detector mesa sidewalls due to a large number of surface states and defects in the bulk material are still a challenge.

In this work, the LWIR detection material is based on type-II quantum dots (QDs) that rely on a spatially indirect transition between the In(Ga)Sb QDs and InAs bulk material (Ref. 1). The interband QD LWIR detector is expected to provide performance levels similar to quantum well infrared photodetectors (QWIPs), but at operating temperature in excess of 200 K. It enables the use of less expensive thermoelectric coolers, thereby making them potentially attractive as a low-cost high-performance LWIR detector.

Wet etching is a key step in fabricating the detectors. X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX) measurements have been performed on the In(Ga)Sb QD samples treated by different wet etching methods, to analyze their surface chemical composition and roughness. The results provide valuable information for optimization of the fabrication process for the LWIR detectors.

The dark current of the fabricated detectors have been characterized by I-V measurements at 77 K and room-temperature. The dark current mechanisms owing to surface shunt or bulk leakage are investigated by analysis of the detector's dark current temperature and geometry dependence. The dark current caused by surface states was also investigated by the simulation tool MEDICI. These results were then compared with the experimental results.

Ref. 1: Oscar Gustafsson et al. Photoluminescence and photoresponse from InSb/InAs-based quantum dot structures, OPTICS EXPRESS, Vol. 20, p. 21264 to 21271, 2012

8704-106, Session PThur

Pyroelectric sensor arrays for detection and thermal imaging

Anthony J. Holden, InfraRed Integrated Systems Ltd. (United Kingdom)

Penetration of uncooled (room temperature operation) thermal detector arrays into high volume commercial products depends on very low cost technology linked to high volume production. A series of innovative and revolutionary developments is now allowing arrays based on bulk pyroelectric ceramic material to enter the consumer marketplace providing everything from sophisticated security and people monitoring devices to hand held thermal imagers for preventative maintenance and building inspection.

Although uncooled resistive microbolometer detector technology has captured market share in higher cost thermal imager products we will describe a pyroelectric ceramic technology which does not need micro electro-mechanical systems (MEMS) technology and vacuum packaging to give good performance. This is a breakthrough for very low cost sensors and imagers.

Recent developments in a variety of products based on pyroelectric ceramic arrays will be described and their performance and applicability compared and contrasted with competing technologies. This will include the use of low element count arrays for applications in people counting and queue management and the technology innovations that are driving higher element count imaging arrays for low cost thermal imaging cameras and intelligent security detectors. The technical challenges and research and development in materials production, device design and low cost manufacture will be described. New research and development will be described which aims to increase performance and array element count for more products and markets.

8704-107, Session PThur

IR and visible images registration method based on cross cumulative residual entropy

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Being the prerequisite of image joint and fusion, image registration technology has been utilized in various fields. Required by application, image registration technology has developed from single module registration to multiple module registration, such as the registration of infrared and visible light image registration[3-4]. The current image registration technology could be devided into two major types: feature-based and gray-based registration[5]. The latter is decided by the grayness of the picture, which needs no pretreatment, and it enjoys a high-precision and is applied in the registration of infrared and visible light image registration, especially MI-based and NMI-based methods.

But in the mutual information calculation, marginal entropy influences the value of mutual information. The larger the overlapping zone of two pictures is, the bigger marginal entropy will be. Therefore, the value of mutual information will be impacted by the overlapping zone of pictures, and the largest change of mutual information is not necessarily the best registration change. In order to eliminate the link between the wait-to-be-registrated image and the way they are overlapped, Studholme(1999) came up with NMI as a similarity test. But as for the multiple registration like infrared and visible light image, the utilization of mutual information and NMI always has no good result as single module registration, because their registration would create partial peak, leading to misregistration. So the idea of the match between feature and mutual information is created. Experiments show that the match of grayness and feature restrains partial peaks greatly and is more precise and stable than

MI and NMI. On the other hand, the amount of calculation is rather big.

This paper presents a method which combines with probability density and cross cumulative residual entropy. In this algorithm, firstly, according to infrared image and optical image characteristics, we put forward edge extraction algorithm based on the probability density. Secondly, we use cross cumulative residual entropy as the similarity measure to match the reference images and transformed images effectively. Bilateral filter can denoising and protect edge, and cross cumulative residual entropy is using cumulative distribution function instead of probability density function to To overcome the noise on the local minima. The experiment proved that registration is effective.

8704-108, Session PThur

Design and fabrication of a MOM diode-coupled frequency-selective surface

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This presentation describes the design, fabrication, and testing of a slot-antenna based Frequency Selective Surface (FSS) coupled with Metal-Oxide-Metal (MOM) diodes integrated into the structure. This design takes advantage of a single self-aligned patterning step using shadow evaporation. The diodes are formed by forming a native oxide on aluminum and overlaying platinum. The structure is optimized at 10.6 µm to have less than 2% reflection with 70% of the incident energy dissipated into the oxide layer using numerical simulation. Initial experimental results conducted on designs patterned with e-beam lithography are also presented. The fabricated structure is shown to produce a polarization sensitive unbiased DC current. This design will be useful for both infrared sensing and imaging as well as direct conversion of thermal energy.

8704-109, Session PThur

Type-II superlattice N-structure operating in the mid-wavelength infrared range (MWIR)

Yuksel Ergun, Anadolu Univ. (Turkey)

We have investigated theoretical and experimental properties of InAs/AlSb/GaSb based type-II superlattice (T2SL) pin photodetector. The band gap and heavy hole-light hole (HH-LH) splitting energies of the structure were carried out by first principles calculations considering possible interface transition layers of AlAs and InSb between InAs/AlSb interfaces and constituent layer thicknesses. According to theoretical findings type-II SL N-structure was optimized to operate as a MWIR detector tailoring the band gap and HH-LH splitting energies. N-structure is a InAs/AlSb/GaSb based SL pin structure where GaSb and InAs layers are sequentially confined by the thin AlSb barriers in each period throught the structure. With the insertion of AlSb barriers, carriers are pushed towards the GaSb/InAs interfaces as under bias and thus the optical transition probability increases when compared with a standard GaSb/InAs T2SL p-i-n diode. The detector structure is constructed by 1/9/2/8.5 monolayers (MLs) of InSb/InAs/AlSb/GaSb SL layers as 90 periods of p-region with GaSb:Be (p=1.5×1017 cm-3), 60 period of i-intrinsic region and 40 periods of n-region with InAs:Te (n=5×1017cm-3). Experimental results show that AlSb barriers in the structure act as blocking barriers reducing the diffusion and G-R component of dark current. Dark current density and RoA product at 79 K were obtained as 4x10-7A/cm2 and 1.8x106 Ωcm2 at zero bias, respectively. The specific detectivity was measured as 3x1012 Jones with cut-off wavelengths of 4.3 µm at 77K reaching to 2x109 Jones and 4.5µm at 255 K.

8704-112, Session PThur

Low-dark current structures for long-wavelength Type-II strained layer superlattice photodiodes

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Dark current reducing pBiBn structures have been employed to reduce dark currents in long-wavelength infrared (LWIR) type-II InAs/GaSb strained-layer superlattice (SLS) diodes. The ability to lower dark current densities has been achieved by way of hetero-structure engineering of electron-blocking and hole-blocking layers via a molecular beam epitaxy (MBE) approach. These samples were fabricated into varying area mesa diodes and small diode arrays using a reactive ion etching (RIE) technique employing inductively coupled plasma using chlorine base chemistry. The samples in this study were passivated with either SiO2 or Al2O3 using plasma enhanced chemical vapor and atomic layer deposition, respectively. A variable area diode analysis (VADA) technique was employed to investigate the overall effectiveness of these passivation layers by extrapolating the surface resistivity and bulk R0A. Temperature dependent dark current measurements enabled an analysis of the dominating current mechanisms, while theoretical fittings of the diode dark currents were used to identify the contributing dark current components observed in the empirical dark current data. The relative per watt and per photon spectral response of these photodiode structures was determined using Fourier transform infrared (FTIR) spectroscopy and the quantum efficiency (QE) and detectivity (D*) was determined using a narrow band filter, a calibrated 500K blackbody source, and a noise spectrum analyzer.

8704-113, Session PThur

Crosstalk analysis in large-area, low-capacitance InGaAs quad photodiodes

Shubhashish Datta, Abhay M. Joshi, Jim Rue, Discovery Semiconductors, Inc. (United States)

Quad photodiodes, namely a 2 x 2 array of p-i-n photodiodes, are required as the front-end photonic sensors in several applications relying on free-space propagation with direction sensing capability, such as long baseline interferometry, laser ranging, and free-space optical communication. The direction sensing accuracy of these quad photodiodes may be limited by the crosstalk between the four quadrants.

We report 0.5 mm diameter, 1 mm diameter, and 2 mm diameter quad InGaAs photodiodes having quadrant-to-quadrant separation of 15 um, 20 um, and 25 um. This crosstalk is a combination of resistive and capacitive coupling between the photodiode quadrants depending on reverse bias, quadrant-to-quadrant separation, load, and reactance at a particular frequency and its interaction with the neighboring pixel. We report crosstalk that varies widely from -20 dB to -60 dB depending on the combination of the above parameters. Thus, the position sensing accuracy is heavily influenced by the operation conditions of the quad photodiode.

8704-114, Session PThur

Low-cost and compact thermal imaging sensors for body temperature measurement

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Infrared sensor in the form of a nice big resolution rather than to produce a compact and low-cost thermal sensor technology is spreading rapidly. Small low-cost infrared sensor on the increasing demand for applications such as intruder, car blind-spot detection, human body temperature detection and gas sensors. In this paper, ROIC over the substrate with a 32x32 array microbolometer sensors were fabricated using surface micromachining technology. In addition, the miniaturized chip using wafer-level vacuum packaging technology were made. Thermal imaging system for the implementation of the analog and digital boards were made for each other, body temperature can be measured by an infrared thermal imaging system was implemented. Monolithic fabricated microbolometer with vanadium-tungsten oxide infrared sensing material on the ROIC wafer substrate was used in order to minimize heat loss sensor was designed as a floating structure. Vacuum packaging is essential to making efficient infrared heat sensing. So microbolometer infrared transmission filter and getter-coated on a silicon wafer leads wafer fabrication crafted ROIC wafer and wafer-level vacuum packaging. Low-level microbolometer array with wafer level packaging, small size and low cost, but it was confirmed that the body temperature to produce a thermal imaging sensor.

8704-115, Session PThur

Characteristic of nickel oxide microbolometer

Gyo-Hun Koo, Kyungpook National Univ. (Korea, Republic of); Young-Chul Jung, Gyeongju Univ. (Korea, Republic of); Sung-Ho Hahm, Kyungpook National Univ. (Korea, Republic of); Dong-Geon Jung, Kyungpook National Univ. (Korea, Republic of); Yong Soo Lee, Kyungpook National Univ. (Korea, Republic of)

We have used reactive sputtering technology for nickel oxide film formation on silicon nitride membrane with 100um x um pixel size. Nickel oxide films obtained by the sputtering of Ni within the argon and oxygen gas mixture have been analyzed from XRD, AFM and XPS methods. And then, ohmic contact structure for optimizing the resistivity of thin nickel oxide films was investigated. High TCR of nickel microbolometer with low 1/f noise spectrum distribution was obtained. For the fabrication of microbolometer, we simulated the optical and device structures for predicting the performance of microbolometer with nickel oxide films. Through the result of calculation on the micribolometer designed in this research, we could verify a low NETD(noise equivalent temperature difference) below 50mK.

8704-116, Session PThur

Development status of Type II superlattice infrared detector in JAXA

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We report the development status of Type II superlattice (T2SL) infrared detector in JAXA. Since 2009, we have started a basic research on InAs/GaSb T2SL infrared detectors. Our final goal is to realize the T2SL array detector having a cutoff wave length of λc=15μm.

In order to confirm a technical feasibility of 15μm cutoff T2SL detector, we fabricated T2SL samples having superlattice thickness of 9 monolayers (ML) InAs/ 7 ML GaSb, 14ML InAs /7ML GaSb, and 16ML InAs /7ML GaSb. These crystals are designed for the cutoff wavelength from 6μm to 12μm. The X-ray Diffraction measurement shows a mismatch between the substrate and superlattice layers is below 0.006%. The surface morphology of the samples with an atomic force microscope is 1.5-3.3Å RMS for 5×5μm square regions. We also fabricated single pixel detectors with these crystals. We show the results of the spectral response measurement using a FTIR system. We also show the development status of an array detector.

8704-119, Session PThur

Nanoantenna-enabled midwave infrared detection

David W. Peters, Jin K. Kim, Darin Leonhardt, Joel R. Wendt, John F. Klem, Charles M. Reinke, Paul S. Davids, Sally Samora, Sandia National Labs. (United States)

We show results of the integration of a nanoantenna in close proximity to the active material of a photodetector. The nanoantenna allows a much thinner active layer to be used for the same amount of incident light absorption. This is accomplished through the nanoantenna coupling incoming radiation to surface plasmon modes bound to the metal surface. These modes are tightly bound and only require a thin layer of active material to allow complete absorption. Moreover, the nanoantenna impedance matches the incoming radiation to the surface waves without the need for an antireflection coating. While the nanoantenna concept may be applied to any active photodetector material, we chose to integrate the nanoantenna with an InAsSb photodiode. The addition of the nanoantenna to the photoiode requires changes to the geometry of the stack beyond the simple addition of the nanoantenna and thinning the active layer. We will show simulations of the electric fields in the nanoantenna and the active region and optimized designs to maximize absorption in the active layer as opposed to absorption in the metal of the nanoantenna. We will briefly review the fabrication processes. Finally, we will review results of characterization in the MWIR, including a comparison of performance with and without the nanoantenna and comparison to the models.

8704-120, Session PThur

Numerical simulation of large-format reduced-pitch HgCdTe infrared detector arrays

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The goal of this work is to extend our current three-dimensional numerical model of single and dual-color HgCdTe detectors to larger format arrays. The current trend of fabricating larger arrays while decreasing pixel pitch makes it desirable to develop a numerical model which can accurately predict intra-pixel effects which cannot be modeled without considering array sizes greater than 3 pixels by 3 pixels. Furthermore, at small pixel pitch, effects such as resonance between mesa sidewalls and optical crosstalk become applicable, requiring a more rigorous solution of the optical properties of the detector. Our numerical model is based on the solution of Maxwell's curl equations using the finite-difference time-domain (FDTD) method to obtain the optical carrier generation profile within the device considering diffraction effects which become relevant at reduced-pitch. The optical generation is then interpolated onto a mixed-element grid which is used to find a numerical solution of the coupled Poisson and electron/hole continuity equations through the implementation of the finite element method (FEM). Using our model, we analyze the quantum efficiency and crosstalk of both single- and dual-color detectors with pixel pitches between 8 and 16 microns as a function of pixel dimension and material composition. In addition, we study the effects of contact placement on both the optical response of the detector as a whole and the pixel-to-pixel uniformity of electrical characteristics.

8704-121, Session PThur

Nanowire grid polarizers for mid- and long-wavelength infrared applications

Matthew C. George, Hua Lee, Jonathon Bergquist, Bin Wang, MOXTEK, Inc (United States)

The wire grid polarizer (WGP) remains one of the most useful optical components in the field and is prevalent in applications ranging from imaging and displays to communications and scientific instrumentation. The WGP typically consists of an array of metallic lines with sub-wavelength pitch supported by a transparent substrate. Existing WGP products designed for infrared applications typically suffer from low contrast between transmission of passing and blocking polarization states due to their relatively large wire grid pitch (typically ≥370 nm). Our current work demonstrates that a dramatic reduction in pitch from that found in typical IR WGP products greatly improves infrared performance. Using our aluminum nanowire, large area patterning capabilities, Moxtek has developed high contrast wire grid polarizers on Silicon suitable for mid- and long-wavelength infrared applications. Our 144 nm pitch MWIR polarizer transmits better than 95% of the passing state while maintaining a contrast ratio of better than 33dB from 3.3-5.7 microns. Between 7 and 15 microns, our LWIR polarizer transmits better than 70% of the passing polarization state and has a contrast ratio better than 40dB. Transmission measurements were made using an FTIR spectrometer and correlated to measurements from an outside lab that used NIST-traceable standards to verify instrument accuracy. Results were compared to RCWA modeling of the WGP performance on antireflection-coated wafers. Performance of a WGP on a narrow band antireflection-coated wafer for 10.6 micron laser line applications will also be presented.

8704-122, Session PThur

Influence of pixel geometry on the 1/f noise coefficient

Francis R. Généreux, Jacques-Edmond Paultre, Bruno Tremblay, Francis Provençal, Christine Alain, INO (Canada)

The increasing demand for infrared systems with reduced volume and improved resolution has paved the way for the development of bolometer FPAs with reduced footprint. Nowadays, 17 µm pixel pitch arrays are already commercially available. Despite this important breakthrough, various pixel properties still need to be improved to achieve highly sensitive 12 µm pitch pixels.

The first step in improving pixel performance is the enhancement of the thermistor material properties, namely the TCR, the resistivity and the 1/f noise coefficient. Among these properties, the 1/f noise coefficient is particularly important for small pixels as its value is, for a given film, inversely proportional to the volume of the thermistor material. This relation holds as long as the current through the thermistor material is uniform, i.e. when the pixel platform has a rectangular shape. Unfortunately when the pixel pitch is reduced, the shape of the platform becomes less rectangular due to restriction on the size of some pixels components.

To develop a model that accounts for a non rectangular platform, we perform a systematic study of the 1/f noise coefficient as a function of the pixel geometry. Structures with various thermistor widths, electrode gaps, electrode widths and via sizes are fabricated and characterized. The experimental results show that the 1/f noise coefficient is adversely affected by current non uniformity, in agreement with the model prediction. Design parameters that impact significantly the current non uniformity are identified and approaches to minimize their importance are proposed.

8704-123, Session PThur

A low-noise silicon-based 20um*20um uncooled thermoelectric infrared detector

Mohammad J. Modarres-Zadeh, Reza Abdolvand, Oklahoma State Univ. (United States)

Presented is an uncooled surface-micromachined thermoelectric (TE) infrared detector that features deep sub-micron P-doped /N-doped polysilicon wires as the thermocouple pair and an umbrella like optical cavity as the absorber to achieve fill factor as high as 90%. An NETD of ~120mK is measured in vacuum from these devices with f/1.5 lens.

Thermoelectricity is a transduction mechanism for infrared sensing that has not been much exploited. Last year, our group demonstrated silicon-compatible TE infrared sensors with promising performance. Here, we report a greatly improved responsivity of more than 10 times compared to that of last year, which is mostly due to the superior thermoelectric properties of the material used in the junction (n-type silicon instead of nichrome), reduction of the dimensions of TE wires (which results in more phonon scattering), higher doping of the polysilicon layers, and improved thermal management of the cell. At room temperature, responsivity of >1000V/W @5Hz and the response time of ~10ms is measured in vacuum when viewing a 500K blackbody with no optics. COMSOL simulation is used to predict the detector performance and the results are in a good agreement with the measurements.

The dominant source of noise in thermoelectric IR detectors is believed to be Johnson noise when the detectors are operating in an open circuit condition. This has also been confirmed for the presented detectors by the noise measurement. The measured resistance of the fabricated detectors is in the range of 20 to 70KOhm which results in Johnson noise of about 20 to 36 nV/Hz^0.5. The D* is calculated to be about 10^8cmHz^0.5/W, which to the best of our knowledge is the highest reported D* for such a small thermoelectric devices.

8704-124, Session PThur

Adaptive control system for vibration harmonics of cryocooler

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Vibration disturbances generated by cryocooler, representing in a series of harmonics, are critical issue in practical application. A control system including electronic circuit and mechanical actuator has been developed to attenuate the vibration. The control algorithm executes as a series of adaptive narrowband notch filters to reduce corresponding harmonics. The algorithm does not require actuator transfer function, thus ensure its adaptiveness. Using this algorithm, all the vibration harmonics of cryocooler were attenuated by a factor of more than 45.9 dB, i.e., the residual vibration force was reduced from 20.1Nrms to 0.102Nrms over the 300 Hz control bandwidth, the converging time is only less than 20 seconds, and the power consumption of mechanical actuator is less than half a watt. The vibration control system has achieved the general requirement of Infrared application.

8704-125, Session PThur

Very broad spectrum Echelle spectrography

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Very Broad Spectrum Echelle Spectrography

An echelle spectrograph provides high spectral resolving power across a broad wavelength range by covering multiple spectral orders in just one image. A spectrograph of this type is commonly used in elemental constituent measurements for astronomical observations and laboratory

analysis. The wavelength range covered by these instruments is highly dependent on the capabilities of the sensor used to acquire the data. Silicon-based CCD detectors typically enable measurements from 200nm to 900nm. Infrared Laboratories and Catalina Scientific Instruments have collaborated to demonstrate a very broadband echelle spectrograph using IR Labs' Triwave camera. The Triwave, with its germanium-enhanced CMOS detector, covers a wavelength range of 300nm to 1600nm. An opportunity exists in the area of dielectric coatingthickness measurement by extracting and analyzing interference fringe data using the echelle spectrograph. Methods and results of this characterization will be presented.

8704-126, Session PThur

Study of Shockley-Read-Hall, radiative, and Auger recombination processes in InAs/InAsSb Type-II superlattices

Jin Fan, Zhiyuan Lin, Shi Liu, Oray O. Cellek, Xiaomeng Shen, David J. Smith, Yong-Hang Zhang, Arizona State Univ. (United States)

Antimony-based type-II superlattices (T2SLs) has attracted strong attentions as a promising alternative to HgCdTe for photodetectors in MWIR and LWIR range. Recent studies of minority carrier lifetime have shown a major breakthrough for long-wave Ga-free InAs/InAsSb T2SLs with lifetime greater than 500 ns, which is more than one order of magnitude longer than that of InAs/GaSb T2SLs, indicating device performance approaching to radiative recombination limited regime. Early theoretical studies also show that InAs/Ga(In)Sb T2SLs could potentially offer suppressed Auger recombination through band-structure engineering. However, the behaviors of radiative and non-radiative recombination in InAs/InAsSb T2SLs have not been fully investigated. This paper reports our recent studies of SRH, radiative, and Auger recombination processes for InAs/InAsSb T2SLs. In this work, a series of InAs/InAsSb T2SLs designed for MWIR and LWIR range have been grown using MBE. Post-growth characterization using X-ray diffraction (XRD) and transmission electron microscopy (TEM) reveals excellent structural properties of the grown samples. Photoluminescence (PL) measurements are carried out from 12 to 150 K with different excitation power densities covering 4 orders of magnitude from 1.5 mW/cm2 to 10 W/cm2. The results show that the recombination in InAs/InAsSb T2SLs at 12 K is dominated by radiative recombination process, indicating excellent optical properties. As the temperature increased to 77 K, SRH, radiative, and Auger recombination processes are all present. A theoretical model is developed to calculate the SRH, radiative, and Auger recombination coefficients. Detailed modeling and characterization results will be present at the conference.

8704-127, Session PThur

Thin-film, wide-angle, design-tunable, selective absorber from near UV to far infrared

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We experimentally demonstrate a structured thin film that selectively absorbs incident electromagnetic waves in discrete bands, which by design occur in any chosen range from near UV to far infrared. The structure consists of conducting islands separated from a conducting plane by a dielectric layer. By changing dimensions and materials, we have achieved broad absorption resonances centered at 0.35, 1.1, 14, and 48 microns wavelength. Angle-dependent specular reflectivity spectra are measured using a UV-visible or Fourier spectrometer. The peak absorption ranges from 85 to 99%. This strong absorption is preserved up to 50 degrees angle of incidence. The absorption is explained using the model of an LCR resonant circuit created by coupling between dipolar plasmon resonance in the surface structures and the image dipoles formed in the ground plane. The resonance wavelength is proportional to the dielectric permittivity and to the linear dimension of the surface structures. These absorbers have application to thermal detectors.

8704-128, Session PThur

A new unit cell design with automatic input stage selection capability for increased SNR

Melik Yazici, Huseyin Kayahan, Omer Ceylan, Yasar Gurbuz, Sabanci Univ. (Turkey)

This paper presents novel unit cell architecture for short wave infrared (SWIR) imaging applications. It has two input stages which are CTIA and SFD covering for both respectively low and high flux levels and automatic input stage selection circuitry that chooses best input stage. User can select 2 modes for FPA: manual and automatic mode. In manual mode, user can set CTIA or SFD for all pixels according to user needs. In automatic mode, each pixel selects input stage itself according to light level. Automatic input stage selection for each pixel brings high SNR level and low noise along with highest possible dynamic range. Since 2 input stage is available inside unit cell this readout is compatible for dual color or dual band detectors. Standard CMOS 0.18um TSMC technology is used to realize unit cell. In the architecture of unit cell, circuit level techniques are used to optimize layout size. Unit cell size is only 30 x 30 um. Simulation level verification is provided for the unit cell architecture.

8704-129, Session PThur

A fully digital readout employing extended counting method to achieve very low quantization noise

Huseyin Kayahan, Melik Yazici, Ömer Ceylan, Yasar Gurbuz, Sabanci Univ. (Turkey)

This paper presents a digital ROIC for staring type arrays with extending counting method to realize very low quantization noise while achieving a very high charge handling capacity. Current state of the art has shown that digital readouts with pulse frequency method can achieve charge handling capacities higher than 3Ge- however both works show a high quantization noise (higher than 1000e-). Even if the integration capacitance is reduced, it cannot be lower than 1-3 fF due to the parasitic capacitance of the comparator. In addition a small capacitance would mean a lot of reset and count operation increasing the power consumption. Furthermore for higher SNR, the voltage swing on the integration capacitor should be kept high which is contradicting to the small quantization noise. For achieving a very low quantization noise of 200 electrons in a power efficient way, a new method based on measuring the time to measure the remaining charge on the integration capacitor is proposed. With this approach SNR of low flux pixels are significantly increased while large flux pixels can store electrons as high as 15Ge-. A prototype array of 32x32 pixels with 30um pitch is implemented in 90nm CMOS process technology for verification. Simulation results are given for complete readout.

8704-130, Session PThur

Design of 90x8 ROIC with pixel level digital TDI implementation for scanning type LWIR FPAs

Omer Ceylan, Huseyin Kayahan, Melik Yazici, Yasar Gurbuz, Sabanci Univ. (Turkey)

Design of a 90x8 CMOS readout integrated circuit (ROIC) based on pixel level digital time delay integration (TDI) for scanning type LWIR focal plane arrays (FPAs) is presented. TDI is implemented on 8 pixels which improves the SNR of the system with a factor of . Oversampling rate of 3 improves the spatial resolution of the system. TDI operation is realized with an under-pixel analog-to-digital converter, which improves the noise performance of ROIC with a lower quantization noise. Since analog signal is converted to digital domain in-pixel, non-uniformities and inaccuracies due to analog signal routing over large chip area is eliminated. Contributions of each pixel for proper TDI operation are added in summation counters, no op-amps are used for summation, hence power consumption of ROIC is lower than its analog counterparts. Due to lack of multiple capacitors or summation amplifiers, ROIC occupies smaller chip area compared to its analog counterparts. ROIC is also superior to its digital counterparts due to novel digital TDI implementation in terms of power consumption, noise and chip area. ROIC supports bi-directional scan, multiple gain settings, bypass operation, automatic gain adjustment, pixel select/deselect, and is programmable through serial or parallel interface. Input referred noise of ROIC is less than 1000 rms electron, while power consumption is less than 20mW. ROIC is designed to perform both in room and cryogenic temperatures. Simulation results are provided.

8704-131, Session PThur

A plasmonic enhanced pixel structure for uncooled microbolometer detectors

Tayfun Akin, Middle East Technical Univ. (Turkey)

No abstract available.

8704-93, Session 17

In(Ga)Sb/InAs quantum dot-based IR photodetectors with thermally activated photoresponse

Amir Karim, Acreo AB (Sweden); Oscar Gustafsson, Royal Institute of Technology (Sweden); Susan M. Savage, Qin Wang, Susanne Almqvist, Acreo AB (Sweden); Carl Asplund, IRnova AB (Sweden); Mattias Hammar, Royal Institute of Technology (Sweden); Jan Y. Andersson, Acreo AB (Sweden)

We report on the investigation results of In(Ga)Sb quantum dots (QDs) on InAs substrates for fabricating IR photodetectors. Such photodetectors are expected to have lower dark currents and higher operating temperatures compared to the current state of the art InSb and mercury cadmium telluride technology. This is due to the matrix material (InAs) having a larger bandgap than the detection energy and the 3D QD confinement. In(Ga)Sb QDs in InAs have type-II band alignment which offers spatially indirect band to band transitions, with longer carrier life times, between the quantized energy levels of the dots and the continuous levels of the matrix material [1]. The structures were grown using metal-organic vapour-phase epitaxy and explored using structural, electrical and optical characterization techniques. Material development resulted in obtaining photoluminescence up to 10 µm, which is the longest wavelength reported in this material system.

We have fabricated photovoltaic IR detectors from the developed material that show an absorption edge up to 8 µm. Photoresponse spectra, showing In(Ga)Sb QD related absorption edge, were obtained up to 200 K. Photoresponse is thermally activated with different activation energies for devices with different cut off wavelengths. Longer wavelengths produced higher activation energies. This can be explained using the energy band alignment diagram of the dots/matrix system for different QD sizes.

Reference

[1] Oscar Gustafsson, et al. OPTICS EXPRESS, Vol. 20, No. 19, 21264 (2012)

8704-94, Session 17

Reduction of dark current density by five orders at high bias and enhanced multicolour photo response at low bias for quaternary alloy capped InGaAs/ GaAs QDIPs, when implanted with low-energy light (H-) ions

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Quantum dot infrared photodetectors (QDIPs) have already established itself as a major technology for infrared detection on account of its significantly low dark current, large responsivity and high detectivity. 10 layered InGaAs/ GaAs QDIPs were grown over semi-insulating GaAs (100) substrates using solid-source molecular beam epitaxy (Riber SYS14020 Epineat III-V). Each layer of dots was capped with a combination of 30 Å In0.21Al0.21Ga0.58As and 500 Å intrinsic GaAs layers. The samples were further implanted with 50 keV H– ions, with fluence varying between 8 E11 to 2 E13 ions/cm^2. When I-V measurements were carried out on the fabricated devices, even at a high bias of -1.5 V, a reduction of dark current density by five orders was observed (2.2 E-7 A/ cm^2) for the device implanted with 2 E12 ions/ cm^2 fluence, compared to as-grown device. Suppression of field assisted tunnelling process due to the increased potential barrier probably led to the above trend in the implanted device. Multicolour photo-response (around 7.35 and 5.5 µm) was observed in the device. For the device, implanted with lower fluence of 8 E11 ions/cm^2, the strongest photo-response was noticed at the lowest bias of -0.1V, which was considerably higher for the as-grown device (a bias of -1.0 V). At this fluence, the peak detectivity increased by more than one order to ~ E10 cm-Hz^1/2/W. This is probably the first report of detectivity enhancement in H– ion implanted quaternary alloy capped InGaAs/ GaAs QDIPs. DST, India is acknowledged.

8704-95, Session 17

Room-temperature SWIR sensing from monolithically integrated colloidal quantum dot photodiode arrays

Ethan J. Klem, Jay S. Lewis, Chris Gregory, Garry Cunningham, Dorota Temple, RTI International (United States); Arvind I. D'Souza, Ernest W. Robinson, DRS Sensors & Targeting Systems, Inc. (United States); Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States)

While InGaAs-based focal plane arrays (FPAs) provide excellent detectivity and low noise for SWIR imaging applications, wider scale adoption of systems capable of working in this spectral range is limited by high costs, limited spectral response, and costly integration with Si ROIC devices. RTI has demonstrated a novel photodiode technology based on IR-absorbing solution-processed PbS colloidal quantum dots (CQD) that can overcome these limitations of InGaAs FPAs. The most significant advantage of the CQD technology is ease of fabrication.

The devices are fabricated directly onto the ROIC substrate at low temperatures compatible with CMOS, and arrays can be fabricated at wafer scale. Further, device performance is not expected to degrade significantly with reduced pixel size.

We will present the results for both passive detectors fabricated on passive Si substrates and for 320 x 10 arrays fabricated on ROICs. We will discuss recent advances in device architecture and processing that resulted in measured dark currents of 4 nA/cm^2 at room temperature, with sensitivity to ~1.7 µm. We will show other devices with spectral sensitivity that extends from UV to 2.2 µm. For the ROIC-integrated devices we will show dark currents <10 nA/cm^2. Histograms of D* will be presented, along with low frequency noise to the mHz range.

This combination of high performance, dramatic cost reduction, and multi-band sensitivity is ideally suited to expand the use of SWIR imaging in current applications, as well as to address applications which require a multispectral sensitivity not met by existing technologies.

8704-96, Session 18

Broadband enhancement of infrared photodetectors with metamaterial resonators

John A. Montoya, The Univ. of New Mexico (United States); David W. Peters, Charles M. Reinke, Sandia National Labs. (United States); Stephen A. Myers, Pankaj Ahirwar, Sanjay Krishna, The Univ. of New Mexico (United States)

Current infrared imaging systems have nearly identical pixels over a broad spectral range, which results with "black and white" images. As a result, there is ever increasing emphasis on the development of new, on the pixel level, photodiodes that can provide spectral information. Attempts at creating a robust imaging system with spectral information have been made through a complex network of external optics, which results with high cost and a large system package. However, enhanced photodiode detectivity (D*) and higher operating temperature can be achieved with the aid of highly resonant metamaterials. Metamaterials permit the construction of materials with exact electric permittivity and magnetic permeability response. As a result, metamaterials impedance matched to free space can minimize the reflectance and improve the photodiodes signal. While metamaterials are a detector agnostic technology, we chose to integrate metamaterials structures with a quantum well infrared photodiode (QWIP). By providing spectral information on the pixel level, a multicolor infrared imaging system reduces in size and cost. The work presented here demonstrates the use of metamaterials for improving the functionality of an infrared photodiode for enhanced signal and multicolor capability.

8704-97, Session 18

3 mega-pixel InSb detector with 10µm pitch

Gal Gershon, Lior Shkedy, Omer Cohen, Zipora Calahorra, Maya Brumer, Michal Nitzani, Eran Avnon, Yossi Aghion, Igal Kogan, Elad Ilan, SCD Semiconductor Devices (Israel); Eylon Merav, SCD (Israel); Asaf Albo, SCD Semiconductor Devices (Israel)

SCD has developed a new 1920x1536 / 10 µm digital Infrared detector for the MWIR window named Blackbird. The Blackbird detector features a Focal Plane Array (FPA) that incorporates two technological building blocks developed over the past few years. The first one is a 10 µm InSb pixel based on the matured planar technology. The second building block is an innovative 10 µm ReadOut Integrated Circuit (ROIC) pixel. The InSb and the ROIC arrays are connected using Flip-Chip technology by means of indium bumps. The digital ROIC consist of a matrix of 1920x1536 pixels and has an analog to digital (A/D) converter per-channel (total of 1920x2 A/Ds). It allows for full frame readout at a high frame rate of 120 Hz. Such an on-chip A/D conversion eliminates the need for several A/D converters with fairly high power consumption at the system level. The ROIC power consumption at maximum bandwidth is less than 400 mW. The ROIC features a wide range of pixel-level functionality such as several conversion gain options and a 2x2 pixel binning. The ROIC design makes use of the advanced and matured CMOS technology, 0.18 µm, which allows for high functionality and relatively low power consumption. The FPA is mounted on a Cold-Finger by a specially designed ceramic substrate. The whole assembly is housed in a stiffened Dewar that withstands harsh environmental conditions while minimizing the contribution to the heat load of the detector. The design enables a 3-megapixel detector with overall low size, weight, and power (SWaP) with respect to comparable large format detectors. In this work we present in detail the characteristic performance of the new Blackbird detector.

8704-98, Session 18

Design and development of wafer-level short wave infrared micro-camera

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Low cost IR Sensors are needed for a variety of Military and Commercial Applications as low cost imagers for various Army and Marine missions. SiGe based IR Focal Planes offers a low cost alternative for developing wafer-level shortwave infrared micro-camera that will not require any cooling and can operate in the Visible-NIR band. The attractive features of SiGe based IRFPA's will take advantage of Silicon based technology, that promises small feature size and compatibility with the low power silicon CMOS circuits for signal processing.

We will present feasibility study of an infrared sensor based on SiGe material system and its performance characteristics. We will also present simulations to compare the sensitivity of the SiGe detector spectral cutoff wavelength of 1.6 micron to other IR Focal Plane arrays. We have tested several SiGe photodetectors and will present results of the electrical and optical measurements on SiGe devices. We will discuss various device designs for SiGe detectors to simulate and model the performance for low dark current and high quantum efficiency and hence higher SiGe sensor performance.

SiGe technology offers a low cost alternative for developing Visible-NIR sensors that will not require any cooling and can operate from 0.3- 1.7 microns. The attractive features of SiGe based IRFPA's will take advantage of Silicon based technology that can be processed on 12-inch silicon substrates, that can promise small feature size and compatibility with the Silicon CMOS circuit for signal processing.

In this paper, we will discuss the design and development of Wafer-Level Short Wave Infrared (SWIR) Micro-Camera. We will discuss manufacturing approaches and sensor configurations for short wave infrared (SWIR) focal plane arrays (FPAs) that significantly reduce the cost of SWIR FPA packaging, optics and integration into micro-systems.

8704-100, Session 19

MEMS clocking-cantilever thermal detector

Evan M. Smith, Imen Rezadad, Javaneh Boroumand Azad, Pedro N. Figueiredo, Deep R. Panjwani, Janardan Nath, Robert E. Peale, Univ. of Central Florida (United States); Oliver Edwards, ZyberTec LLC (United States)

We present estimations of Noise Equivalent Temperature Difference (NETD), speed, and sensitivity for a radiant energy imager using null switching, a novel infrared detector based on MEMS cantilevers (US Patent No. 7977635). These cantilevers operate as a repeatedly cycled switch, where incident infrared radiation causes a measurable change in the on/off duty cycle. Since most detectors transduce IR to a change in resistance or capacitance, rather than to a change in a timing measurement, the usual methods of estimating performance need to be reconsidered for this new type of detector. We present a determination of

the detector's noise influenced sensitivity defined by its Noise Equivalent Temperature Difference (NETD). Thermal fluctuations, radiative losses, and vibrations in the cantilever resulting from acoustic and thermal sources affect NETD. Vibrations are potentially the most significant cause of timing uncertainty, though the detector's null position is intended to dampen them, allowing for attractively low NETD. Preliminary results indicate a total NETD of 3.8 mK, with a corresponding responsivity (change in duty cycle) of 0.4 ns, requiring a 3 GHz digital clock rate. We estimate that this high sensitivity might be achieved at a cycling rate of 1 kHz.

8704-101, Session 19

High-resistivity and high-TCR vanadium oxide thin films for infrared imaging prepared by bias target ion-beam deposition

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Vanadium oxide (VOx) thin films have been intensively studied as an imaging material for uncooled microbolometers due to their low resistivity, high temperature coefficient of resistivity (TCR), and low 1/f noise. Our group has studied pulsed DC reactive sputtered VOx thin films while reactive ion beam sputtering has been exclusively used to fabricate the VOx thin films for commercial thermal imaging cameras. The typical resistivity of imaging-grade VOx thin films is in the range of 0.1 to 10 ohm-cm with a TCR from -2%/K to -3%/K.

In this work, we report for the first time the use of a new biased target ion beam deposition (BTIBD) tool to prepare vanadium oxide thin films. In this BTIBD system, ions with energy lower than 25ev are generated remotely and vanadium targets are negatively biased independently for sputtering. High TCR (>-4.5%/K) VOx thin films have been reproducibly prepared in the resistivity range of 1E3-1E4 ohm-cm by controlling the oxygen partial pressure using real-time control with a residual gas analyzer. These high resistivity films may be useful in next generation uncooled focal plane arrays for through film rather than lateral thermal resistors. This will improve the sensitivity through the higher TCR without increasing noise accompanied by higher resistance. We report on the processing parameters necessary to produce these films as well as details on how this novel deposition tool operates. We also report on controlled addition of alloy materials and their effects on VOx thin films' electrical properties.

8704-102, Session 19

Room-temperature microphotonic bolometer based on dielectric optical resonator

Tindaro Ioppolo, Edoardo Rubino, Southern Methodist Univ. (United States)

In this paper we present a room-temperature micro-photonic bolometer that is based on the whispering gallery mode of dielectric resonator (WGM). The sensing element is a hollow micro-spherical or cylindrical polymeric resonator. The hollow resonator is filled with a fluid (gas or liquid) that has a large thermal expansion. When an incoming radiation impinges on the resonator it will be absorbed by the absorbing fluid leading to a thermal expansion of the micro-resonator. The thermal expansion induces changes in the morphology of the resonator (size and index of refraction) leading to a shift of the optical resonances (WGM). In addition the incoming radiation is chopped so that elastic waves are generated within the micro-photonic resonator via thermo-elastic effect. The chopping frequency is chosen so that a mechanical resonance of the resonator is exited. This will amplify the induced WGM shift and hence the resolution. Different geometry and sizes will be investigated to increase the sensor resolution. The optical modes are exited using a tapered single mode optical fiber. One end of the optical fiber is coupled to a distribute feedback laser while the other end is connected to a photodiode to monitor the transmission spectrum.

8704-103, Session 20

Wafer-level reliability characterization for wafer-level packaged microbolometer with ultra-small array size

Hee Yeoun Kim, Chungmo Yang, Jae Hong Park, Ho Jung, Tae Hyun Kim, Gyung Tae Kim, Sung Kyu Lim, National Nanofab Ctr. (Korea, Republic of); Sang Woo Lee, ePack Inc. (United States); Wook Joong Hwang, Kwyro Lee, National Nanofab Ctr. (Korea, Republic of)

Ultra-small and low cost microbolometers are highly required for mobile applications such as hand-held and automobile camera. These kinds of low-end sensors need small array size and low cost vacuum packaging technology. Wafer-level vacuum packaging (WLVP) is indispensable to satisfy the requirement of small size and low cost microbolometer at the same time. While WLVP process consisting of solder deposition, getter activation and bonding are very well known, wafer level characterization have not been studied systematically. For the commercialization of WLVP, wafer level characterization is so important to decrease overall chip cost including WLVP process cost. In this report, wafer level characterization and reliability of WLVP processed wafers will be described. Amorphous silicon based microbolometers with 64x64 array size are fabricated in 8 inch wafer. Cap wafers with cavity depth of 50~100um and membrane thickness of 50~400um are fabricated and bonded with sensor wafer by Au-Sn eutectic solder. Optical detection and integrated vacuum sensor are independently used to characterize the vacuum leak rate. For the wafer-level packaged samples with membrane thickness below 100um, it is possible to characterize the leak rate by optical detection technique. Integrated vacuum sensor having the same structure as bolometer pixel shows the vacuum level below 10mTorr and leak rate below 1e-13(Torr•L/sec) which are enough for commercialization. Long time reliability in wafer level is also characterized by the same methods and all steps for final product are implemented in wafer level.

8704-104, Session 20

Application of mosaic pixel microbolometer technology to very high-performance, low-cost thermography, and pedestrian detection

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

The mosaic pixel focal plane array (MP-FPA) was initially developed by Electro-optic Sensor Design (EOSD) for next generation passive infrared (PIR) security sensors. As originally conceived the technology involved a novel microbolometer FPA design which, together with advanced packaging and integrated optics, would provide enhanced performance in short range sensing applications. Two base products were envisaged, a small, typically 4x4 FPA format, non-imaging sensor, and a 40x30 or 80x60 format imaging sensor. It soon became evident that the technology could be applied to other non-military applications where large pixel size is adequate and high detective performance is required.

However, the main attention in the IR industry has until recently been directed to progressively larger format, smaller pixel FPA. The potential of small format, large pixel FPA for many applications in the emerging very high volume industry and consumer markets is now becoming recognised; made possible with availability of CMOS/MEMS foundries capable of large scale microbolometer manufacture.

The MP-FPA concept has been demonstrated and the results of analysis and measurement previously reported at SPIE IR Technology and Applications. In this paper we extend the discussion to two applications in depth: high performance low cost thermography with very low NETD,

and non-imaging cheap sensors for pedestrian detection. We also comment on progress of microbolometer technology development for miniaturised sensors.

8704-105, Session 20

A 160x120 Microbolometer FPA for Low-Cost Applications

Tayfun Akin, Selim Eminoglu, Murat Tepegoz, Mikro-Tasarim San. ve Tic. Ltd. Sti. (Turkey)

No abstract available,

8704-111, Session 20

Development of improved NEP hybrid pyroelectric radiometers for low radiant-power measurement in the LWIR

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The 3 nW/Hz^½ to 10 nW/Hz^½ Noise Equivalent Power (NEP) of recently developed hybrid pyroelectric radiometers is not quite low enough to use them in low-temperature radiation thermometers or at the output of blackbody-monochromator sources in the far IR. The output of a blackbody radiator in the 20 to 25 micrometer wavelength interval is very low, therefore enhanced performance of these detectors is needed. In order to do this, in cooperation with the material supplier SRICO Inc. a number of pyroelectric detectors that feature higher voltage responsivity and lower NEP have been developed. The responsivity increase was achieved through the use of ever thinner detector crystals down to 9 micrometer and use of larger feedback resistors in their built-in current measuring preamplifiers. The goal was to create a 3 mm diameter (or greater) detector with an NEP of less than 0.5 nW/Hz^1/2 at a signal frequency of 5 Hz. This is an order of magnitude NEP improvement. The main characteristics of the improved pyroelectric radiometers, such as voltage responsivity, NEP, output signal-to-noise ratio, upper roll-off frequency, and spatial non-uniformity of responsivity have been evaluated.

8705-1, Session 1

In-situ calibration of a microbolometer camera for the study of large-scale fires

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Understanding fire dynamics and fire protection is of great importance to life safety and property protection. At its Fire Technology Laboratory, FM Global continues to advance the understanding of how combustible materials and protection systems interact under fire conditions. In fact, spanning 10,000-m2 (108,000-ft2), FM Global's Fire Technology Laboratory is the centerpiece of the Research Campus and the largest facility of its type in the world. Quantitative temperature measurements of large-scale fires are of key interest to FM Global's researchers and engineers.

This work investigates the effectiveness of extending the useable temperature range of a microbolometer IR camera using a reduced aperture. The corresponding calibration of the FPA was performed, in situ, by investigating spatially resolved radiance levels with and without the aperture present. In-the-field calibration results thus obtained were compared and validated using a blackbody ($\varepsilon = 1$) source. The increase in the noise equivalent temperature difference (NETD) caused by the reduction in exposure was investigated over a wide temperature range. Finally, new image processing techniques were applied to reduce the 1/f (pink) noise levels in the low temperature regime.

The results show that the application of an aperture can effectively extend the temperature range of a fixed-integration-time IR camera from 650ºC (1200ºF) to 1200ºC (2192ºF), making this camera particularly suitable for the scientific study of fires. This temperature extension was accomplished at low cost without changing the FPA's integration time, removing the cameras lens, or the use of a neutral density (ND) filter.

8705-2, Session 1

Thermographic analysis of the thermal properties of wood for wooden windows

Alessandro Bortolin, Gianluca Cadelano, Giovanni Ferrarini, Paolo Bison, Consiglio Nazionale delle Ricerche (Italy); Fabio Peron, Univ. Ca' Foscari di Venezia (Italy)

The frame of windows are typically made of wood in Italy, even though aluminum, PVC and other materials are more and more utilized in the building manufacture. On the other hand, the growing attention on the problem of energy saving makes more stringent the attention to the insulation properties of any component of the building envelope. Therefore, it is paramount to evaluate the thermal properties of wood that will be utilized in the windows frame manufacture.

Wood is a material characterized by a high anisotropy due to its characteristic growing. Mechanical properties, and thermal as well, are very different if considered along the direction of grain or perpendicular to it. For example, the resistance to tensile and compression strengths is much higher along the fibers direction than perpendicular to it. Moreover the cross section of a trunk shows an approximately circular/elliptical symmetry, but more generally the stress/strain relation is represented by a tensor. Again, the same is true for thermal properties and the relation between temperature gradient and heat flux is in generally a linear one connected by the conductivity tensor of rank 2.

In manufacturing the frame for windows, the fiber or grain direction must be selected in such a way to maximize the thermal resistance along the inside to outside direction, that means the inside/outside direction of frame (i.e. inside/outside direction of window) must be perpendicular to the grain direction. Indeed the grain direction is the one with the maximum thermal conductivity while the perpendicular one (crossing the fiber direction) owns a lower conductivity value.

The anisotropic characteristics of wood made it a challenging material for the measurement of thermal conductivity. Three types of wood have been measured: oak, larch and fir-wood. Three instruments have been utilized: a) the guarded hot plate method; b) the hot disk apparatus; c) the IR thermography equipment in transmission scheme (a variant of Parker's method) complemented by density and specific heat measurements.
In particular, IR thermography gives the possibility to evaluate by images the preferential direction of heat propagation by looking at the deformation of a localized heat source released on the surface (i.e. a circular shape can become an ellipse as heat diffuses on the surface). Results coming from different kind of measurements are compared and critically considered.

8705-3, Session 1

High-resolution survey of buildings by lock-in IR thermography

Alessandro Bortolin, Gianluca Cadelano, Giovanni Ferrarini, Paolo Bison, Consiglio Nazionale delle Ricerche (Italy); Fabio Peron, Univ. Ca' Foscari di Venezia (Italy); Xavier P. V. Maldague, Univ. Laval (Canada)

Applications of IR-thermography in buildings surveys are not limited to the identification of the temperature distribution and heat losses on building envelopes. As it is well known from NDT testing in industrial applications, active IR-thermographic methods such as heating-up/cooling-down or lock-in thermography improves the results in many investigations. In civil engineering these techniques have not been used widely. Mostly, thermography is used in a quasi-static manner. The paper illustrates a new approach to achieve, by the lock-in technique, an in depth view of the structure of the wall evidencing the presence of buried elements, interfaces and cracks. The idea is to take advantage of the periodic heating and cooling of earth surface due to the alternating of day and night. It produces a thermal wave of period 24 hours that can probe the walls of buildings with a penetration depth of the order of some tenths of centimeters. The periodic temperature signal is analyzed to extract amplitude and phase. It is expected that the phase image gives the indication of inhomogeneity buried in the wall structure.

As a case study, the exterior surface of Palazzo Ducale in Venice is analyzed and illustrated. In addition to IR images, Near IR and visible electromagnetic bands are considered to evaluate the strength of the solar radiation. Indeed, the periodicity due to the earth rotation is only approximately of 24 hours. The passing clouds or the possibility of rainy days can superimpose other heating/cooling frequencies to the main one. The Fourier analysis of the impinging radiation on the wall is considered. A final attempt to deconvolve the temperature signal by the impinging radiation signal, coming from the contemporary acquisition of the surface in the visible/near IR bands, is described and compared with the lock in analysis.

The façade of Palazzo Ducale is tiled with marble of two different colors and types. The thermal properties (effusivity and diffusivity) are measured to take into account the different thermal responses of different tiles.

8705-4, Session 1

The case for using a sacrificial layer of absorbent insulation in the design of flat and low-sloped roofing

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

Starting about twenty-five years ago, there was a slow, steady increase in the number of single-ply membrane roof designs, mainly because they cost less to install then conventional built-up roofs (BURs). But over the past ten years, there have been a marked increase in single-ply roof systems -mostly white and more reflective roofs, using cellular foam insulation in the substrate. These roofs generally do not last as long, but cost much less to install.

Another factor in the increase in popularity is the fact that many governments offer incentives for building owners to use reflective, better insulated roofs. Now, owing to the energy-efficient requirements for the design and construction of new buildings put forth in ASHRAE Standard 90.1, “Energy Standard for Buildings Except Low-Rise Residential Buildings” and the world’s apparent desire to be (at least appear to be) “green”, more and more roof designs include these reflective single-ply membranes, which use cellular foam boards and higher density spray foam insulation to meet these requirements. Using a lower density traditional insulation will mean that the roof will have to be very thick, increasing the costs of installation.

High density cellular foams do not absorb water for the first 5-7 years (until UV breaks down the foam and they become absorbent), so any water that enters the roof through a breach in the membrane goes straight into the building. This is not a good consequence, since keeping the water out of the building is the purpose of waterproofing. This paper puts forth the idea and reasoning behind having a sacrificial layer of very absorbent insulation installed in every flat and low-sloped roof so that when a breach occurs, it can easily be found and documented during an annual infrared inspection which is an effective predictive maintenance technique and best practice condition monitoring for roof maintenance.

8705-5, Session 1

Methods to attack, or defend the professional integrity and competency of an Infrared Thermographer and their work. What every Attorney and Infrared Thermographer needs to know before going into a lawsuit

Fred P. Colbert, Colbert Infrared Services (United States) and Professional Thermographers Association (United States) and Thermal Trend (United States)

This paper outlines the 4 areas for critical review that an attorney should focus on with regards to how to prepare a case for trial by reviewing the qualifications of personal, their equipment, their training, and the body of their work. It is based on practical experience while working as an expert witness for the US Dept. of Justice Department, DEA, State and Local law enforcement, as well as in the Civil Court system.

Today with the introduction in the last few years of low cost infrared cameras, there has been a massive influx of either internal Electrical/Mechanical Predictive Maintenance programs, or as outsourced consulting services, as well as thermographic imaging services in the market segments of, Building Envelopment for both commercial and residential, Refractory/Boiler Evaluations, etc. This influx is driven by two factors, the low cost of investment in the equipment and extreme over simplification and understating the technical and skill level required to use this equipment in an effort to sell more cameras to an otherwise saturated market.

Along with this influx of new thermographers, also comes the result of their work. And unfortunately in many cases the outright lack of professional competency in the quality of the data that is provided. In many cases this data is vital to the operation of critical equipment and processes in industrial, commercial, and utility industries where the failure of equipment can mean the loss of millions of dollars and catastrophic of facilities and loss of life.

The liability and exposure of what is at risk for both parties, the consumer and the provider of these types of services, whether in-house, or our-sourced is overwhelming. The cost to prepare your defense if you are even named as a potential litigant in a lawsuit is in excess of US $100,000.

8705-6, Session 2

Flow detection via sparse frame analysis for suspicious event recognition in infrared imagery

Henrique C. Fernandes, Univ. Laval (Canada); Marcos A. Batista, Univ. Federal de Goiás (Brazil); Celia Z. Barcelos, Univ. Federal de Uberlândia (Brazil); Xavier P. V. Maldague, Univ. Laval (Canada)

It is becoming increasingly evident that intelligent systems are very beneficial for society and that the further development of such systems is necessary to continue to improve society’s quality of life. One area that has drawn the attention of recent research is the development of automatic surveillance systems. In our work we outline a system capable of monitoring an uncontrolled area (an outside parking lot) using infrared imagery and recognizing suspicious events in this area. The first step is to identify moving objects and segment them from the scene’s background. Our approach is based on a dynamic background-subtraction technique which robustly adapts detection to illumination changes. It is analyzed only regions where movement is occurring, ignoring influence of pixels from regions where there is no movement, to segment moving objects. Regions where movement is occurring are identified using flow detection via sparse frame analysis. During the tracking process the objects are classified into two categories: Persons and Vehicles, based on features such as size and velocity. The last step is to recognize suspicious events that may occur in the scene. Since the objects are correctly segmented and classified it is possible to identify those events using features such as velocity and time spent motionless in one spot. In this paper we recognize the suspicious event “suspicion of object(s) theft from inside a parked vehicle at spot X by a person” and results show that the use of flow detection increases the recognition of this suspicious event from 78.57% to 92.85%.

8705-7, Session 2

Standoff laser-induced thermal emission of explosives

Nataly Y. Galán-Freyle, Leonardo C. Pacheco-Londoño, Amanda Figueroa-Navedo, John R. Castro-Suarez, Samuel P. Hernandez-Rivera, Univ. de Puerto Rico Mayagüez (United States)

A laser based thermal excitation of analytes followed by standoff IR detection has been evaluated for detection of explosives. The goal was to determine the feasibility of using laser induced thermal emission (LITE) from vibrationally excited explosives residues on surfaces to detect explosives remotely. FT-IR based spectral measurements were carried out to examine surfaces containing trace amounts of threat compounds used in explosive devices. A highly energetic material: PETN was used at surface concentrations of 200 to 5 ug/cm2. Target support substrates of different thicknesses were heated using a high power CO2 laser, and their mid-infrared thermal emission was recorded. The telescope was configured from reflective optical elements in order to minimize emission losses in the infrared wavelength range and to provide optimal performance in the system. Spectral replicas were acquired at a distance of 4 m with an FT-IR interferometer at 4 cm-1 resolution and 10 scans. Laser power was varied from 4 to 12 W at radiation exposure times of 10-30 s. Laser powers were adjusted to improve the detection of HEM and to reduce degradation of target chemicals. The advantages of increasing the thermal emission were easily observed in the results, for which optimal conditions were obtained prior to IR emission measurements. The best conditions were laser power of 8 W and an exposure time of 30 s. Signal intensity was proportional to the thickness of the coated surface (a function of the surface concentration), as well as the laser power and laser exposure time.

8705-8, Session 2

Ballistic impact performance analysis using FAST infrared imagery

Frédérick Marcotte, Vincent Farley, Simon Savary, Telops (Canada)

For numerous years, soldier protection and military vehicle armor dedicated research groups have been using high-speed visible imaging and other statistical technique in order to evaluate the level of protection offered by various ballistic materials. The main objective of these studies consist in evaluating the amount of energy absorbed by a given material, and how efficient this material is at spreading the absorbed energy to a large area. Obviously, the outputs lead to the commercialization of better and more efficient soldier protective gear and vehicles.

Recent technological progress demonstrated this phenomenon can straightforwardly be measured very efficiently by a high-speed scientific grade infrared camera. This paper presents the results of measurements of ballistic high speed (6500 fps) infrared impact of small caliber projectile on ballistic material.

8705-9, Session 2

Metal particles explosion in dust cloud analysis using FAST infrared imagery

Frédérick Marcotte, Vincent Farley, Simon Savary, Telops (Canada)

Often metal particles are added to explosive in order to improve the ballistic and blast properties of the explosion. Metal particle can also be used as explosive in the form of a dust cloud.

This paper presents the results of a 2D dynamic flow analysis of metal particles explosion in dust cloud. The ignition points, the flow rate as well as the propagation direction of the flow have been characterized using FAST IR imagery.

8705-10, Session 3

Fusion of active and passive infrared images for face recognition

Moulay A. Akhloufi, Univ. Laval (Canada) and Ctr. of Robotics and Vision (Canada); Abdelhakim Bendada, Univ. Laval (Canada)

This work introduces a new framework for active and passive infrared image fusion for face recognition applications. Two multispectral face recognition databases were used in our experiments: Equinox Database (Visible, SWIR, MWIR, LWIR) and Laval University multispectral-Faces Database (Visible, NIR, MWIR, LWIR).

The proposed framework uses a fusion scheme in texture space in order to increase the performance of face recognition. The proposed texture space is based on the use of binary and ternary patterns. A new adaptive ternary pattern is also introduced.

Active (SWIR and NIR) and passive (MWIR, LWIR) infrared modalities are used in this fusion scheme. An intra-spectrum and inter-spectrum fusion approaches are introduced.

The obtained results are promising and show an increase in the recognition performance when texture channels are fused in a multi-scale fusion scheme.

8705-11, Session 3

A multistep approach for infrared face recognition in texture space

Moulay A. Akhloufi, Univ. Laval (Canada) and Ctr. of Robotics and Vision (Canada); Abdelhakim Bendada, Univ. Laval (Canada)

Face recognition is an area of computer vision that has attracted a lot of interest from the research community. A growing demand for robust face recognition software in security applications has driven the development of interesting approaches in this field. A large quantity of research in face recognition deals with visible face images. In the visible spectrum the illumination and face expressions changes represent a significant challenge for the recognition system. To avoid these problems, researchers proposed recently the use of 3D and infrared imaging for face recognition.

In this work, we introduce a new multistep approach for face recognition in the infrared spectrum. The proposed approach works in texture space using binary and ternary patterns descriptor. The approach operates in two steps. In the first step, dimensionality reduction techniques are used to classify the preprocessed infrared face image. This operation permits the selection of the highest score candidates. In the second step, a small set of these candidates are then classified using a correlation filer approach. This last step permits the selection of the best matching candidate.

The obtained results show a high increase in recognition performance when a multistep approach is used compared to dimensionality reduction face recognition techniques.

8705-12, Session 4

Compact high-speed MWIR spectrometer applied to monitor CO^2 exhaust dynamics from a turbojet engine

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Due to international environmental regulations, aircraft turbojet manufacturers are required to analyze the gases exhausted during engine operation, including CO, CO2, NOx, particles, unburned hydrocarbons, among others. Complex measurement procedures are requested, using emission's rakes located in the back of the nozzle, and mobile laboratories for sampling the gases from the exhaust plume. However, there is an opportunity to move from the traditional gas sampling methods to real-time, high-speed and non-intrusive stand-off gas analysis using optical spectroscopy techniques in the infrared spectra.

In this work, some results of these hot gases IR emission signatures are presented using a high-speed spectroscopy measurement technique. The measurements were carried out during the test campaigns of commercial turbines at Turbojet Testing Center-INTA. As a remarkable fact, the results demonstrate the reliability of the technique for studying and monitoring the dynamics of the exhausted CO2 using the infrared emission signature.

For the measurements, a compact (no moving parts) high-speed uncooled MWIR spectrometer device was used. The system is able to provide more than 4,000 spectral lines per second in the IR band ranging between 3.0 and 4.6 microns. Each spectrum is formed by 128 spectral sub-bands with a bandwidth of 60 nm. The spectrometer was operating in passive, stand-off mode and the measurements provided information of both dynamics and concentration of CO2 during the engine test operation.

8705-13, Session 4

Design of a remote infrared images and other data acquisition station for outdoor applications

Marc-André Béland, Abdelhakim Bendada, Xavier P. V. Maldague, Univ. Laval (Canada); Giovanni Ferrarini, Paolo Bison, Ermanno G. Grinzato, Consiglio Nazionale delle Ricerche (Italy)

No abstract available.

8705-14, Session 4

Infrared thermography inspection of glass-reinforced plastic (GRP) wind turbine blades and the concept of an automated scanning device

Nicolas Avdelidis, Innovative Technology and Science Ltd. (United Kingdom); Clemente Ibarra-Castanedo, Xavier P V Maldague, Universite Laval (Canada)

Infrared thermography techniques have been used for many years in the non-destructive testing and evaluation (NDT & E) of materials and structures. The main advantage of thermography over classical NDT techniques resides in the possibility of inspecting large areas in a fast and safe manner without needing to have access to both sides of the component. Nonetheless infrared thermography is limited to the detection of relatively shallow defects (a few millimetres under the surface), since it is affected by 3D heat diffusion. However, the most common types of anomalies found on composites, such as GRP wind turbine blades are delaminations, disbonds, water ingress, node failure and core crushing, and can be effectively detected and sometimes quantified using active thermographic techniques. This research work presents the use of infrared thermography on glass reinforced plastic (GRP) wind turbine blades assessment. Finally, the development of an autonomous, novel and lightweight multi-axis scanning system, as a concept, deploying in situ thermography NDT is also presented, with the intention of developing maximisation of the blade area coverage in a single run, at a known sensitivity, with the utilisation of the minimum number of system degrees of freedom and the maximum repeatability, as well as positional accuracy possible.

8705-15, Session 5

Results of the first 1000 patients: A method to defeat breast cancer without using traditional surgery, chemotherapy, or radiation: We must rethink breast cancer diagnosis and treatment

Phillip Bretz, Richard Lynch, Desert Breast & Osteoporosis Institute (United States)

Since the National Cancer Act of 1971, all the taxpayer funding provided the National Cancer Institute and major cancer centers has been unable to reduce the 40,000 deaths yearly from breast cancer yet the same path is being followed decade after decade. Exploiting the genomic code has revealed that breast cancer is almost different in each individual and that heterogeneity protects the cancer cell from a myraid of new drugs costing billions that in many cases provide only months of prolonged life with poor quality. This paper is meant to investigate an alternative to main stream thought. Its center piece is the melding of pharmacogenomics, modified military infrared and Halo which allows for diagnosing breast cancer at an ultra-small size 2-4mm allowing for its destruction without traditional surgery using cryogenic probe. As a result chemotherapy and radiation is also eliminated.

Using medical IR the smallest cancer found to date is 4mm and a full three years before mammography, ultrasound and MRI identified the cancer. A high false negative rate for mammography (20%) and the elimination of mammography below age 50 for Medi-Cal enrollees in California, for example, makes investigation of this new approach imperative. This paper presents the results of the first 1000 patients.

8705-16, Session 5

Experimental model for determining developmental stage of chicken embryo using infrared images and artificial neural networks

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Development of a chicken embryo is conventionally assumed to follow a set growth pattern over the course of 21 days. However, despite identical incubation settings, many factors may contribute to an egg developing at a different rate from those around it. Being able to determine an embryo's actual development instead of relying on chronological assumptions of normal growth should prove to be a useful tool in the poultry industry for responding early to abnormal development and improving hatch rates. Previous studies have used infrared imaging to enhance candling observation, but relatively little has been done to implement infrared imaging in problem-solving. The purpose of this research is to construct a quantitative model for predicting the development stage and early viability of a chicken embryo during incubation. It may be noted that a similar project was conducted previously using different input parameters but having lower accuracy. In this project, infrared images of eggs were processed to calculate air cell volumes and cooling rates, and daily measurements of egg weight and ambient temperature were compiled. Artificial neural networks (ANNs) were "trained" using multiple input parameters to recognize patterns in the data. Various training functions and topologies were evaluated in order to optimize prediction rates and consistency. The prediction rates obtained for the ANNs were around 81% for development stage and around 92% for viability. It is recommended for future research to expand the potential combinations of input parameters used in order to increase this model's versatility in the field.

8705-17, Session 5

Thermal imaging to detect physiological indicators of stress in humans

Carl B. Cross, Julie A. Skipper, Wright State Univ. (United States); Douglas Petkie, Wright State University (United States)

Real-time, stand-off sensing of human subjects to detect emotional state would be valuable in many defense, security and medical scenarios. We are developing a multimodal sensor platform that incorporates high-resolution electro-optical and mid-wave infrared (MWIR) cameras and a millimeter-wave radar system to identify individuals who are psychologically stressed. Recent experiments have aimed to: 1) assess responses to physical versus psychological stressors; 2) examine the impact of topical skin products on thermal signatures; and 3) evaluate the fidelity of vital signs extracted from thermal imagery and radar signatures. Registered image and sensor data were collected as subjects (n=32) performed mental and physical tasks. In each image, the face was segmented into 29 non-overlapping segments based on fiducial points automatically output by our facial feature tracker. Image features were defined that facilitated discrimination between psychological and physical stress states. To test the ability to intentionally mask thermal responses indicative of anxiety or fear, subjects applied one of four topical skin products to one half of their face before performing tasks.

Finally, we evaluated the performance of two non-contact techniques to detect respiration and heart rate: chest displacement extracted from the radar signal and temperature fluctuations at the nose tip and regions near superficial arteries to detect respiration and heart rates, respectively, extracted from the MWIR imagery. Our results are very satisfactory: classification of physical versus psychological stressors is repeatedly greater than 90%, thermal masking was usually ineffective, and accurate heart and respiration rates are detectable in both the thermal and radar signatures.

8705-18, Session 6

Developing a successful and sustainable predictive maintenance program

John W. Pratten III, Proactive Maintenance Consultants, LLC (United States)

Much has been written about the many important issues that need to be addresses when trying to develop a predictive maintenance program within your facility. The sad fact however is that very few infrared camera owners or their respective employers have done enough to receive maximum benefit from their infrared technology investment.

While visiting and working with hundreds of customers all over the US, the problem seems to break down to three simple issues. The first is the trend of lower prices for infrared cameras. The issue here is that the cost of training is now a much higher percentage of the total cost of acquisition and good training is taking a back seat.

The second point is that there may or may not be a conversation about the importance of training during the sales process. Often the focus is on the science of infrared, very important indeed, but the conversations regarding training need to go beyond that.

The third issue can be contributed to the overwhelming feeling of “where do I start” from the customer’s point of view. These points are touched on during many of the regular training classes, but due to the vast number of customers struggling in this area, it is apparent that not enough information is available. Many customers need to fend for themselves as they try to realize a reasonable return on their investment.

The focus of this paper will focus on the third point above, developing a successful and sustainable predictive maintenance program.

8705-19, Session 6

Thermographic in-situ process monitoring of the electron-beam melting technology used in additive manufacturing

Ralph B. Dinwiddie, Ryan R. Dehoff, Peter D. Lloyd, Larry E. Lowe, Oak Ridge National Lab. (United States)

Oak Ridge National Laboratory (ORNL) has been utilizing the Arcam electron beam melting technology to additively manufacture complex geometric structures directly from powder materials. Although the technology has demonstrated the ability to decrease costs, decrease manufacturing lead-time and fabricate complex structures that are impossible to fabricate through conventional processing techniques, certification of the component quality can be challenging. Because the process involves the continuous deposition of successive layers, each layer can be examined without destructively testing the component. However, in-situ process monitoring is difficult due to metallization on inside surfaces caused by evaporation of metal from the melt pool. This work describes the challenges overcome to continuously image inside of the chamber during the EBM process such as utilization of a continuously moving Mylar film canister. Results will be presented related to in-situ process monitoring and how this technique results in improved mechanical properties and reliability of the process.

8705-20, Session 6

Real-time process monitoring and temperature mapping of the 3D polymer printing process

Ralph B. Dinwiddie, Lonnie J. Love, John C. Rowe, Oak Ridge National Lab. (United States)

An extended range IR camera was used to make temperature measurements of samples as they are being manufactured. The objective is to quantify the temperature variation inside the system as parts are being fabricated, as well as quantify the temperature of a part during fabrication. The IR camera was used to map the temperature within the build volume of the oven and surface temperature measurement of a part as it was being manufactured. The development of the temperature map of the oven provides insight into the global temperature variation within the oven that may lead to understanding variations in the properties of parts as a function of location within the build volume. The development of the temperature variation of a part that fails during construction helps in understanding how the deposition process impacts temperature build up within a single part leading to failure.

8705-21, Session 6

Thermal imaging for assessment of electron-beam free form fabrication (EBF3) additive manufacturing welds *(Invited Paper)*

Joseph N. Zalameda, Eric R. Burke, Robert A. Hafley, Karen M. Taminger, NASA Langley Research Ctr. (United States)

Additive manufacturing is a rapidly growing field where 3-dimensional parts can be produced layer by layer. NASA’s electron beam free-form fabrication (EBF3) technology is being evaluated to manufacture metallic parts in a space environment. The benefits of EBF3 technology are weight savings to support space missions, rapid prototyping in a zero gravity environment, and improved vehicle readiness. The EBF3 system is composed of 3 main components: electron beam gun, multi-axis position system, and metallic wire feeder. The electron beam is used to melt the wire and the multi-axis positioning system is used to build the part layer by layer. To insure a quality weld, a near infrared (NIR) camera is used to image the melt pool and solidification areas. This paper describes the calibration and application of a NIR camera for temperature measurement. In addition, image processing techniques are presented for weld assessment metrics.

8705-22, Session 7

Crack detection using induction thermography during high-temperature testing

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Thermo-mechanical fatigue test and strain to crack test at elevated temperature are important aspect to the total fatigue life for many engineering applications. During a thermo-mechanical fatigue (TMF) test, crack inspections are commonly done in a disruptive manner using an acetate replication method; and post-test crack evaluations are done using both optical and scanning electronic microscope methods. Similarly, inspections during typical strain to crack (SC) are performed in disruptive manner. This paper demonstrates that infrared imaging can be used in-situ, as a non-destructive inspection approach to detect crack during TMF testing and SC at high temperature. It also shows that this technique allows reducing or eliminating the need for downtime typically required for inspection. The results obtained by induction thermography are compared to those obtained via traditional methods and post-test evaluation. The induction thermography inspections were carried out at several temperatures and show that the temperature used during the test does not influence the crack detection capability. It is demonstrated that induction thermography can detect cracks smaller than 500 um and has potential for quantifying the crack length. The potential for generating crack growth curve is also presented.

8705-23, Session 7

Spectroradiometric calibration of sub-ambient flat plate blackbodies

Sergey N. Mekhontsev, National Institute of Standards and Technology (United States); Vladimir B. Khromchenko, National Institute of Standards and Technology (United States) and SDL, Inc. (United States); Leonard M. Hanssen, National Institute of Standards and Technology (United States)

The current NIST capabilities for infrared spectroradiometry calibration support for customers includes a pair of complementary facilities: the Advanced IR Radiometry and Imaging (AIRI) laboratory for blackbody source and pyrometer characterization, and the Fourier Transform Infrared Spectrophotometry (FTIS) laboratory for material optical property characterization, including emittance. The wavelength and temperature ranges covered by the facilities are respectively: 3.4 μm to 13.5 μm and 15 °C to 1000 °C for AIRI, and 3 μm to 23 μm and 200 °C to 900 °C for FTIS Emittance. The limitations on these ranges are determined by the available spectral comparators and radiometers, which are used for spectral radiance and surface temperature measurements, as well as by condensation of the water vapor on the surfaces at sub-ambient temperatures (in case of AIRI, where no dry air purge is available). To meet the newly emerging requirements, we will need to extend the functionality of both facilities, to enable the measurement of spectral radiance and emittance of blackbody sources and targets at near- and sub-ambient temperatures and shorter wavelengths. We report the first results of our efforts. The approach taken has been to: (a) transition to spectrometers that are better suited for this particular job; (b) add new detectors or improve operation of existing ones, and (c) introduce design features, allowing for dry air purge in the vicinity of the radiator's surface, with minimal possible interference with radiative or convective heat exchange, experienced in free-standing mode at the user facility.

8705-24, Session 7

Recent developments in infrared reflectometry at NIST

Leonard M. Hanssen, National Institute of Standards and Technology (United States); Jinan Zeng, Space Dynamics Lab. (United States); Sergey N. Mekhontsev, National Institute of Standards and Technology (United States); Vladimir B. Khromchenko, Space Dynamics Lab. (United States)

We present an update on recent progress in the extension of NIST's reflectometry capabilities in support of existing and emerging requirements for higher accuracy optical measurements in the infrared for the characterization of detectors, sources and materials. NIST's Sensor Science Division (SSD) is responsible for maintaining the national scales for the infrared spectral characterization of materials. A complimentary pair of facilities, the Fourier Transform Infrared Spectrophotometry laboratory and the Laser-based Infrared Reflectometry laboratory, have been established for the characterization of reflectance, transmittance, and emittance of materials, as well as the reflectance of cavities in the infrared spectral region from approximately 1.5 μm to beyond 20 μm. Besides scales for these properties, these two facilities also support the SSD's infrared spectral radiance and responsivity scales through the measurement of cavity reflectance and detector reflectance, respectively. We will discuss recent improvements to the facilities' capabilities along with examples of recent calibration measurements in support of defense and aerospace applications.

8705-25, Session 8

Nondestructive inspection in adhesive-bonded joint CFRP using pulsed phase thermography

Peter H. Shin, Sean C. Webb, Kara J. Peters, North Carolina State Univ. (United States)

Many forms of damages in fiber reinforcement polymer (FRP) composites are difficult to detect because they occurs in subsurface layers of the composites. One challenging need for inspection capabilities is in adhesively bonded joints between composite components, a common location of premature failure in aerospace structures. This paper investigates pulsed phase thermography (PPT) imaging of fatigue damage in these adhesively bonded joints. Simulated defects were created to calibrate parameters for fatigue loading conditions and PPT imaging parameters of a carbon fiber reinforced polymer (CFRP) single lap joint. Afterwards, eighteen lap joint specimens were fabricated with varying quality of manufacturing. PPT imaging of the pristine specimens revealed defects such as air bubbles, adhesive thickness variations, and weak bonding surface between the laminate and adhesive. These initial manufacturing flaw detections are important since they contribute to damage progression and eventually failure during fatigue loading cycles. Next, fatigue testing was performed and acquired PPT imaging data identified fatigue induced damage prior to final failure cycles. After failure of each sample, those images were confirmed by visual inspections of failure surface. Ten samples also included fiber Bragg grating (FBG) sensors embedded in the adhesive bond for real-time inspection during a simulated flight condition of these single-lap joints.

8705-26, Session 8

Non-visible defect detection in glass using infrared thermography and artificial neural networks

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Bubble defects in glass are a major problem in the glass industry as these defects result in recall and rejection of materials and products. Optical imaging has been applied to detect bubble defects. However, for tinted glass, optical approaches are more challenging. In this study, infrared imaging was applied to detect hidden bubbles in tinted glass with diameters of less than 2 mm and varying depths. Results suggest that infrared imaging can be used to detect bubbles within tinted glass and artificial neural network models can be used to predict the diameter and depth of the defects with prediction accuracy of ~60% for diameter and 76% for depth.

8705-27, Session 9

Comparison of pulse phase and thermographic signal reconstruction processing methods

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Active thermography data for nondestructive testing has traditionally been evaluated by either visual or numerical identification of anomalous surface temperature contrast in the IR image sequence obtained as the target sample cools in response to thermal stimulation. However, in recent years, it has been demonstrated that considerably more information about the subsurface condition of a sample can be obtained by evaluating the time history of each pixel independently. In this paper, we evaluate the detection limits of two such techniques, Pulse Phase Thermography (PPT) and Thermographic Signal Reconstruction (TSR)

using various heating methods and samples. Both processing techniques are applied to the same data sequence, and results are evaluated in terms of signal-to-background ratio. In addition to the experimental data, we present finite element simulation models with varying flaw diameter and depth, and discuss size measurement accuracy and the effect of noise on detection limits and sensitivity for both methods.

8705-28, Session 9

Evaluating quality of adhesive joints in glass-fiber plastic piping by using active thermal NDT

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Glass-fibre Reinforced Plastic (GRP) has been continuously employed in the oil industry in recent years, often on platforms and, particularly, in pipes for transportation of water or oil under moderate temperatures. In this case, the pipes are usually connected with adhesive joints and, consequently, the detection of defects in these joints, such as areas without adhesive or adhesive failure (disbond), gains great importance. Due to increasing investments into applications of composite materials on platforms, PETROBRAS has undertaken certain efforts to identify the best practices in service inspection of GRP pipe lines, having invested in the study of some NDT techniques. One of such techniques being presently tested is active thermography. One-sided inpection on the joint front surface is a challenging task because the joint collar thickness can exceed 10 mm that is far beyond of the reported limits of IR thermographic NDT applied to GRP composites. The detection limits have been evaluated both theoretically and experimentally as a function of joint collar thickness and defect lateral size. The 3D modeling was accomplished by using the ThermoCalc-6L software. The experimental unit consisted of a FLIR SC640 IR imager and a home-made heater which included two halogen lamps of the 1,5 kW power each. The results obtained with pulsed heating have demonstrated that inspection efficiency is strongly dependent on the collar thickness with a value of about 8 mm being a detection limit. In the future, potentials of a lock-in IR thermographic procedure, as well as powerful ultrasonic stimulation, is to be studied to compare with the pulsed technique.

8705-29, Session 9

Nondestructive testing of externally-reinforced structures for seismic retrofitting using flax fiber reinforced polymer (FFRP) composites

Clemente Ibarra-Castanedo, Univ. Laval (Canada); Stefano Sfarra, Domenica Paoletti, Univ. degli Studi dell'Aquila (Italy); Abdelhakim Bendada, Xavier P. V. Maldague, Univ. Laval (Canada)

Natural fibers constitute an interesting alternative to synthetic fibers, e.g. glass and carbon, for the production of composites due to their environmental and economic advantages. The strength of natural fiber composites is on average lower compared to their synthetic counterparts. Nevertheless, natural fibers such as flax, among other bast fibers (jute, kenaf, ramie and hemp), are serious candidates for seismic retrofitting applications given that their mechanical properties are more suitable for dynamic loads. Strengthening of structures is performed by impregnating flax fiber reinforced polymers (FFRP) fabrics with epoxy resin and applying them to the component of interest, increasing in this way the load and deformation capacities of the building, while preserving its stiffness and dynamic properties. The reinforced areas are however prompt to debonding if the fabrics are not properly installed. Nondestructive testing is therefore required to verify that the fabric is uniformly installed and that there are no air gaps or foreign materials that could instigate debonding. In this work, the use of active infrared thermography was investigated for the assessment of (1) a laboratory specimen reinforced with FFRP and containing several artificial defects; and (2) an actual FFRP retrofitted masonry wall in the Faculty of Engineering of the University of L'Aquila (Italy) that was seriously affected by the 2009 earthquake. Thermographic data was processed by advanced signal processing techniques, and post-processed by computing the watershed lines to locate suspected areas. Results coming from the academic specimen were compared to digital speckle photography and holographic interferometry images.

8705-30, Session 9

Improved sizing of impact damage in composites based on thermographic response

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Impact damage in thin polymer matrix graphite fiber (PMGF) composites often results in a relatively small region of damage at the front surface, with increasing damage near the back surface. Conventional methods for reducing the pulsed thermographic responses of the composite tend to underestimate the size of the back surface damage, since the smaller near surface damage gives the largest thermographic indication. A method is presented for reducing the thermographic data to produce an estimated size for the impact damage that is much closer to the size of the damage estimated from other NDE techniques such as microfocus x-ray computed tomography and pulse echo ultrasonics. Examples of the application of the technique to experimental data acquired on impacted composite specimens are presented. The technique is also applied to the results of thermographic simulations to investigate the limitations of the technique.

8705-31, Session 9

Analysis of signal processing techniques in pulsed thermography

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Pulsed Thermography (PT) is one of the most widely used approaches for the inspection of composites materials, being its main attraction the deployment in transient regime. However, due to the physical phenomena involved during the inspection, the signals acquired by the infrared camera are nearly always affected by external reflections and local emissivity variations. Furthermore, non-uniform heating at the surface and thermal losses at the edges of the material also represent constraints in the detection capability. For this reason, the thermographic signals should be processed in order to improve – qualitatively and quantitatively – the quality of the thermal images. Signal processing constitutes an important step in the chain of thermal image analysis, especially when defects characterization is required. Several of the signals processing techniques employed nowadays are based on the one-dimensional solution of Fourier's law of heat conduction. This investigation brings into discussion the three-most used techniques based on the 1D Fourier's law: Thermographic Signal Reconstruction (TSR), Differentiated Absolute Contrast (DAC) and Pulsed Phase Thermography (PPT), applied on glass and carbon laminated fiber composites. It is of special interest to determine the detection capabilities of each technique on both kinds of materials, allowing in this way more reliable results when performing an inspection by PT. The results obtained from this research will be used in

later investigation to compare and analyze the performance of Fourier's law-based versus statistical multivariate-based signal processing techniques.

8705-32, Session 9

Detection of defects in laser powder deposition (LPD) produced components by laser thermography

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Detection of defects in Laser Powder Deposition (LPD) produced components has been achieved by laser thermography. An automatic in-process NDT defect detection software system has been developed for the analysis of laser thermography to automatically detect, reliably measure and then sentence defects in individual beads of LPD components. A deposition path profile definition has been introduced so all laser powder deposition beads can be modelled, and the inspection system has been developed to automatically generate an optimized inspection plan in which sampling images follow the deposition track, and automatically control and communicate with robot-arms, the source laser and cameras to implement image acquisition. Algorithms were developed so that the defect sizes can be correctly evaluated and these have been confirmed using test samples. Individual inspection images can also be stitched together for a single bead, a layer of beads or multiple layers of beads so that defects can be mapped through the additive process. A statistical model was built up to analyse and evaluate the movement of heat throughout the inspection bead. Inspection processes were developed and positional and temporal gradient algorithms have been used to measure the flaw sizes. Defect analysis is then performed to determine if the defect(s) can be further classified (crack, lack of fusion, porosity) and the sentencing engine then compares the most significant defect or group of defects against the acceptance criteria – independent of human decisions. Testing on manufactured defects from the EC funded INTRAPID project has successful detected and correctly sentenced all samples.

8705-33, Session 9

Nondestructive testing and evaluation of composites by non-invasive IR Imaging techniques

Ravibabu Mulaveesala, Indian Institute of Technology, Ropar (India); Juned A. Siddiqui, PDPM IIITDM Jabalpur (India); Vanita Arora, Indian Institute of Technology, Ropar (India); Subbarao V. Ghali, K L Univ. (India) and PDPM IIITDM Jabalpur (India); Amarnath Muniyappa, PDPM IIITDM Jabalpur (India); Masahiro Takei, Graduate School of Chiba Univ. (Japan)

InfraRed Thermography (IRT) is one of the promising technique for non-destructive testing method for characterization of materials. This technique relies on evaluation of the surface temperature variations to detect the presence of surface and subsurface anomalies within the material. Due to its whole field and remote testing capabilities, IRT has gained significant importance in testing of Glass Fiber Reinforced Plastic (GFRP) materials. A GFRP specimen with defects of various sizes at a given depth was inspected using non-stationary thermographic techniques. In order to highlight the defect detection capabilities of the proposed non-stationary schemes, a comparison has been made using matched excitation energy in frequency domain by taking signal to noise ratio into consideration. Further, results obtained from the conventional phasegrams at matched frequency have been compared with recently introduced pulse compression based approach for non-stationary excitation schemes.

8705-34, Session 9

Theory, modeling, and simulations for thermal wave detection and ranging

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Active infrared thermography for nondestructive testing and evaluation is a rapidly developing technique for quick and remote inspection of subsurface details of test objects. Sinusoidal modulated thermal wave imaging such as Lock-in thermography (LT) significantly contributed to this field by allowing low power controlled modulated stimulations and phase based subsurface detail extraction capabilities. But demand of repetitive experimentation required for depth scanning of the test object, limits its applicability for realistic applications and demands multi frequency low power stimulations. Non-stationary thermal wave imaging methods such as frequency modulated thermal wave imaging (FMTWI), digitized FMTWI and coded thermal wave imaging methods permitting multi frequency stimulations cater these needs and facilitate depth scanning of the test object in a single experimentation cycle. This contribution highlights theory, modeling and simulations for non-stationary modulated thermal wave imaging methods for non-destructive characterization of solid materials.

8705-35, Session 9

Recent advances in thermal wave detection and ranging for non-destructive testing and evaluation of materials

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Thermal Wave Detection and Ranging (TWDAR) for non-destructive testing (TNDT) is a whole field, non-contact and non-destructive inspection method to reveal the surface or subsurface anomalies in the test sample, by recording the temperature distribution over it, for a given incident thermal excitation. Present work proposes recent trends in non-stationary thermal imaging methods which can be performed with less peak power heat sources than the widely used conventional pulsed thermographic methods (PT & PPT) and in very less time compared to sinusoidal modulated Lock-in Thermography (LT). Furthermore, results obtained with various non-stationary thermal imaging techniques are compared with the phase based conventional thermographic techniques.

8705-36, Session 10

The Zombie Thermographer Apocalypse Preparedness 101: Zombie Thermographer Pandemic

Fred P. Colbert, Colbert Infrared Services (United States) and Thermal Trend (United States) and Professional Thermographers Association (United States)

The U.S Government Centers for Disease Control and Prevention (CDC), Office of Public Health Preparedness and Response, actually has part of their web site dedicated to" Zombie Preparedness". See: http://www.

cdc.gov/phpr/zombies.htm for more information. This is a tongue-in-cheek campaign with messages to engage new audiences with the hazards of preparedness. The CDC director, U.S. Assistant Surgeon General Ali S. Khan (RET), MD, MPH notes, “If you are generally well equipped to deal with a zombie apocalypse you will be prepared for a hurricane, pandemic, earthquake, or terrorist attack. “Make a plan, and be prepared!”

Today we can make an easy comparison between the humor that the CDC is bringing to light, and what is actually happening in our Thermographic Industry, but the reality is that we must recognize that we actually do have “Zombie Thermographers” out there, and that this is a pandemic apocalypse that is attacking the creditability and legitimacy of this science of this industry that we have all been working hard to advance for over 30 years.

This paper outline strategies to be prepared for the trends that are already in place and what needs be done to overcome these problems. Awareness, education, practical expectations and understanding of the real science behind thermal imaging is vital to being able to further advance scope of this technology.

We have what is the equivalent of the night of the living dead, zombie thermographers walking around with thermal imagers in their hands, and believing that they are just as qualified as a real professional thermographer, all the time not even knowing what they do not know, but telling people that all you have to do is just point and shoot. The internet and You Tube are full of examples of them, demonstrating that you can see through walls, see mold, and even see ghosts, space aliens and big foot!

We are seeing a decline in the quality of professional thermographic consulting services that are offered today. As well as a serious drop in the skill sets that in-house thermographers have within their own facilities. Market economics that are based on commodity sales of material products like light bulbs are being transferred onto engineering/technical consulting services, where unsuspecting consumers and naive purchasing agents are awarding contracts to the lowest bidder. The first mistake is to confuse quality technical services with a commodity based business model; they are simply not the same. For example just look at Washington State (USA), where history has taught us this lesion repeatedly, but we don’t seem to get the message. The history of engineering failures like the Tacoma Narrows Bridge, the Hood Canal Bridge, and the I90 Floating Bridge and now the 520 Bridge are all a testimony to short sidedness and commodity economics for technical services.

There are 4 key areas where we can become more prepared, and understand what the outcome will be if we do not make the necessary changes to advert this Night of the living dead, Zombie Thermographer Apocalypse that is becoming a pandemic problem for our industry.

8706-1, Session 1

Resampling in hyperspectral cameras as an alternative to correcting keystone in hardware, with focus on benefits for the optical design and data quality

Andrei Fridman, Norsk Elektro Optikk AS (Norway); Gudrun Høye, Norwegian Defence Research Establishment (Norway); Trond Løke, Norsk Elektro Optikk AS (Norway)

In this work we compare the performance of hyperspectral cameras where keystone is corrected in hardware with cameras where very large keystone is corrected by resampling. Design and manufacturing of hyperspectral cameras are challenging tasks because of very stringent requirements for co-registration between spectral bands. These requirements severely limit specifications of these imaging instruments in terms of spatial resolution and ability to collect light. General opinion seems to be that, despite these limitations, it is better to aim for correcting co-registration errors in hardware instead of correcting them in postprocessing.

We model several cameras with realistic specifications using a Virtual Camera software that was developed specifically for this purpose. The cameras where the keystone is corrected in hardware, are modelled to have different degree of keystone correction. For the cameras where a large keystone is corrected by resampling, different resampling methods are investigated. High-resolution hyperspectral images containing objects of various size and contrast are used as the input scenes for the simulations. Since the precise content of the scene is known, this method allows to measure performance of different modelled hyperspectral cameras very accurately.

Different criteria are suggested for quantifying performance, and the tested cameras are compared according to these criteria.

The results of these simulations may found the basis for choice of architecture and design of future hyperspectral imaging systems.

8706-2, Session 1

Infrared camera NUC and calibration: comparison of advanced methods

Frédérick Marcotte, Pierre Tremblay, Vincent Farley, Telops (Canada)

Image uniformity and accurate radiometric calibration are key features of state-of-the-art infrared cameras. Over the past years several non-uniformity correction and radiometric calibration techniques have been developed. In this paper we present and compare 3 different techniques: Telops' Real-Time Image Processing (patent-pending), user multi point's calibration, and factory interpolated multi point's calibration. For each method we assess the performances, the ease of use, the advantages and drawbacks as well as the most important operational limitations considering a broad range of exposure times, ambient and scene temperatures. Capabilities of adequately supporting InSb and MCT detectors are also discussed.

8706-3, Session 1

An evaluation of image quality metrics to validate pixel uniformity and the performance of NUC methods

Thomas Svensson, Swedish Defence Research Agency (Sweden)

The performance of a non-uniformity correction (NUC) depends on the characteristics of the fixed pattern noise in the image data, in addition to the correction method itself. If external conditions (e.g. ambient temperature) are varying during a trial, the fixed pattern noise in the image data being collected will also vary. By visual inspections a substantial time may be needed to select the most optimal NUC methods if the amount of data is large. In addition, by (subjective) visual inspections it is not always obvious which NUC methods that most efficiently reduce the pixel noise. By using image quality metrics, the quality of corrected image data is given by computed objective values. In this paper a number of image quality metrics have been studied. Different NUC methods have been applied on image data collected from imaging sensors in the thermal infrared spectral region, where image data may be severely distorted by fixed pattern noise, followed by calculations of image quality metrics for the corrected image data. The results are compared with visual evaluations.

8706-4, Session 1

Development of 3D infrared imaging system using nanocarbon-based photodetectors

Ning Xi, Michigan State Univ. (United States)

The development of 3D infrared imaging system is challenging and difficult, and it also requires an understanding of processing and presenting the data via various methods for acquiring signals across a wide range of electromagnetic spectrum. Traditionally, infrared camera is made by integrating a photosensor array to an optical processing system. As a result, the resolution of the final image depends on the dimension of the focal plane array. Moreover, the conventional imaging system losses of the directional information of the infrared signal, it is because the sensor acquires the total intensity of signals arriving each point on the focal plane array. If it is required to reconstruct a 3D image, two infrared cameras or two focal plane arrays are required. In order to overcome the current limitation, we report the development of a new generation of 3D infrared imaging system based on nanocarbon-based photodetectors. Various nanocarbon-based materials, such as carbon nanotubes and graphene, have been employed for infrared photo sensing materials because of their excellent electrical and optical properties such as adjustable electrical band gap, low dark current, fast optical response time etc. In our system, a large-scale focal plane array is not required. Instead, 3D images can be recovered by the nanocarbon-based photodetectors using compressive sensing. The development of the imaging system overcomes the problems of pixel crosstalk phenomenon. Moreover, stereoscopic infrared imaging will be demonstrated in this paper, and this represents a potential advancement of 3D infrared imaging.

8706-5, Session 1

A long-wave infrared (LWIR) spectral imager (7.7 to 13 microns) based on cooled detector array and high-resolution circular variable filter (CVF)

Dario Cabib, Moshe Lavi, Amir Gil, CI Systems (Israel) Ltd. (Israel)

Spectral imagers in the Long Wave IR spectral range suffer from the problem of high production costs because the existing cooled array detectors are expensive, and in fact they are prohibitively expensive for many applications.

As a result, the drive to lower the cost of IR spectral imagers is strong, and CI has found a way to achieve this feat by significantly lowering the cost of the monochromating method used to provide the spectral

information. In fact, CI Systems has developed a long wave IR (7.7 to 13 micron) spectral imager using a Circular Variable Filter (CVF) instead of the common interferometric Fourier Transform method used in this spectral range. The CVF method is an environmentally stable, easy-to-align optical set-up, which may be suitable for many applications in which a spectral resolution in the range of 0.5% of the wavelength or 50 nm at 10 (best case) to 2% of the wavelength or 200 nm at 10 (worst case) is acceptable. System design, calibration procedure and examples of preliminary measurements, applications and specifications will be given in this paper.

8706-7, Session 2

Compensation for instrument anomalies in imaging infrared measurements

Christopher L. Dobbins, U.S. Army Aviation & Missile Research, Development & Engineering Ctr. (United States); James A. Dawson, Jay A. Lightfoot, William D. Edwards, Ryan S. Cobb, Amanda R. Heckwolf, Dynetics, Inc. (United States)

Infrared imaging is commonly used for performing thermography based on field calibration that simply relates image levels to apparent temperature levels based on field blackbodies. Under normal conditions, the correlation between the image levels and blackbody temperature is strong, allowing conversion of the raw data into units of blackbody-equivalent temperature without consideration of other factors. However, if instrument anomalies are present, a complicated calibration procedure is required involving use of a thermal chamber. The procedure and expected results are described based on analysis of temperature-dependent dark current, optical emissions, and detector response. The procedure involves first cold soaking a thermal camera and then observing the cooldown behavior of the sensor under non-stressing conditions. Increased temperature levels are then used to observe cooler performance and, if present, increases in dark current levels. A multi-variate linear regression is performed that allows temperature-dependent dark current, lens emission, lens transmission, and detector response to be fully characterized. The resulting multipliers describe for each image pixel a relationship between the scene temperature and the observed values of image signal, detector temperature, and camera temperature. The calibration procedure includes analysis of detector and camera temperatures as an indicator of cooler performance. Using error residuals, the expected accuracy of the compensation technique is derived based on the deviation between the measurement condition and the ground calibration using field blackbodies. Given the need to perform thermography with a specified level of accuracy, the limiting deviation in camera and detector temperature relative to the ground calibration is derived.

8706-8, Session 2

Characterization of domestic and foreign image intensifier tubes

Edward J. Bender, Michael V. Wood, Dan J. Hosek, Steve D. Hart, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States)

The market for military-use Generation 2 and Generation 3 image intensifier (I2) tubes has become truly global, with major manufacturers and customers spanning five continents. This worldwide market is becoming increasingly important to U.S. manufacturers, with the majority of U.S. Army intensifier fielding being completed in 2012. Given this keen global competition, it is not surprising that the advertised tube performance of a given source is often discounted by competitors, and the customers have no objective "honest broker" to determine the relative accuracy of these claims. To help fill this void, the U.S. Army RDECOM CERDEC NVESD recently measured a number of domestic and foreign image intensifier tubes, using consistent test equipment/procedures with which the U.S. industry must correlate for Army tube deliveries. Data and analysis will be presented for the major tube parameters of luminance gain, equivalent background input (EBI), signal-to-noise ratio (SNR), limiting resolution, halo, and modulation transfer function (MTF). This will additionally include the high-light resolution provided by various auto-gated and non-gated tubes, since this area has been an important factor in the international market. NVESD measurement data will be compared to the corresponding manufacturer data whenever possible.

8706-9, Session 2

Data analysis tools for imaging infrared technology within the ImageJ environment

Ryan K. Rogers, William D. Edwards, Dynetics, Inc. (United States); Caleb E. Waddle, Christopher L. Dobbins, Sam B. Wood, U.S. Army Research, Development and Engineering Command (United States)

For over 30 years, the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) has specialized in characterizing the performance of infrared (IR) imaging systems in the laboratory and field. In the late 90's, the AMRDEC developed the Automated IR Sensor Test Facility (AISTF), which allowed efficient deployment testing of UAS payloads. More recently, ImageJ has been predominantly used as the image processing environment of choice for analysis of laboratory, field, and simulated data. The strength of ImageJ is that it is maintained by the U.S. National Institute of Health, exists in the public domain, and functions on all major operating systems. Three new tools or "plug-ins" have been developed at AMRDEC to enhance the accuracy and efficiency of analysis. First, a Noise Equivalent Temperature Difference (NETD) plugin was written to process Signal Transfer Function (SiTF) and 3D noise data. Another plugin was produced that measures the Modulation Transfer Function (MTF) given either an edge or slit target. Lastly, a plug-in was developed to measure Focal Plane Array (FPA) defects, classify and bin the customizable defects, and report statistics. This paper will document the capabilities and practical applications of these tools, and profile the advantages of them over previous methods of analysis.

8706-10, Session 2

Enhanced extended area blackbody for radiometric calibration

Joseph D. LaVeigne, Gregory Franks, Santa Barbara Infrared, Inc. (United States)

Emissivity and uniformity are two of the most important features that determine the radiometric performance of an extended area blackbody. SBIR has developed an enhanced blackbody a highly emissive surface and improved its uniformity. We describe the design of the enhanced blackbody and present performance metrics including emissivity, uniformity, slew rate, stability and temperature range.

8706-11, Session 2

Active SWIR Laboratory testing methodology

Curtis M. Webb, Northrop Grumman Electronic Systems (United States); Stephen G. White, Santa Barbara Infrared, Inc. (United States)

Active Short Wave InfraRed (SWIR) imaging presents challenges to laboratory testing. It is always important to have laboratory testing that will directly relate to field performance. This paper will present the modeling and corresponding laboratory testing that was developed for these systems. The paper will present the modeling that was used to derive the lab metric used for verification testing of the system and provide details into the design of the lab equipment that was necessary

to ensure accurate lab testing.

The Noise Limited Resolution test, first developed for low light imaging systems in the 1960s, serves as the basic lab test procedure for the evaluation of the active SWIR system. This test serves well for a quick test metric and is used for this system during production testing. The test derivation will be described and shown how it relates to the field performance.

The test equipment developed by SBIR for this application allows for accurate uniform radiance levels from an integrating sphere for both 1.06um and 1.57um imaging applications. The source has the ability to directly mimic any laser system and can provide pulsed laser source radiation from 10 nanoseconds to 100 nanoseconds resulting in levels from 0.01 to 1 W/cm2/sr, peak radiance levels. The light source can be triggered to replicate a laser return at any range from 100m to 100,000m. Additionally, the source provides the ability to output Mid Wave IR (MWIR) illumination through the use of a small extended area IR source in the integrating sphere. This is critical for the use of boresighting the Forward Looking IR (FLIR) with the 1.06um and 1.57um sensors in the pod.

8706-12, Session 2

Testing missile warning and countermeasure systems (MWCS): instrumentation for development, production, and maintenance of MWCS

Dario Cabib, Adam Inbar, Tamir Barak, Doron Rozenstein, Larry Davidzon, Alon Edri, CI Systems (Israel) Ltd. (Israel)

CI has adopted a unique, all-encompassing approach to testing missile warning and countermeasure systems (MWCS). This is an integrated approach from two points of view: i) It specifically answers the testing needs of all stages in the life of an MWCS, from development to maintenance in the field, and ii) it is capable of carrying out all needed tests of most electro-optical subsystems of the MWCS.

For this purpose CI has developed unique equipment and methodology, examples of which are: i) a small, cost effective, easy-to-use, thermal envelope allowing environmental tests of MWCS sensor performance on a bench instead of the need to use cumbersome testing in a chamber, ii) a complex missile simulator for a civilian aircraft MWCS, including both scenario feedback loop for acquisition and tracking by five or more IR imagers and a sensor for jamming code emission testing, and iii) a double theodolite system that easily allows mutual alignment and field of view calibration of a number of sensors mounted on the sides and rear of an airplane for threat detection and acquisition.

The general approach, specific solutions, methodology and other examples of unique instrumentation for this MWCS testing application will be presented in this paper.

8706-39, Session 2

Evaluation of dome-input geometry for pyroelectric detectors

Jinan Zeng, National Institute of Standards and Technology (United States) and Utah State Univ. (United States); Leonard M. Hanssen, George P. Eppeldauer, National Institute of Standards and Technology (United States)

Hemispherical dome-input pyroelectric radiometers with gold black and organic black coatings have been developed to extend the spectral responsivity scale from near infrared (NIR) up to 25 µm. The dome was gold coated to increase the detector absorptance and to minimize spectral structures and obtain spectrally constant responsivity. The trap efficiency mainly depends on the optical properties of the black coating on the detector, such as the reflectance and distribution of the reflected light in the wavelength range of interest. The trap efficiency for specular and diffuse detector coatings was obtained from the reflectance measurements with/without dome using NIST's Complete Hemispherical Infrared Laser-based Reflectometer (CHILR) at 1.56 µm, 4 µm, 5 µm, 9.5 µm, and 10.6 µm. The detector absorptance with dome is determined by using the trap efficiency to correct the spectral reflectance of the bare coating on the detector using NIST's Fourier Transform Infrared Spectrophotometry (FTIS) facility. The relative spectral responsivity associated to absorptance and absolute tie-point method can determine the absolute spectral responsivity of the radiometer.
The direct calibration of the dome-input pyroelectric radiometers with organic black coating using Infrared Spectral Comparator Facility (IRSCF) and traditional sources can be conducted with dome/without dome to make a comparison with the reflectance measurements from CHILR and FTIS. This comparison is useful to understand the loss of the reflected light outside the detector inside the trap dome. The systematic study of the radiation trap efficiency on dome-input geometry is significant for optimizing the dome trap effect, reducing the uncertainty of the calibration, and building responsivity scale at the lower signal levels.

8706-14, Session 3

An investigation of image-based task performance prediction

Eddie L. Jacobs, Univ. of Memphis (United States)

Human task performance with imaging sensors is characterized by perception experiments involving ensembles of observers viewing an ensemble of task relevant images from real sensors. Summary statistics from perception experiments are used, along with detailed descriptions of the sensors and early human vision processes to build predictive models such as NV-IPM. Use of these models typically requires knowledge of more than 100 specific parameters regarding the sensor, the viewing conditions, and the task. In this research we seek to do a blind prediction of task performance using task relevant image ensembles and image processing operations that produce statistically similar outputs to those obtained in real human perception experiments. We restrict our investigation to the task of identifying tracked vehicles. The data we seek to replicate through image processing are similarity matrices derived from the confusion matrices of actual perception experiments. This paper presents our work to date examining primarily the correspondence between several image processing approaches and perception data. In particular, our goal of identifying image processing steps that result in accurate task performance indicators is presented.

8706-15, Session 3

Validating the time-dependent search parameter search model

Melvin H. Friedman, U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate (United States); Hee-Sue Choi, Jae H. Cha, Joseph P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The time dependent search parameter (TDSP) search model was described in a recent paper and compared with perception experiments. It was found that the TDSP search model was in approximate agreement with perception results. Here the focus is on determining if the agreement between the TDSP search model and experiment can be improved by reducing experimental errors in the perception experiments and including a response time in the TDSP search model. The perception experiments described in the previous paper showed the response time was comparable to the mean detection time, which implies that observer response time could be introducing discrepancies between modeled and measured results. Another factor that introduced discrepancies between modeled and measured results is errors in the vehicle time-line calibration. This paper describes a version of the TDSP search model that includes a response time, describes techniques used for improving the perception experiment and compares TDSP model predictions with experimental results.

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8706-16, Session 3

Performance characterization of night-vision equipment based on triangle orientation discrimination (TOD) methodology

Nicolas Laurent, Cédric Lejard, Geoffroy Deltel, PHOTONIS France S.A.S. (France); Piet Bijl, TNO Defence, Security and Safety (Netherlands)

Night vision equipment is crucial in order to accomplish supremacy and safety of the troops on the battlefield. Evidently, system integrators, MODs and end-users need access to reliable quantitative characterization of the expected field performance when using night vision equipment. The Image Intensifier tube is one of the most important engines driving the performance for night vision equipment. As a major tube manufacturer, PHOTONIS has investigated the link between its products physical design parameters and the actual end-user field performance. The developments include 1) an end-to-end performance measurement method and test facility, 2) an image-based night vision simulation and 3) a range estimation model. The purpose is twofold: i) being able to support the need of its customers, and ii) further systematic improvement of night vision equipment design. For the end-to-end test, PHOTONIS and TNO cooperated in the implementation of the TOD (Triangle Orientation Discrimination) test for night vision equipment. This test provides a clear and rigorous ranking of the products with respect to their performance level. With respect to the image-based simulation, PHOTONIS performs physical and performance comparisons between artificial and real imagery, promising exciting further development of a model based on the merging of the different approaches of night vision evaluation and modeling.

8706-17, Session 3

MACCAO: a software tool for the assessment of electro-optical and infrared sensor performance

Stephane Barbe, Eric Coiro, Jean-Claude Krapez, ONERA (France)

A new software tool for the assessment of electro-optical and infrared (EO/IR) sensor performance is currently under development at ONERA (French Aerospace Lab). This tool named MACCAO is dedicated to the sensor trade-off studies, sensitivity analysis, sensors performance comparison studies and sensor performance assessment for a large number of environmental conditions (climatic and weather conditions), target/background characteristics and mission task requirements representative of an operational need.

MACCAO, which already implements target / background radiance model, passive EO/IR sensors models, the radiative transfer code MATISSE and, in the near future, the aircraft infrared signature code CRIRA, all developed at ONERA, is able to process larges series of simulation cases with short computing times.

Two specific applications are considered: target acquisition with observer at the end of the imaging chain and target detection for automatic search and track system. In the first application, the tool uses a discrimination (detection, recognition, identification) range performance model based at first on the Johnson criteria, then later towards more recent criteria like Targeting Task Performance (TTP) metric. In the second application, it uses a point source target detection model.

This paper describes the structure of the MACCAO software tool, the models and codes used, the operating mode, two application examples and future developments planned. The two application examples presented are respectively:

(a) the target discrimination ranges assessment for several EO/IR sensors mounted on unmanned ground vehicles and dedicated to land border surveillance;

(b) the target detection ranges assessment for various IR sensors mounted on unmanned aerial vehicles and dedicated to sense and avoid task.

8706-18, Session 4

Sensor performance and atmospheric effects using NvThermIP/NV-IPM and PcModWin/MODTRAN models: a historical perspective *(Invited Paper)*

John W. Schroeder, Ontar Corp. (United States)

Atmospheric effects have a significant impact on the target detection, recognition and identification capabilities of electro-optical sensors. Adverse atmospheric and weather conditions can render the most sophisticated hardware system virtually blind.

It is not feasible to test a sensor under all the conditions that may be encountered in an operational environment. Engineers and designers rely on computer models to simulate the performance for anticipated extreme conditions.

This paper will focus on the effect of atmospheric conditions on EO sensor performance using computer models. It will discuss both the benign and disturbed atmosphere effects and provide guidelines for the appropriate model to use for different conditions, e.g. broadband versus LIDAR/LADAR. Finally, it will provide a historical perspective for the model development and model distribution.

The current state-of-the-art model for computing atmospheric transmission and radiance is MODTRAN 5 developed by the US Air Force Research Laboratory and Spectral Science, Inc. Historically the Air Force focused on the “normal” and naturally disturbed atmosphere; the US Army on battlefield conditions, e.g. smoke, fires etc.; and the US Navy on the marine environment. An amalgamation of their efforts resulted in the public release of LOWTRAN 2 in the early 1970’s. Subsequent release of LOWTRAN and MODTRAN continue until the present.

The corresponding state-of-the art in sensor models is the NVESD’s NVThermIP and soon to be released NV-IPM. This model has also undergone an evolutionary process starting with the FLIR and ACQUIRE models to the present. NVThermIP, version 2002 through 2009, had the capability to interface with 3rd party MODTRAN software, along with a Beer’s law and table inputs. The replacement, NV-IPM, uses a different approach. It continues to use Beers law and table, however it primary interface if via a library of pre-calculations. The capability to interface to a complete set of MODTRAN inputs no longer exists. The paper will discuss the importance of restoring this capability showing the potential calculations errors using the existing capabilities.

8706-19, Session 4

Impact of the spectral nature of signatures on targeting with broadband imagers

Van A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

For the purpose of detecting an object or feature of particular interest in or against a background of other objects or features of little or no interest with an imaging system, the spectral information in the scene can be as important as the spatial information. A useful measure of the visibility of a target is the apparent contrast between it and the background on the visual display of the imager. In broadband imaging, the scene’s spectra resulting from the interactions between illumination and reflectivities, or thermal emission, with the atmospheric path and optical system transmission are mixed irretrievably together by the spectral responsivity of the image detectors. A single pixel in a broadband image is nothing more than a measure of the net spectrally integrated radiance from the corresponding part of the scene and thus provides no spectral indication of whether it’s a target or background pixel. If the scene is heterogeneous, that is, it contains different objects

and features, or has spatial variation in illumination or temperature, then the apparent contrast between groups of target and background pixels will most likely be a function of the degree of correlation between the net target and background spectra within the pass-band of the imager. This paper documents how the spectral nature of the target and background reflectivities and the illumination impact target discrimination with reflective broadband imaging systems.

8706-20, Session 4

TOD characterization of the Gatekeeper electro-optical security system

Guido A. Gosselink, Hugo Anbeek, Thales Nederland B.V. (Netherlands); Piet Bijl, Maarten A. Hogervorst, TNO Defence, Security and Safety (Netherlands)

The Triangle Orientation Discrimination (TOD) test method was applied to characterize thermal and visual range performance with the Gatekeeper Electro Optical Security System in use with the Royal Netherlands Navy. The system consists of uncooled IR and TV cameras providing up to 360° view in azimuth. The images shown to the user are automatically optimized based on the scene intensity distribution. Proper measurement of such a system with scene-based optimization requires careful surround illumination of the TOD setup over a large part of the camera Field Of View. Threshold estimates showed a very small error and relatively small differences between the observers. The resulting TOD curves that characterize the sensor system in terms of acuity and contrast sensitivity can directly be used as input to a Target Acquisition model to predict range performance for real targets under practical conditions.

8706-22, Session 4

Quantitative evaluation of turbulence compensation

Adam W. W. van Eekeren, Klamer Schutte, Judith Dijk, Piet B. W. Schwering, TNO Defence, Security and Safety (Netherlands)

A well-known phenomena that diminishes the recognition range in infrared imagery is atmospheric turbulence. In literature many methods are described that try to compensate for the visual artifacts caused by atmospheric turbulence. Most of these methods use a global processing approach in which they assume a global shift and a uniform blurring in all frames. Because the effects of atmospheric turbulence are often spatial and temporal varying, we presented previous year a turbulence compensation method that performs local processing leading to excellent results. In this paper an improvement of this method is presented which uses a temporal moving reference frame in order to be capable of processing imagery containing moving objects. Furthermore we will evaluate our method in a quantitative way, which will give a good insight in which components of our method contribute to the obtained visual improvements.

8706-23, Session 5

What good is SWIR? part I: passive day comparison of SWIR, NIR, and Vis

Ronald G. Driggers, U.S. Naval Research Lab. (United States); Van A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Richard H. Vollmerhausen, Univ. of Delaware (United States)

This paper is the first of a three part series associated with the military benefits of SWIR imaging. This first paper describes the benefits associated with passive daytime operations with comparisons of SWIR, NIR, and VIS bands and sensors. This paper includes quantitative findings from previously published papers, analysis of open source data, summaries of various expert analyses, and calculations of notional system performance. We did not accept anecdotal findings as acceptable benefits. Topics include haze and fog penetration, atmospheric transmission, cloud and smoke penetration, target and background contrasts, spectral discrimination, turbulence degradation, and long range target identification. The second and third papers in this series will address passive night imaging and active night imaging.

8706-25, Session 5

Sensor model for space-based local area sensing of debris

Paul McCall, Florida International Univ. (United States); Madeleine Naudeau, Air Force Research Lab. (United States); Thomas Farrell, Schafer Corp. (United States) and Air Force Research Lab. (United States); Marlon E. Sorge, The Aerospace Corp. (United States); Malek Adjouadi, Florida International Univ. (United States)

A model is being developed to evaluate the capabilities of various sensors and combinations of sensors to provide Local Area Awareness for satellites in geostationary orbit. LWIR sensors have been chosen as the detector technology for the initial phase of research because of their ability to operate with the sun in their field of view (FOV) while imaging nearby objects in the long-wave infrared band without the need for additive components such as baffles or solar occluders.

The Local Area Awareness model is comprised of three main components: inputs, sub-models, and outputs. The inputs consist of the physical and material construction of the observed object, the configuration of the sensing platform, orbital dynamics scenarios that will be simulated, and a waveband specific star catalog. The sub-models are defined to simulate the physical properties of the space environment in the sensor waveband and approximate a preliminary noise model. The sensors are oriented in such a way to yield a full 360° in-plane field-of-view around the body of the satellite, and a 180° field-of-view from the back of the solar panels. Multiple orbital dynamics scenarios are used for simulation of the observed object's orbit; the observed object is modeled as a configurable cube with solar panels.

Results are presented in terms of radiant flux of the tracked object. It is shown that intensity-based detection techniques can be quantified from this research. This research demonstrates the feasibility of the use of the LWIR waveband for imaging nearby objects from a geostationary-based sensing platform.

8706-28, Session 6

Producing a color target acquisition metric

Assaf Asbag, Racheli Hayoon, Ricky Shama, Neta Gadot, Stanley R. Rotman, Ben-Gurion Univ. of the Negev (Israel)

Infrared sensing is increasing being done with multispectral data; such images would be presented as a color image to observers. Our research deals with developing metrics for quantizing the contrast of target to background in color images and the degree such contrast affects the detection of the target by human observers. When dealing with a gray scale image, the only parameter affecting the detectability of targets is the luminance contrast; in color images, there are several parameters. This research examines these parameters and defines the importance of each one of them. Our system parameters of color image are the CIELAB space (brightness-color). We examine how each axis affects the contrast of the targets. From our conclusions, we will suggest how color targets can be best modeled.

8706-29, Session 6

Image enhancement technology research for Army applications

Piet B. W. Schwering, Rob A. W. Kemp, Klamer Schutte, TNO Defence, Security and Safety (Netherlands)

Recognition and identification ranges are limited to the quality of the infrared images. Both the received contrast and the spatial resolution determine of objects are recognizable. Several aspects affect the image quality. First of all the sensor itself. The image quality depends on the size of the infrared detector array and the sensitivity. Second, also the intervening atmosphere, in particular over longer ranges, has an impact on the image quality. It degrades the contrast, due to transmission effects, as well as influences the resolution, due to turbulence blur, of the image. We present studies in the field of infrared image enhancement. Several techniques are described: noise reduction, super resolution, turbulence compensation, contrast enhancement, stabilization. These techniques operate in real-time on COTS/MOTS platforms. They are especially effective in the army theatre, where long horizontal paths, and short line-of-sight limited urban operations are both present. Application of these techniques on observation masts, such as on camp sites, and on UAVs and moving ground vehicles are discussed. Examples will be presented from several trials in which these techniques were demonstrated, including the presentation of test results.

8706-42, Session 6

Multisensor fusion of electro-optic and infrared signals for high-resolution visible images, part I

Xiaopeng Huang, Stevens Institute of Technology (United States); Ravi Netravali, Columbia Univ. (United States); Hong Man, Victor B. Lawrence, Stevens Institute of Technology (United States)

Electro-Optic (EO) image sensors exhibit the properties of high resolution and low noise level, but they cannot reflect information about the temperature of objects and do not work in dark environments. On the other hand, infrared (IR) image sensors exhibit the properties of low resolution and high noise level, but IR images can reflect information about the temperature of objects all the time. Therefore, in this paper, we propose a novel framework to enhance the resolution of EO images using the information (e.g., temperature) from IR images, which helps distinguish temperature variation of objects in the daytime via high-resolution EO images. The proposed novel framework involves four main steps: (1) select target objects with temperature variation in original IR images; (2) fuse original RGB color (EO) images and IR images based on image fusion algorithms; (3) blend the fused images of target objects in proportion with original gray-scale EO images; (4) superimpose the target objects' temperature information, onto original EO images via the modified NTSC color space transformation. Therein, the image fusion step will be conducted by qualitative (frame pipeline) approach. Revealing temperature information in EO images for the first time is the most significant contribution of this paper. Simulation results will show the transformed EO images with the targets' temperature information.

8706-30, Session 7

Climatic data analysis for input to ShipIR

David A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada); Yoonsik Kim, Korean Ocean Research and Development Institute (Korea, Republic of)

This paper presents a new methodology to analyse the climatic data for input to ShipIR. Historical hourly data from a weather buoy (in the region of interest) are used to come up with a small number of scenarios (N=100) that have the same statistics (CDF, PDF) as the original data set (N=49072). A new data selection algorithm is described which uses a coarse bin (1/3) to subdivide the variable space (35=243 bins), and an ordered approach to ranking the bins and selecting individual points so that a maximum coverage of each variable is achieved (1/100). A comparison of signature and detection results from an unclassified DDG ShipIR model will show the merits of the new climatic data selection process.

8706-31, Session 7

Range and contrast imaging improvements using circularly polarized light in scattering environments

John D. van der Laan, College of Optical Sciences, The Univ. of Arizona (United States); Shanalyn A. Kemme, David A. Scrymgeour, Sandia National Labs. (United States); Eustace L. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States)

We find for near to mid-wave infrared wavelengths there are clear particle size ranges and indices representative of fog and rain where the use of circular polarization imaging can penetrate to larger optical depths than linear polarization. Using Monte Carlo simulations for varying particle size, wavelength, and index, we show that for specific scene parameters circular polarization vastly outperforms linear polarization in maintaining degree of polarization for large optical depths in transmission and reflection. This enhancement in circular polarization can be exploited to improve imaging in obscurant environments that are important in many critical imaging applications.

Polarization imaging can greatly increase contrast when imaging through scattering media compared to traditional intensity imaging. Past research has often not shown the effectiveness of circular polarization's degree of polarization memory in a broader range of imaging environments and wavelength regimes. The majority of currently available research exploring the use of circularly polarized light was conducted in the visible wavelength range with scenes immersed in water, using varying concentrations of polystyrene microspheres as scattering objects. In contrast, this work seeks to expand the regions where circular polarization outperforms linear by systematically simulating combinations of environmental parameters and imaging wavelengths. We will show that additional environments exist where the use of circular polarization can improve imaging. Finally, we propose that the Mie scattering efficiency value for the scattering media generally predicts when circular polarization imaging will perform better than linear and intensity imaging.

8706-32, Session 7

Simulation of laser-beam reflection at the sea surface modeling and validation

Frédéric Schwenger, Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

A 3D simulation of the reflection of a Gaussian shaped laser beam on the dynamic sea surface is presented. The simulation is suitable for the pre-calculation of images for cameras operating in different spectral wavebands (visible, short wave infrared) for a bistatic configuration of laser source and receiver for different atmospheric conditions. In the visible waveband the calculated detected total power of reflected laser light from a 660nm laser source is compared with data collected in a field trial.

Our computer simulation comprises the 3D simulation of a maritime scene (open sea/clear sky) and the simulation of laser beam reflected at the sea surface. The basic sea surface geometry is modeled by a composition of smooth wind driven gravity waves. To predict the view of a camera the sea surface radiance must be calculated for the specific waveband. Additionally, the radiances of laser light specularly reflected at the wind-roughened sea surface are modeled considering an analytical

statistical sea surface BRDF (bidirectional reflectance distribution function).

Validation of simulation results is prerequisite before applying the computer simulation to maritime laser applications. For validation purposes data (images and meteorological data) were selected from field measurements, using a 660nm cw-laser diode to produce laser beam reflection at the water surface and recording images by a TV camera. The validation is done by numerical comparison of measured total laser power extracted from recorded images with the corresponding simulation results. The results of the comparison are presented for different incident (zenith/azimuth) angles of the laser beam.

8706-33, Session 7

IR signature management for the modern navy

David A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada); Yoonsik Kim, Korean Ocean Research and Development Institute (Korea, Republic of)

A methodology for the analysing the infrared signature and susceptibility of naval platforms using ShipIR/NTCS was presented by Vaitekunas (2010). This paper will update that previous analysis utilising three key model improvements: the use of a larger set of climatic conditions (N=100), a new target sub-image algorithm (which addresses a previous problem with detection of horizon pixel-aliasing), and a new seeker model which performs line-by-line background clutter rejection. Existing commercial stealth technologies (exhaust stack suppression, low solar absorptive paints, extended hull film-cooling) are re-assessed to provide a more comprehensive and rigorous assessment of IR stealth technology, and to provide naval platform mangers with a methodology for setting the IR requirements for a new ship program.

8706-34, Session 7

Hyperspectral imaging spectro-radiometer improves radiometric accuracy

Florent M. Prel, Louis Moreau, Robert Bouchard, ABB Analytical Measurement (Canada); Ritchie D. Bullis Jr., Naval Air Warfare Ctr. (United States); Claude B. Roy, Christian A. Vallieres, Luc E. Lévesque, ABB Analytical Measurement (Canada)

Reliable and accurate infrared characterization is necessary to measure the specific spectral signatures of aircrafts and associated infrared counter-measures protections (i.e. flares). Infrared characterization is essential to improve counter measures efficiency, improve friend-foe identification and reduce the risk of friendly fire.

Typical infrared characterization measurement setups include a variety of panchromatic cameras and spectroradiometers. Each instrument brings essential information; the camera measure the spatial distribution of targets and the spectroradiometers provide the spectral distribution of the emitted energy. However, the combination of separated instrument brings out possible radiometric errors and uncertainties that can be reduced with Hyperspectral imagers. These instruments combine both spectral and spatial information into the same data. These instruments measure both the spectral and spatial distribution of the energy at the same time ensuring the temporal and spatial cohesion of collected information.

This paper presents a quantitative analysis of the main contributors of radiometric uncertainties and shows how a hyperspectral imager can reduce these uncertainties.

8706-36, Session PS1

Simultaneous measurement of the thickness profile and refractive index distribution of silicon wafers

Jungjae Park, Korea Research Institute of Standards and Science (Korea, Republic of); Jonghan Jin, Jae Wan Kim, Korea Research Institute of Standards and Science (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of); Jong-Ahn Kim, Korea Research Institute of Standards and Science (Korea, Republic of); Chu-Shik Kang, Korea Research Institute of Standards and Science (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of)

The thickness uniformity of a silicon wafer is one of the most important measurable factors because patterns fabricated by a lithography process can be distorted when having poor thickness uniformity. Among the various thickness measurement methods, optical interferometry can determine the thickness very precisely with the advance information of a refractive index. In this paper, a high speed measurement method have been proposed and realized to simultaneously measure both thickness profile and refractive index distribution of a silicon wafer by analyzing interference spectrums in Fourier domain based on an optical comb of a femtosecond pulse laser. To obtain the thickness profile as well as the refractive index distribution of the silicon wafer having a diameter of 100 mm, the sample was translated mechanically in the range of 90 mm along its center line. The total number of measurement points was 450 due to the lateral scanning step of 0.2 mm. At each measurement point, the interference spectrums were acquired 10 times repeatedly to eliminate random noise. The thickness and refractive index were determined from several optical path differences calculated in spectral domain. As a result, the averaged thickness and refractive index of the silicon wafer in the center line were measured to be 478.03 ?m and 3.603, respectively. In addition, differences of the thickness profile and refractive index distribution were calculated to be 2.03 ?m and 0.005 in terms of a P.V. value.

8706-37, Session PS1

Uncertainty evaluation of the geometrical thickness and refractive index of silicon wafers

Jonghan Jin, Korea Research Institute of Standards and Science (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of); Jungjae Park, Korea Research Institute of Standards and Science (Korea, Republic of); Jae Wan Kim, Korea Research Institute of Standards and Science (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of); Jong-Ahn Kim, Korea Research Institute of Standards and Science (Korea, Republic of); Chu-Shik Kang, Korea Research Institute of Standards and Science (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of)

In the field of semiconductor industry, silicon wafer is one of the basic components for manufacturing semiconductor devices. To achieve high degree of integration in semiconductor devices, the thickness of the silicon wafer becomes thinner. Therefore, to measure a geometrical thickness of the silicon wafer accurately with high speed is an important task in in-line inspection. Optical interferometer has long been used as one of the most accurate measurement method, but it gives only the optical thickness coupled with both geometrical thickness and refractive index. To obtain the geometrical thickness precisely without the previous knowledge of the refractive index of a silicon wafer, KRISS proposed a novel measurement method based on the optical comb of a femtosecond pulse laser having a spectral bandwidth from 1500 nm to 1600 nm. The infrared optical pulses can be transmitted partially through the silicon

material because of its optical property. By analyzing interference spectrums in Fourier-domain, both quantities were separated and obtained at the same time with high speed. In the case of the refractive index, it was determined as a group refractive index of the sample. In this paper, to evaluate the measurement system, uncertainties related to geometrical thickness and refractive index were estimated. The uncertainty components for Fourier analysis, such as refractive index of air, wavelength resolution of spectrum analyzer, and measurement repeatability were chosen and considered. For the silicon wafer having the geometrical thickness of 321 μm, the combined uncertainties for both quantities were 50 nm and 0.001.

8706-38, Session PS1

Characterization of non-uniformity and bias-heating for uncooled FPA detectors using simulator

Jungeon Lee, Chong-Min Kyung, KAIST (Korea, Republic of)

There are some difficulties in the development of uncooled focal plane array (FPA) detectors due to the absence of full simulation model which reflects the characterization of FPA detectors by variations of various parameters. In this paper we propose the simulator for the both readout integrated circuit (ROIC) and bolometer FPA which is based on a state difference equation of thermal equivalence equation of bolometer and mathematical modeling of optical and electrical part in infrared sensor system. The simulator shows the characteristics and the behaviors of individual components of infrared sensor system in the steady-state and transient-state. We present here the simulation results for output characteristics of detectors owing to variations of parameters induced non-uniformity in FPA detectors and find the dominant parameter to be the leading source non-uniformity in FPA detectors. We also present the simulation results for some typical ROICs to cancel the bias self-heating which wastes most of the dynamic range of infrared sensor system. These show the effectiveness of compensation for the bias self-heating according to variations of parameters. Using the proposed simulator we can expect the quantitative amount of non-uniformity due to the statistical variations in various processing steps and design of ROIC components. It can be used for the systematic design of infrared sensor system which cannot be performed in fabrication procedure.

8706-40, Session PS1

The analysis and experiments of ghost image for solid catadioptric mid-wave IR system

Qun Wei, Changchun Institute of Optics, Fine Mechanics and Physics (China)

In this paper, a mid-wave infrared solid catadioptric system is designed with a focal length 86mm, and F number 1.95. The ideal MFT at 17lp/mm is 0.57, and the spot image RMS radius for each field is 13.901 μm at 0°, 15.146μm at 1.7°, and 14.409μm at 2.44°. First, Zemax and Lighttools are used to analysis the stray light and ghost image. The analysis shows that the first refract surface and the second reflect surface are the main surfaces cause the problem. The outdoor experiments show that the image is not as clear as ideal system. To reduce the influence of stray light and ghost image, there are three ways. The first one is to slightly change the distance between lens and detector, the protect window between cold stop; the second method is to add light shades and battle vanes in front of the imaging system; the last way is optimizing the imaging process program. All the three ways are used to increase the image quality. After making these changes, the ghost image is nearly disappeared. The image blur of a point target from 610m away is reduced to 2 pixels from 10 pixels, and the image blur of a structure target from 1.3km away is reduced to 5 pixels from 30 pixels. The actual MTF at 17lp/mm is 0.3 by testing. The contract increases from 0.57 to 0.96.

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8707-1, Session 1

Analytic determination of optimal projector lens design requirements for pixilated projectors used to test pixilated imaging sensors

Joseph P. Rice, National Institute of Standards and Technology (United States)

A model is described for the problem of optimally projecting a pixellated light source onto a pixellated imaging sensor, in the context that the projected source is used for performance testing of the sensor. This is a common problem in hardware-in-the-loop testing using infrared scene projectors, and in hyperspectral image projection. The model can be used, for example, to compute the paraxial design requirements of the projection lens, given that the parameters of all other subsystems in the problem are fixed. For remote sensing applications, where the performance of a sensor focused at infinity is to be tested, the projector lens becomes a collimator. For optimal projection when using the source for performance testing of the sensor, one then requires that the projector pixels are not spatially resolved by the imaging sensor, the entrance pupil of the sensor is overfilled without vignetting, and also, where feasible, the sensor field of view is overfilled. The model uses paraxial analytical ray tracing approximations to provide a set of equations that are used in an associated spreadsheet to determine the basic collimator requirements such as effective focal length, f/#, and relief distance, given the geometrical characteristics of the projector spatial light modulator and the sensor under test. Beyond this, the model provides a sense of intuition and guidance prior to detailed computerized ray tracing.

8707-2, Session 1

A 2-color 1024x1024 dynamic scene projector system

Joseph D. LaVeigne, Gregory Franks, Santa Barbara Infrared, Inc. (United States)

We report on the design and testing of a 2-color dynamic scene projector system based on the MIRAGE-XL infrared scene projector. The system is based on the optical combination of two 1024x1024 MIRAGE-XL resistive arrays. We present test data including sup-pixel spatial co-registration and compensation for spectral cross-talk.

8707-3, Session 1

Superlattice LED 512x512 two-dimensional infrared scene projector system

Rodney McGee, Nicholas Waite, Fouad E. Kiamilev, Univ. of Delaware (United States); Thomas F. Boggess, The Univ. of Iowa (United States); Dennis T. Norton, Univ. of Iowa (United States)

Using SLEDs (Superluminescent Light Emitting Diodes), we created an infrared scene projector system designed to test a wide variety of infrared detector arrays. The type of optoelectronic systems discussed herein, created at the University of Iowa, target the 3-5 and 8-12 micrometer wavelength because atmospheric absorption is minimal in the these windows. Large IR detector arrays, particularly ones intended for military and aerospace applications, are often difficult and expensive to directly test, so for these detectors, an IR projector for scene simulation is required. The simulations are used in hardware in the loop (HWIL) sensor testing. The sensor testing requires large 2D array, high frame rate, high apparent temperature, and large dynamic range IR sources.

The SLEDS projection system consists of the optical devices paired with the RIIC driver which is known as a hybridized optoelectronic device or hybrid. That hybrid is mounted into a package which is a custom design and mounted into a cryogenic vessel with electrical connections to the outside which are connected to high-speed electronics with a digital video input. Our wide-ranging responsibility at the University of Delaware included the LED driver ASIC, packaging, wire bonding, cryogenic cooling, interfacing PCBs, power electronics, digital/analog interface hardware, software control system, and associated test and diagnosis equipment. Previously we demonstrated a 68x68 hybrid device and associated system, now we discuss a 512x512 projector system exceeds the prior in apparent temperature, dynamic range, and refresh rate.

8707-4, Session 1

Scalable system for close support electronics in future large-format infrared scene projectors

Joshua Marks, Christopher Kerwien, Kassem Nabha, Robert Haislip, Ron Reisor, Rodney McGee, Nicholas Waite, Fouad E. Kiamilev, Univ. of Delaware (United States)

State-of-art infrared detectors arrays now exceed infrared emitter arrays in both resolution and frame rate. For this reason, many government organizations are interested in increasing the resolution and frame rate of Infrared Scene Projectors (IRSPs). Increasing the size of emitter device arrays and read-in integrated circuits (RIICs) involves its own set of challenges, but another major challenge is scaling the close support electronics (CSE) to drive larger emitter arrays. This paper presents a scalable architecture for CSE electronics that meets the needs of today's IRSPs, and efficiently scales to drive larger, future generation emitter arrays.

Our scalable CSE architecture is based on an actual CSE system built to control a 512x512 Read In Integrated Circuit (RIIC) that drives a 512x512 Super Lattice LED (SLEDs) array at a frame rate of 1 KHz with 16-bit resolution. The 512x512 RIIC is made from four identical 256x256 sub-RIICs. These sub-RIICs are operated independently of each other, but are able to share control signals. This limits the number of signals being driven from the CSE. The CSE is implemented as a custom graphics accelerator implemented in a state-of-the-art FPGA. This accelerator takes DVI signals as their input. It can be easily expanded to accommodate more sub-RIICs. Our CSE architecture is also able to handle the increased power requirements through the use of feedback controlled voltage regulation and efficiently designed power routing.

8707-6, Session 2

High-dynamic range DMD-based infrared scene projector

David J. Mansur, Robert Vaillancourt, Ryan Benedict-Gill, Scott P. Newbry, OPTRA, Inc. (United States); Julia Rentz Dupuis, OPTRA Inc (United States)

OPTRA is developing a next-generation digital micromirror device (DMD) based two-band infrared scene projector (IRSP) with infinite bit-depth independent of frame rate and an order of magnitude improvement in contrast over the state of the art. Traditionally DMD-based IRSPs have offered larger format and superior uniformity and pixel operability relative to resistive and diode arrays, however, they have been limited in contrast and also by the inherent bit-depth / frame rate tradeoff imposed by pulse width modulation (PWM). OPTRA's high dynamic range IRSP (HIDRA SP) has broken this dependency with a dynamic structured illumination solution. The HIDRA SP uses a source conditioning DMD to impose the structured illumination on two projector DMDs – one for each spectral

band. The source conditioning DMD is operated in binary mode, and the relay optics which form the structured illumination act as a low pass spatial filter. The structured illumination is therefore spatially grayscaled and more importantly is analog with no PWM. In addition, the structured illumination concentrates energy where bright object will be projected and extinguishes energy in dark regions; the result is a significant improvement in contrast. The projector DMDs are operated with 8-bit PWM, however the total projected image is analog with no bit-depth / frame rate dependency. In this paper we describe our progress towards the development, build, and test of a prototype HIDRA SP.

8707-7, Session 2

Progress in LED arrays for infrared scene projection

David Westerfeld, Sergey D. Suchalkin, Seungyong Jung, Takashi Hosoda, Gregory Belenky, Stony Brook Univ. (United States)

Arrays of light emitting diodes (LEDs) have advantages for infrared scene projection (IRSP) applications. As IRSP sources, LEDs are unsurpassed in terms of modulation rate and spectral flexibility. We describe progress that has been made with these LEDs in two directions: the creation of more efficient superlattice emitters through an improved understanding of hole transport and the demonstration of LEDs for high pixel density arrays.

LED arrays radiating simultaneously in two infrared bands are attractive for infrared scene projection. The ability to simultaneously and independently control the mid and far infrared emission from each pixel in an LED array eliminates the need for image combining and greatly simplifies IRSP systems.

These dual band LED structures may include both direct (type-I) and broken band (type-II) superlattice light emitting structures and can emit anywhere from 2 µm to more than 8 µm. Carrier transport has been studied in superlattice structures containing alternating thin layers of InAs and InGaSb. Calculation and experimental results revealed that charge is carried mostly by electrons, while holes are blocked near the superlattice boundary. This results in recombination being largely confined to the p-side boundary. This presents opportunities for improving the efficiency of these sources.

LEDs grown on commercially available 3 inch diameter wafers have been grown and show good performance. Improved processing techniques have enabled the creation of single color LEDs that can be arrayed at a pitch of 25 µm. The combination of large arrays and small pixels should enable the creation of 2048x2048 LED arrays.

8707-8, Session 2

Calibration of infrared test chambers with the missile defense transfer radiometer

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

The Missile Defense Transfer Radiometer (MDXR) is designed to calibrate infrared collimated and flood sources over the fW/cm^2 to uW/cm^2 power range from 3 um to 28 um in wavelength. The MDXR operates in three different modes: as a filter radiometer, a Fourier-transform spectrometer (FTS)-based spectroradiometer, and as an absolute cryogenic radiometer (ACR). Since 2010, the MDXR has made measurements of the collimated infrared irradiance at the output port of seven different infrared test chambers at several facilities. We present a selection of results from these calibration efforts compared to signal predictions from the respective chamber models for the three different MDXR calibration modes. We also compare the results to previous measurements made of the same chambers with the NIST BXR. In general, the results are found to agree within their combined uncertainties, with the MDXR having lower uncertainty and greater spectral coverage. We demonstrate use of the MDXR data to provide corrections to the spectral throughput, aperture area, and source radiance temperature parameters in a chamber model.

8707-9, Session 2

Precision radiometric surface temperature (PRST) sensor

James T. Daly, Carson B. Roberts, Andrew Bodkin, Bodkin Design & Engineering, LLC (United States); Scott Beaven, Jeffrey Weinheimer, Space Computer Corp. (United States); Robert L. Sundberg, Spectral Sciences, Inc. (United States)

There is a need for a Precision Radiometric Surface Temperature (PRST) measurement capability that can achieve non-contact profiling of a sample's surface temperature when heated dynamically during laser processing or aerothermal heating. Target surface temperature maps within and near the laser spot provide critical quantitative diagnostic data for laser-target coupling effectiveness and laser damage assessment. The challenge is to measure the temperature of a target under laser illumination while the target surface's temperature and emissivity are changing rapidly and with incomplete knowledge of how the emissivity and surface texture (scattering) changes with temperature.

Bodkin Design & Engineering, LLC (BD&E), with partners Spectral Sciences, Inc. (SSI) and Space Computer Corporation (SCC), has developed a PRST sensor that is based on a hyperspectral MWIR imager spanning the wavelength range 2-5 micron and providing a hyperspectral datacube of 20-24 wavelengths at 60 Hz frame rate or faster. This imager is integrated with software and algorithms to extract surface temperature from radiometric measurements over the range from ambient to 2000K with a precision of ±20K, even without a priori knowledge of the target's emissivity and even as the target emissivity may be changing with time and temperature.

In this paper, we will present a description of the PRST system as well as laser heating test results which show the PRST system mapping target surface temperatures in the range 600-2600K on a variety of materials.

8707-10, Session 3

Development of tools, technologies, and methodologies for imaging sensor testing

Heard S. Lowry, Aerospace Testing Alliance (United States)

Ground testing of space- and air-borne imaging sensor systems are supported by vis-to-LWIR imaging sensor calibration and characterization, as well as Hardware in the Loop (HWIL) simulaltion with high-fidelity complex scene projection to validate sensor mission performance. To accomplish this successfully, there must be the development of tools, technologies, and methodologies that are used in space simulation chambers for such testing. This paper provides an overview of such efforts being investigated and implemented at Arnold Engineering Development Complex (AEDC).

8707-11, Session 3

Dynamic thermal signature prediction for real-time scene generation

Chad L. Christie, Efthimios T. Gouthas, Defence Science and Technology Organisation (Australia); Owen M. Williams, Daintree Systems Pty Ltd. (Australia); Leszek Swierkowski, Defence Science and Technology Organisation (Australia)

A real-time scene generation framework, VIRSuite, has been developed in recent years at the Defence Science and Technology Organisation, Australia, driven by the needs both for hardware-in-the-loop (HWIL) simulation and benchtop test and evaluation of guided weapons. The simulated objects are represented within VIRSuite as 3D models with radiative signatures deduced predominantly from trials data. Although the use of measured data is the most reliable and preferred way for representing the radiometric properties, in many cases the data are incomplete or insufficient. Also, the signature may vary in some simulated engagements.

In order to address these shortcomings, a physics-based simulator capable of predicting the infrared signatures of objects and their backgrounds is being developed as a new VIRSuite module. The simulator predicts not only the steady-state surface temperatures but also real-time thermal transient effects. At the core is a dynamic heat transfer model used for calculating the temperature distributions throughout both the target objects and background terrains. It includes transient heat conduction within the materials and boundary conditions that take into account the heat fluxes due to solar radiation, wind convection and radiative transfer. The simulator embodies variable insolation (dependent on the sun position in the sky and cloud cover), changes due to target movement and wind shifts, and includes sky radiance and atmospheric propagation profiles calculated from MODTRAN. In this paper, an overview of the current implementation of the model is presented, covering both its steady-state and transient performance.

8707-14, Session 3

The design of flight motion simulators: high accuracy versus high dynamics

Robert W. Mitchell, Ideal Aerosmith, Inc. (United States)

A Flight Motion Simulator (FMS) requires a specific configuration to satisfy test payload specifications. The design of the FMS must carry the payload, meet the accuracy, and dynamic requirements. In a typical simulator configuration, the high accuracy and high dynamics have conflicting requirements. The high accuracy requires a stiff gimbal design to minimize deflections. The high dynamics design requires a low inertia, lightweight system to provide high performance.

Parametric curves are presented of the relative comparison of accuracy in relation to dynamic performance. Relationships are provided to support the basis for the simulator design for both cases. A compromise in the simulator configuration is required for the standard nested gimbal design to achieve both the accuracy and dynamic requirements. Other types of designs and materials are available with positive and negative features. A typical set of specifications is presented that can be used as a baseline and a beginning point for FMS performance requirements.

8708-1, Session 1

Hyper hemispherical sapphire domes: remarkable breakthrough for fulfilling real market needs

Benny Ballin, Rotem Industries Ltd. (Israel)

This presentation will demonstrate how a real threat led toward a rapid and efficient development of the new Hyper Hemispherical Sapphire Domes that require new capabilities that were not available before. The threat is all those shoulder-fired missiles used by terrorist that aim to take down commercial aircrafts or helicopters mainly during landings or takeoffs. “Up to a million man-portable missiles produced since the 1970s…” National Defense, April 2006 . DIRCM (Directional Infrared Counter Measures) and CIRCM (Common Infrared Countermeasures) are two United States Government and Army initiatives intended to develop systems to protect commercial aircraft and U.S. helicopters from infrared homing (“heat seeking”) man-portable missiles. The new developed Hyper-Hemispherical sapphire domes solve problem in current systems design such as limited field of view, optical obstacles and huge drag. The compelling event in entering this project was the decision of Israeli Ministry of Transportation to equip Israeli airlines with laser-based anti-missile system. Elbit Systems was chosen as the main contractor, while Rotem Industries provides the sapphire hyper-hemispherical domes. The presentation will demonstrate the advantages of using sapphire, the Threat of those shoulder-fired missiles used by terrorists, the problem and the limitations of current DIRCM/CIRCM designs and the solution of the new developed domes.

8708-2, Session 1

Growth and characterization of 14”-wide sapphire plates by edge-defined, film-fed growth (EFG)

John O. Outwater, Sapphire Systems, Inc. (United States)

Sapphire’s hardness, strength, and transparency in the UV through IR range make it the optimal window material for many sensor applications. Single-crystal windows up to 32” wide are desired in a number of applications. The need is especially acute for Air Force applications, which use high-resolution Infrared (IR) sensors in their onboard imaging, sensing, and targeting systems. These sensors require protective windows with optical clarity and mid-wave IR transmission capability, and sapphire appears to be the most promising material.

Sapphire Systems has developed an innovative Edge-defined, Film-fed Growth (EFG) method for growing single-crystal sapphire plates 14 inches wide and 5/16” thick, with lengths up to 24”. The as-grown plates have a clean, clear, bubble-free surface and interior. The high quality of the as-grown plates has the potential to greatly reduce post-growth processing costs, which can be a significant fraction of the cost of a finished window. It is anticipated that windows made from these plates will find wide application in military and civilian service.

8708-3, Session 1

Scale up of large ALON® windows

Lee M. Goldman, Sreeram Balasubramanian, Uday K. Kashalikar, Robyn Foti, Suri A. Sastri, Surmet Corp. (United States)

Aluminum Oxynitride (ALON® Optical Ceramic) combines broadband transparency with excellent mechanical properties. ALON’s cubic structure means that it is transparent in its polycrystalline form, allowing it to be manufactured by conventional powder processing techniques. Surmet has established a robust manufacturing process, beginning with synthesis of ALON® powder, continuing through forming/heat treatment of blanks, ending with optical fabrication of ALON® windows. Surmet has made significant progress is production capability in recent years. Additional scale up of Surmet’s manufacturing capability, for larger sizes and higher quantities, is currently underway.

ALON® transparent armor represents the state of the art in protection against armor piercing threats, offering a factor of two in weight and thickness savings over conventional glass laminates. Tiled and monolithic windows have been successfully produced and tested against a range of threats.

Large ALON® window are also of interest to a range of visible to Mid-Wave Infra-Red (MWIR) sensor applications. These applications often have stressing imaging requirements which in turn require that these large windows have optical characteristics including excellent homogeneity of index of refraction and very low stress birefringence.

Surmet is currently scaling up its production facility to be able to make and deliver ALON® monolithic windows as large as ~19x36-in. Additionally, Surmet has plans to scale up to windows ~3ftx3ft in size in the coming years. Recent results with scale up and characterization of the resulting blanks will be presented.

8708-4, Session 1

Transparent ceramics for sensor applications

Mark V. Parish, Marina R. Pascucci, Normand Corbin, Brenda Puputti, John Bonin, CeraNova Corp. (United States)

CeraNova’s transparent polycrystalline alumina (CeraLumina™) exhibits high transmittance in the mid-wave infrared (MWIR) and useful bands of transmission in the RF. The fine, uniform grain size also leads to high hardness, high strength, and high thermal shock resistance. Polycrystalline alumina is a viable replacement for sapphire domes, particularly for aerodynamic dome shapes. Both transparent hemispheric and ogive dome blanks have been successfully produced; CeraLumina optical fabrication progress will be presented. CeraNova’s spinel has high transmittance in the visible and MWIR, and enhanced mechanical properties due to its fine grain size. Results of optical and mechanical testing for both materials will be presented.

8708-5, Session 1

Large-size spinel windows and domes

Juan L. Sepulveda, Raouf O. Loutfy, Sharly Ibrahim, Simon Bilodeau, Materials and Electrochemical Research Corp. (United States)

Excellent transmission in the Mid IR wavelength range coupled with good mechanical properties make the use of spinel ceramics very attractive for high performance windows and domes. MER has concentrated its current development efforts in the scale up to windows as large as 25”x32” and domes/hyperdomes as large as 10” in diameter. The MER spinel technology allows producing complex 3-D shape parts like hyper-hemispherical domes and other aspheric lenses. The thickness can reach 1” and above. MER has shown the feasibility of producing several windows 25”x32” and 18”x22” per run. Optimization of transmittance and strength, minimization of the stress birefringence, keeping the variation of the index of refraction to a minimum, has been the main objective. MER also pursued edge bonding technology, where large, thick, panes were edge bonded into a final large window. High optical and IR transparency in the 0.3 – 5.5 µm wavelength range is obtained. Optical metrology measurement of a polished 18”x22”x0.86” window indicated tolerable levels of high frequency variation in the index of refraction homogeneity as well as acceptable low values of residual stress birefringence. MER is also scaling up production to several 7” diameter hemispherical domes blanks per run. After rendering, polishing, and coating, defect free domes

in conformance with optical, mechanical, and dimensional specifications have been produced. Details of MER's technology achievements to produce low cost, high strength, transparent magnesium aluminum spinel windows and domes are described. Optical and mechanical properties were measured and are provided.

8708-6, Session 1

Manufacturing process scale-up of Optical Grade Transparent Spinel Ceramic at ArmorLine Corporation

Joseph Spilman, Joseph Nick, Lawrence Shaffer, John B. Voyles, ArmorLine Corp. (United States)

While transparent Spinel ceramic's mechanical and optical characteristics are ideal for many UV, visible, SWIR, MWIR, and multispectral sensor window applications, commercial adoption of the material has been hampered because the material has historically been available in relatively small sizes (one square foot per window or less), low volumes, unreliable supply, and with unreliable quality. Recent efforts, most notably by Technology Assessment & Transfer (TA&T), have scaled-up manufacturing processes and demonstrated the capability to produce larger windows on the order of two square feet, but with limited output not suitable for production type programs. ArmorLine Corporation licensed the hot-pressed Spinel manufacturing know-how of TA&T in 2009 with the goal of building the world's first dedicated full-scale Spinel production facility, enabling the supply of a reliable and sufficient volume of large Optical Grade Spinel plates. With over $20 million of private investment by J.F. Lehman & Company, ArmorLine has installed and commissioned the largest vacuum hot press in the world, the largest hot isostatic press in North America, and supporting manufacturing processes within a 75,000 square foot facility. ArmorLine's equipment is capable of producing window blanks as large as 50" x 30" and the facility is capable of producing substantial volumes of material with its Lean configuration and 24/7 operation. Initial production capability was achieved in 2012. ArmorLine will discuss the challenges that were encountered during scale-up of the manufacturing processes, ArmorLine Optical Grade Spinel optical performance, and provide an overview of the facility and its capabilities.

8708-7, Session 2

Polycrystalline yttrium aluminum garnet (YAG) for aircraft IR window applications

Duraiswamy Ravichandran, Texas Biochemicals, Inc. (United States)

Polycrystalline Yttrium Aluminum Garnet (YAG) is being considered as an alternative material for IR transparent multispectral sensor windows (1-5 microns), due to its superior optical clarity and mechanical properties.

Texas Biochemicals Inc. have fabricated optical quality transparent YAG IR window by a tape-casting process. The advantages of this method are 1. Cost effectiveness, 2. Low production time for fabricating optical quality transparent YAG ceramics, and 3. Tape casting offers an easy path for scale-up. The processing parameters of transparent YAG IR windows in terms of pH, slurry viscosity, particle sizes, particle morphology, powder-X-ray diffraction, IR transmittance, mechanical properties and TEM analysis results will be presented.

8708-8, Session 2

Assessment of low-expansion tungstates for thermal-shock-resistant infrared windows

Daniel C. Harris, Lee R. Cambrea, Naval Air Warfare Ctr. Weapons Div. (United States)

Low-thermal-expansion tungstate materials have the potential to be used as thermal-shock-resistant midwave (3-5 μm) infrared windows. Material properties that favor thermal shock resistance are high strength, high thermal conductivity, low elastic modulus, and low thermal expansion. Sapphire, for example, owes its high thermal shock resistance to high strength and high thermal conductivity. In principle, it is possible to obtain even higher thermal shock resistance if a window material with near-zero thermal expansion can be made. This paper assesses recent work on $Zr(WO_4)_2$ and $Al_{0.5}Sc_{1.5}(WO_4)_3$. It is concluded that multi-phonon absorption in the midwave spectral region limits the optical capabilities of tungstate materials. These materials have more absorption—and therefore, more emission—than aluminum oxynitride in the 4-5 μm wavelength region.

8708-9, Session 2

Transparent ceramics for spacecraft windows

Jonathan Salem, NASA Glenn Research Ctr. (United States)

A variety of transparent ceramics developed for military applications hold promise as spacecraft windows. Working against such applications is their high density as compared to tradition window materials such as fused silica. Advantages include higher fracture toughness, lower stress corrosion cracking rates, and higher melting point. One key aspect for application to space craft windows is residual strength after hypervelocity impact damage: the strength must be sufficient to sustain mission completion. Some of the mechanical properties of transparent armor materials are reported and some life related estimates are compared.

8708-10, Session 2

Multifunctional windows

Nagendra Nag, Lee M. Goldman, Sreeram Balasubramanian, Suri A. Sastri, Surmet Corp. (United States)

The requirement for modern aircraft is driving the need for conformal windows for future sensor systems. However, limitations on optical systems and the physical properties of optically transparent materials currently limit the geometry of current windows and window assemblies to faceted assemblies of flat windows held in weight bearing frames. Novel material systems will have to be developed which combine different materials (e.g. ductile metal with transparent ceramic) into structures that combine transparency with structural integrity. Surmet's demonstrated ability to produce novel transparent ceramic/metal structures will allow us to produce such structures, in the types of conformal shapes required for future aircraft applications. Furthermore, the ability to incorporate transparencies into such structures also holds out the promise of creating multi-functional windows which provide a broad range of capabilities that might include RF antennas and de-icing in addition to transparency. Recent results will be presented.

8708-42, Session 2

Synthesis and characterization of large optical grade sapphire windows produced from a horizontal growth process

Jonathan B. Levine, Timothy Burks, John Ciraldo, Matthew Montgomery, Andrey Novoselov, Sergey Podlozhenov, Rubicon Technology Inc. (United States)

As sensor technology and applications have advanced over the years, the size of sapphire sensor windows has grown substantially to satisfy current and future demands. Rubicon Technology, with their strong history in scaling sapphire crystal growth and commercial scale production processes, has successfully produced large sapphire blanks using a highly modified horizontal directional solidification process. Several prototypes, 1.75 inches thick, 14 inches wide and over 20

inches long have been synthesized. The optical characteristics such as transmission and refractive index homogeneity were measured with excellent results and these data will be presented on several polished bubble-free windows. This research sets the standard for high quality monolithic sapphire sheets large enough for use as seamless integrated optical windows in both military and civilian applications.

8708-44, Session 2

New gelling systems to fabricate complex-shaped transparent ceramics

Yiquan Wu, Alfred Univ. (United States); Yan Yang, New York College (United States)

Gel-casting process has been recognized as a conventional method to fabricate complex ceramic parts, which is based on a polymerization of slurry in a mold and an in-situ formation of green body in the mold cavity. A newly developed gelling system without toxic organic compounds has been studied to make transparent complex-shaped ceramics. In this system, the gelling agent not only functions as a ligand substance but also acts as a dispersant for preparing the slurry. The developed gelling system enables the casted bodies to be dried at a room temperature and processed for a debinding at a high heating rate without cracks. This novel process is very promising to fabricate large-size and complex-shaped transparent ceramics for the dome and window applications.

8708-11, Session 3

Midwave-infrared-transparent yttria-magnesia nanocomposite optical ceramics

Daniel C. Harris, Lee R. Cambrea, Linda F. Johnson, Robert Seaver, Meghan Baronowski, Naval Air Warfare Ctr. Weapons Div. (United States); Richard Gentilman, C. Scott Nordahl, Todd R. Gattusso, Stephanie R. Silberstein, Patrick S. Rogan, Thomas M. Hartnett, Raytheon Co. (United States); Brian J. Zelinski, Wayne L. Sunne, Jennifer Klose, Eric C. Fest, William H. Poisl, Raytheon Missile Systems (United States); Charles B. Willingham, Raytheon Co. (United States); Giorgio Turri, Florida Southern College (United States); Michael A. Bass, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); David E. Zelmon, Air Force Research Lab. (United States); Steven M. Goodrich, Univ. of Dayton Research Institute (United States)

A fully dense, midwave-infrared-transparent nanocomposite optical ceramic containing equal volumes of 100- to 200-nm-diameter grains of MgO and Y2O3 has been fabricated from nanopowders of the pure oxides. The small grain size provides low optical scatter in the 3-5 µm wavelength region and increases mechanical strength and hardness relative to those of yttria and magnesia. Infrared absorption of the nanocomposite at 4.85 µm is 5-10 times less than that of spinel and sapphire. This paper reports the optical, mechanical, and thermal properties of the nanocomposite material and compares these properties with those of yttria, magnesia, spinel, and sapphire.

8708-12, Session 3

Optical properties of a nanocomposite material for durable infrared applications

Michael E. Thomas, Cadence A. Martin, Andrea M. Brown, William J. Tropf, Johns Hopkins Univ. Applied Physics Lab. (United States)

There is currently a need for durable IR-transparent materials demonstrating improved physical characteristics while still retaining their useful optical properties. Nanocomposite materials have the potential to fill this need, though they have not been fully developed and characterized. Their polycrystalline nature leads to increased strength and durability. Additionally, the small grain size of these materials leads to optical transparency in the desired infrared region. The edges of the transparency region are determined by multiphonon absorption on the low frequency side and scatter on the high frequency side. By keeping the grain size less than 1 m, the scatter edge is in the Rayleigh limit and the scatter loss rapidly decreases. This creates a near intrinsic infrared window material. A grain size on the order of nanometers can be obtained in such materials by combining oxide materials, since the additional phases inhibit grain growth.

In this study, a nanocomposite material is characterized. Transmittance was measured over the range of wave numbers from 1,000 to 11,000 cm-1 with a Fourier transform spectrometer in order to study the entire window region and the properties of the edges. Additionally, temperature-dependence of these optical properties was studied. A hot cell was inserted into the spectrometer, allowing measurements to be taken at various temperatures between room temperature and 500 C. Laser measurements were also made in order to more precisely determine the transmittance.

8708-14, Session 3

Optical properties of ceramic YAG

Thomas M. Hartnett, Raytheon Co. (United States)

Ceramic YAG (yttrium aluminum garnet) has been fabricated into a variety of components including windows, domes as well as planer waveguides and fibers. This presentation will discuss the processing, optical properties and performance of Nd and Yb doped ceramic components.

8708-43, Session 3

Gelcasting of aluminum oxynitride (AlON) ceramics

Jun Wang, Fang Zhang, Jian Zhang, Shiwei Wang, Shanghai Institute of Ceramics (China)

Gelcasting is a very useful technique for producing ceramic parts with complex shapes. In this paper, gelcasting in air and pressureless sintering in nitrogen were applied to manufacture transparent AlON ceramics which have been developed for infrared domes and windows.

8708-15, Session 4

Elemental zinc sulfide (eZnS®) provides a clear view for tri-mode seekers

Teresa J. Clement, Raytheon Missile Systems (United States)

Elemental zinc sulfide (eZnS), an optical material with wide-band transmittance now being produced at Missile Systems in Tucson, is an enabling technology for discriminating tri-mode seeker missile applications. In early 2009 a Raytheon team of scientists and engineers designed and installed a new manufacturing facility to recapture the eZnS chemical vapor deposition process previously developed by Raytheon in the 1990s; collaborating with experienced and retired Raytheon scientists responsible for the original material development, the new team baselined the chemical vapor deposition of eZnS using the legacy process. Immediately thereafter, using a 10-factor reduced-matrix design of experiments, the team showed ability to increase deposition rates while maintaining the high optical quality of the material, thus driving down the cycle time of domes produced at RMS by over 30%. Additional value stream improvements for the finished tri-mode seeker dome served to further reduce the cycle time and cost. Impact of such improvements will assure both high-quality and low-cost dome solutions for advanced missile systems using tri-mode seeker technology.

8708-17, Session 4

Large-scale production of monodispersed ZnS nanopowder for missile window applications

Duraiswamy Ravichandran, Thomas Shi, Texas Biochemicals, Inc. (United States)

The existing material choice for long wave-infrared (LWIR) and semi-active laser domes is multispectral Zinc Sulfide (ZnS). ZnS (both standard and multispectral versions) have very poor environmental durability and are subject to damage in sand and rain flight environments. An alternative route to make more erosion-resistant and high mechanical strength ZnS could be through hot pressing ZnS nanoparticles into small-grain material.

We are attempting to produce large scale monodispersed ZnS nanoparticles (100 nm) by a homogeneous precipitation route. The powder X-ray diffraction patterns of ZnS show the presence of broad reflections corresponding to the (1 1 1), (2 2 0), and (3 1 1) planes of the cubic crystalline ZnS material. This novel route produced ultrahigh purity, homogeneous, well dispersed, and monodispersed ZnS nanoparticles. The correlation of processing variables with respect to morphology, purity, IR transmittance, X-ray diffraction and TEM analysis will be presented.

8708-18, Session 4

Large-scale development of ZnS nanoparticles for IR windows and domes

David Battaglia, Jeremy Lange, Brian Lewis, Lynntech, Inc. (United States); Ralph Korenstein, Raytheon Integrated Defense Systems (United States)

Aqueous methods for nanomaterial synthesis are environmentally friendly, very versatile, inexpensive, and convenient for the processing of large scales of multi-component ceramics and semiconductors. Using these techniques, we have investigated the potential of developing methods for the production of multi-kilogram scale quantities of high quality, optical grade ZnS nanomaterials. These nanomaterials are suitable for use in the creation of optical windows and components through sintering and pressing processes. The quality of the ZnS nanoparticles is achieved and maintained through the strict control of the reaction parameters and processing techniques. Currently, our processing techniques have been successful in lowering the impurity levels well below 100 ppm. Drying and de-agglomeration techniques have also shown substantial improvements in the pressed density of the nanopowders enabling their use in optical applications and powder XRD patterns of the ZnS nanoparticles have shown the production of highly crystalline particles of pure cubic (zinc blende) structure.

8708-19, Session 4

Transparent zinc sulfide processed from nanocrystalline powders

De Gao, Todd S. Stefanik, Nanocerox, Inc. (United States)

Nanocerox produces oxide nanopowders via flame spray pyrolysis that have proven effective in the processing of a host of high quality optical ceramic materials. In order to produce LWIR windows to compete with ZnS, however, oxide materials are not suitable. Nanocerox has therefore developed aqueous synthesis techniques for the production of zinc sulfide nanopowders. The proprietary processing technique allows control of primary particle size, high purity, low levels of agglomeration, and cost effective synthesis. Crystallinity, particle size, and purity of the powders will be presented. Characterization of parts fabricated from these powder via sinter/HIP processing will also be discussed, including optical performance and microstructural characterization.

8708-20, Session 4

Infrared-transmitting glass ceramics

John S. McCloy, Brian J. Riley, David A. Pierce, Pacific Northwest National Lab. (United States)

A large body of literature is reviewed with the aim of identifying binary and ternary systems for producing long-wave infrared transmitting glass-ceramics for window applications. Known optical and physical property data is summarized for many ternary sulfides as well as their constituent binary sulfides. Some phosphide and arsenide chalcopyrite structures are reviewed as well. Where available, data on the transmission range, energy gap, refractive index, and hardness are tabulated. Several glass-forming systems are identified containing Ga¬2S3, GeS2, or As2S3.

8708-22, Session 5

Challenges of developing hemispherical ZnS domes coated with a durable antireflection coating

Shay Joseph, Doron Yadlovker, Evyatar Kassous, Avichi Levi, Orna Marcovich, Arit E. Shinman-Avraham, Rafael Advanced Defense Systems Ltd. (Israel); Hedva Zipin, Rafael Advanced Defense Systems Ltd (Israel)

The design of a modern optical system often raises new challenges for manufacturers of high end optical components. One such challenge, which has become more and more common, is the requirement for highly durable hemispherical domes to allow for wide field of view. There are many difficulties to overcome before the final product can be made. In this paper we present some of the major difficulties of developing such domes made from ZnS grown by chemical vapor deposition (CVD). First, the CVD process which introduces the challenge of removing the grown raw dome from the mandrel without causing cracking and breakage is discussed. Then, the challenges introduced by the EB-gun evaporation method, most commonly used for evaporating the anti-reflection coating, are presented. Amongst these challenges, the mounting of the dome inside the coating chamber, the coating uniformity over the dome's curvature and the coating's environmental durability are the most difficult problems to overcome. The paper presents how computerized modeling along with experimental procedures can be combined to minimize the difficulties in the production processes and improve the overall product quality and yield.

8708-23, Session 5

Recent advancements in antireflective surface structures (ARSS) for mid-infrared optics

Catalin Florea, Sotera Defense Solutions, Inc. (United States); Lynda E. Busse, Shyam S. Bayya, Brandon Shaw, U.S. Naval Research Lab. (United States); Ish D. Aggarwal, Sotera Defense Solutions, Inc. (United States); Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Anti-reflective surface structures (ARSS) represent an alternative approach to anti-reflective (AR) thin film coatings used to reduce reflection loss at an optical interface. While the thin film AR coating technology has been widely used for visible, near-infrared and infrared optics, it does have its drawbacks due to reduced laser damage threshold and increased environmental sensitivity. In contrast, the ARSS approach offers more robust results by using surface structures directly built into the actual surface of the optics, without the need for coating with extraneous materials. We will present recent results which demonstrate superior ARSS performance on a variety of infrared optics for use in the mid-infrared spectral region. Fused silica, YAG crystals,

and spinel ceramics substrates have all been successfully patterned through reactive ion etching (RIE) with or without initial patterning through photolitography. Reflection losses as low as 0.1% or better have been demonstrated for fused silica at 1.06 microns. Laser damage thresholds have been measured for substrates with ARSS and compared with uncoated and/or AR coated samples. Thresholds as high as 100 J/cm2 have been demonstrated in fused silica with ARSS at 1.06 microns. In general, ARSS substrates show much improved thresholds when compared with uncoated substrates. These results have direct implications for systems using optical windows for which robust optical performance is required.

8708-24, Session 5

Performance measurements of infrared windows with surface structures providing broadband wide-angle antireflective properties

Byron Zollars, Steve M. Savoy, Qizhen Xue, Jeremy John, Kyle Hoover, Gabriel Elpers, Roger Wood, Nanohmics, Inc. (United States)

Infrared and visible windows have been fabricated with surface structures that provide broadband and large angle-of-incidence antireflective coatings (ARC). The ARC is composed of nanoscale pillars formed by reactive ion etching of either a sacrificial buffer layer or the underlying optical substrate, using a random array of nickel dots as an etch mask. The Ni dots are formed either by a photonic sintering process or using a rapid thermal annealing process. The size and spacing of the Ni dots are found to be highly dependent on the initial Ni film thickness and the annealing parameters, as well as the nature of the surface interaction between the Ni and the buffer layer. The diameter and spacing of the resulting pillars can be parametrically tuned between <100 nm to >1 µm to yield broad antireflection properties from visible through the long-wave infrared. Recently, Cleartran (ZnS) optical substrates treated (both sides) with the ARC process have exhibited a greater than 90% transmittance over the short-wave infrared and mid-infrared wavelengths (1-5 µm), and at incident angles up to 50°. The process for making the surface structures is suitable for low-cost application of broadband wide-angle ARCs on curved optical surfaces. With the appropriate choice of buffer layer composition and thickness, durability against rain and sand erosion can be achieved beyond that of the bare substrate. Recent measurements of optical and mechanical performance will be discussed.

8708-25, Session 5

AR microstructures in spinel combining optical and environmental durability in high-energy laser (HEL) exit apertures

Douglas S. Hobbs, Bruce D. MacLeod, Ernest Sabatino III, TelAztec LLC (United States); Catalin Florea, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Power scaling of high energy laser (HEL) technology is becoming limited by the short term optical and environmental survivability of conventional thin-film coatings. In particular, HEL exit aperture windows must reliably pass a high power density beam while exposed to salt-water spray, sand impacts, and wind driven rain, conditions easily withstood by durable materials such as magnesium aluminate spinel (SPINEL), but where thin-film AR coatings readily fail. A high performance, long life solution is provided through AR microstructure (ARMs) technology where a non-scattering texture etched directly into the surface of a SPINEL window produces a graded refractive index profile for high optical transmission and damage resistance, while retaining SPINEL's favorable chemical and mechanical durability. ARMs textures designed for HEL windows passing near infrared wavelength light at 1064nm, will be fabricated in SPINEL window materials being developed by the Naval Research Laboratory. Results of both pulsed and continuous-wave (CW) standardized laser damage testing of ARMs-treated windows will be presented in comparison to untreated and thin-film AR coated SPINEL windows. The environmental durability of ARMs-treated SPINEL windows will also be evaluated through rain and sand erosion, and salt-fog exposure testing to military standards.

8708-26, Session 5

AR microstructures in diamond for high-power infrared laser optics

Bruce D. MacLeod, Douglas S. Hobbs, Ernest Sabatino III, TelAztec LLC (United States); Eugene V. Anoikin, Element Six (United States)

Due to its low infrared absorption, low dispersion, high thermal conductivity and extreme mechanical durability, polycrystalline diamond material has become the first choice for producing aperture scalable windows and output couplers within high power lasers based on carbon dioxide (CO2) gas. A barrier to the continued power scaling of CO2 lasers using diamond is the poor laser damage resistance and reliability of the critical anti-reflection (AR) treatment currently realized through conventional thin-film AR coatings. A high performance, long life solution is provided through AR microstructure (ARMs) technology where a non-scattering texture etched directly into the surface of a diamond window produces a graded refractive index profile for high optical transmission and damage resistance, while retaining diamond's favorable thermal and mechanical properties. ARMs textures designed for CO2 laser output couplers will be fabricated in polycrystalline diamond window materials produced by Element Six, Limited of the Netherlands. Various ARMs design concepts will be presented through optical modeling and prototype fabrication, along with results of continuous-wave laser damage testing comparing the survivability of ARMs-treated diamond to thin-film AR coated diamond windows. An initial evaluation will be presented of the survivability of ARMs-treated diamond operating within the high intensity infrared laser produced plasma environment of emerging extreme UV lithography tools.

8708-45, Session 5

ZnS/diamond composite coatings for infrared transmission applications formed by the aerosol deposition method

Scooter D. Johnson, American Society for Engineering Education (United States); Fritz J. Kub, U.S. Naval Research Lab. (United States); Charles R. Eddy Jr., U.S. Naval Reserch Lab. (United States)

The deposition of nano-crystalline ZnS/diamond protective coatings on sapphire substrates, as a preliminary step to coating infrared transparent ZnS substrates from powder mixtures by the aerosol deposition method (ADM) is presented.

The advantages of the ADM include the ability to form dense, nanocrystalline films up to hundreds of microns thick at room temperature and at a high deposition rate on a variety of substrates. Deposition is achieved by creating a pressure gradient that accelerates micrometer-scale particles in an aerosol to high velocity. Upon impact with the target substrate the particles fracture and embed. Continued deposition forms the thick compacted film.

Deposition from an aerosolized mixture of ZnS and diamond powders onto sapphire results in linear trend from sputter erosion of the substrate at 100% diamond to formation of a film with increasing fractions of ZnS. The crossover from abrasion to film formation occurs between about 50 – 60 % ZnS and a mixture of 90% ZnS and 10% diamond forms a well-adhered film of about 0.7 microns thickness at a rate of 0.14 microns/min. Infrared transmission measurements of these films indicate good transparency in the far infrared. These initial films mark progress toward the future goal of coating ZnS substrates.

8708-27, Session 6

Optical properties of ZnS in terahertz regime

Satya R. Ganti, Alfred Univ. (United States); S. K. Sundaram, New York State College of Ceramics at Alfred Univ. (United States); John S. McCloy, Pacific Northwest National Lab. (United States)

Zinc sulfide (ZnS) is a II-VI semiconductor used in missile domes and other space-borne systems due to its excellent optical properties in the infrared as well as the far-infrared regimes. Several samples of ZnS were measured in the GHz to the THz range using both backward wave oscillators (BWO) and THz-time domain spectroscopy (THz-TDS) approaches. Samples were processed using standard chemical vapor deposition, hot-pressing, and spark plasma sintering (SPS) processes. We used a free-space quasi-optical millimeter wave (MMW) spectrometer equipped with a set of high-power BWOs for transmittance measurements in the frequency ranges of 35-55 GHz and 170-270 GHz. A commercially available THz-TDS system from TeraView consists of a mode-locked Ti:Sapphire laser with a center wavelength approximately 800 nm , repetition rate of 80 MHz and 100 fs pulse width. With high signal-to-noise ratio (S/N) and coherent phase detection, the THz-TDS was known to be generally more advantageous compared to other approaches. The frequency-dependent coefficient of power absorption was extracted from the experimental spectra. Multispectral as well as single crystals of ZnS were measured from 0.25 - 3 THz. Dielectric constant, loss tangent, refractive index, and absorption coefficient are reported for these materials. Data from BWO and THz-TDS approaches were compared. Additionally, three low-frequency phonon resonance lines were reported at 0.78, 2.20, and 2.80 THz. Data reported in the literature showed a significant difference in these resonances between single crystals, polycrystalline samples or nanoparticles of ZnS. Our results were compared to the reported data in the literature.

8708-28, Session 6

Integrated computational materials engineering of impact damage in E/O windows and domes

Brian J. Zelinski, Raytheon Missile Systems (United States); Stefan Bringuier, Toby Shearman, Pierre A. Deymier, Ibrahim Guven, Krishna Muralidharan, Robert G. Erdmann, The Univ. of Arizona (United States)

Steady improvements in modeling, simulation, and economical computing power continue to promote virtual design and manufacturing of materials, from the atomic level, through the mesoscale, to parts. This multi-scale, multi-physics approach, known as Integrated Computational Materials Engineering (ICME), promises to reduce product development, qualification, and test costs while improving performance and manufacturing efficiency. Raytheon is collaborating with the University of Arizona to apply ICME to the properties of ZnS, with an emphasis on mechanical erosion by sand impact to assess the ability of these multi-scale techniques to reproduce the characteristics and extent of damage under a variety of impact conditions.

Results are shown that demonstrate the ability of quantum or ab initio simulations to predict basic properties of ZnS at the unit cell level. Fracture behavior at the level of a million atoms, as simulated by molecular dynamics, is described, as well as damage at the part level, as modeled by Peridynamics, a technique that naturally incorporates damage initiation and propagation, with no a priori assumptions. Finally, recent progress on developing an analytical bridge or methodology for translating failure criteria between Molecular Dynamics and Peridynamics simulations is discussed. This linkage seeks to allow transfer of critical physics-based information between these two approaches, despite the disparity in their simulation volumes. In short, this paper reports on recent progress to establish the basic components of a multi-scale, multi-physics computational model of sand erosion, the fundamentals of which should have broad applicability to a range of materials and environments.

8708-29, Session 6

Peridynamic modeling of damage and fracture in EM windows and domes

Ibrahim Guven, The Univ. of Arizona (United States); Brian J. Zelinski, Raytheon Missile Systems (United States)

The brittle nature of EM window and dome materials limits electrical and magnetic performance due to impact of sand particles, hailstones and raindrops. The damage and fracture patterns due to such impacts are well documented with distinct association to the impact type. However, the underlying mechanisms that lead to those patterns are not well understood. Adding to the complexity, multiple layers of coatings with varying thicknesses are applied to the external surfaces of these structures, which affects the extent and nature of the impact damage. A physics-based analysis method that captures correct damage and fracture patterns due to particle impact is well warranted.

In this paper, Peridynamic (PD) Theory will be demonstrated as a simulation methodology for fracture analysis of EM windows and domes under particle impact. This theory involves reformulation of classical continuum mechanics in integral form (no spatial derivatives), alleviating the stress singularity problem common to previous fracture analysis approaches. The PD theory enables accurate description of failure events via natural generation and accumulation of defects, cracks, and damage; it can capture complex, 3-D and multiple non-coplanar crack initiation and propagation. The fracture behavior of materials is influenced by an important material parameter, critical stretch, which is specific to PD theory. This study will offer a combined experimental-computational method in extracting critical stretch parameter for glass and ceramic materials based on simulations of indentation tests. Additional simulations involving sand impact and subsequent fracture patterns will be presented.

8708-30, Session 7

Design of uniform window heating structures for electro-optical systems

Matthew W. Pieratt, Sean N. Carney, Melissa Stout, Douglas L. Hibbard, Gregory F. Miller, Exotic Electro-Optics, Inc. (United States)

Temperature non-uniformity in a heated window can result in a significant distortion in the transmitted wavefront. Aberrations are introduced by actual physical distortion of the window due to differential thermal expansion and by localized optical path variations due to the change in index with temperature (dn/dT) of the substrate material. Typically, the second factor is the more pronounced. This effect represents a significant limitation in the performance of windows with non-symmetric geometries made from materials that exhibit combinations of high dn/dT and low thermal conductivity.

EEO has recently developed a software tool capable of quantitatively modeling the thermal distribution of a heated window in operation. This capability allows the design team to optimize the heater layer sheet resistance (whether the layer is a metallic grid or a transparent conducting oxide thin film) and the configuration of bus-bar (electrode) connections prior to any hardware fabrication. Consideration of both of these factors is critical to achieving a uniform thermal distribution at the specified temperature across a given window.

This presentation will describe the recent efforts of EEO to establish the capability for quantitatively modeling the temperature homogeneity across a heated window based on window material and dimensions, heater layer characteristics and bus-bar configuration. Data will be presented that demonstrates the validity of these models via comparison to actual heated windows observed under heated conditions.

8708-31, Session 7

Spinel domes with integrated electromagnetic interference protection

Todd Heil, Greg Slavik, Alex Smith, Jeffrey J. Kutsch, Lynda Renomeron, Igor Vesnovsky, Evans A. LaRoche, Lawrence L. Fehrenbacher, Technology Assessment & Transfer, Inc. (United States); Brian Mayers, Mark Somers, Nano Terra, Inc. (United States)

Magnesium aluminate spinel is a durable electro-optical material with high visible through mid-IR transmission. Technology Assessment & Transfer (TA&T) reports on their efforts to integrate electromagnetic interference (EMI) protection into spinel domes through the use of metallic grids. Two approaches are being developed to embed noble metal EMI grids in spinel domes; 1) encapsulate the grid with a germanate glass that has matching refractive index and coefficient of thermal expansion to spinel, and 2) embed the grid in spinel in the green state and proceed through all subsequent ceramic densification steps. Achievements to date and outlooks on both methods as viable manufacturing routes are presented. Concurrent TA&T spinel development efforts are also highlighted.

8708-32, Session 7

Electromagnetic sensing for deterministic finishing of gridded domes

Steve L. Galbraith, Resodyn Corp. (United States)

Electromagnetic sensing is a promising technology for precisely locating conductive grid structures buried in optical ceramic domes. Burying grid structures directly in the ceramic makes gridded dome construction easier, but a practical sensing technology is required to locate the grid relative to the dome surface. This paper presents a novel approach being developed for locating grids that are physically thin, on the order of a mil, curved, and 80% open. By contrast, thick, flat, solid metal conductors are the typical sensed objects of similar technologies. Non-contact location sensing takes place over a distance of ? inch. A non-contact approach was required because the presence of the ceramic material precludes touching the grid with a measurement tool. Furthermore, the ceramic which may be opaque or transparent is invisible to the sensing technology which is advantageous for calibration. The paper first details the physical principles being exploited. Next, sensor impedance response is discussed for thin, open, grids vs. thick, solid, metal conductors. Finally, the approach for developing sensors and evaluating their impedance response is presented. A concluding discussion about practical field use tools that will use the technology is presented. These tools include simple hand held device that can be used on the shop floor and a more sophisticated tool that can be integrated into a coordinate measuring machine in a metrology environment.

8708-33, Session 7

Multimodal characterization of transparent dome blanks

John S. Steckenrider, Jojit C. Tancredo, Jeffrey J. Kutsch, Technology Assessment & Transfer, Inc. (United States)

In a multi-step process such as the manufacturing of transparent ceramic domes, there are often multiple intermediate opportunities for the evaluation of component integrity and/or defect detection. While characterization of the final condition is obviously critical, there is much to be gained by exploiting NDE/NDI methods earlier into the process, so as to either make the necessary changes to subsequent processing steps to mitigate the issue(s) or remove that component from the manufacturing stream, thereby eliminating the subsequent processing costs. Given that the processing cost per each sequential step increases throughout the manufacturing process, the opportunity for substantial cost savings is maximized the earlier in the process that issues can be detected, thereby improving process efficiency. A comprehensive NDE/NDI method has been developed to rapidly inspect transparent ceramic domes in order to characterize a wide range of critical defects/issues so as to improve dome manufacturing and yield through the reduction or elimination thereof. A matrix of hot-pressed, hot isostatically pressed and pressureless sintered spinel samples with a range of defect types and a variety of surface conditions were inspected using a suite of nondestructive evaluation (NDE) methods. In summary, the combination of three such methods demonstrated the capability to detect of all the critical defects with statistical significance for shop floor inspection of spinel domes. The equipment is relatively inexpensive and easy to use, and perhaps most importantly, has the potential of detecting defects prior to the grinding and polishing steps with resultant payoffs for improving yields and final finishing costs.

8708-35, Session 8

Ultrasonic processing of hard materials for conformal optics

Edward M. Fess, OptiPro Systems (United States)

Hard ceramic optical materials such as sapphire, ALON, Spinel, or PCA can present a significant challenge in manufacturing precision optical components due to their tough mechanical properties. These are also the same mechanical properties that make them desirable materials when used in harsh environments. Tool wear and tool loading conditions during the grinding process for these materials can be especially problematic. Because of this, frequent dressing and reshaping of grinding wheels is often required. OptiPro systems is developing an ultrasonic grinding process called OptiSonic to minimize the forces during grinding an make the grinding process more efficient. The ultrasonic vibration of the grinding wheel allows for a grinding process that has the capacity for longer tool life and reduced tool wear for a more deterministic process. This presentation will discuss the OptiSonic process, and present current results.

8708-36, Session 8

Deterministic manufacturing of large sapphire windows

Teddy Lambropoulus, Scott DeFisher, OptiPro Systems (United States)

There is a need for precisely figured large sapphire windows with dimensions of up to 20 inches with thicknesses of 0.25 inches that will operate in the 1- to 5-micron wavelength range. In an effort to reduce manufacturing cost during grinding and polishing, OptiPro Systems is developing technologies that provide an optimized deterministic approach to making them. This development work is focusing on two main areas of research. The first is optimizing existing technologies, like deterministic microgrinding and UltraForm Finishing (UFF), for shaping operations and precision controlled sub-aperture polishing. The second area of research consists of a new large aperture deterministic polishing process currently being developed at OptiPro called UltraSmooth Finishing (USF). The USF process utilizes deterministic control with a large aperture polishing tool. This presentation will discuss the challenges associated with manufacturing large sapphire windows and present results on the work that is being performed to minimize manufacturing costs associated with them.

8708-37, Session 8

Freeform and conformal optical manufacturing

Scott DeFisher, Frank Wolfs, OptiPro Systems (United States)

Future optical systems are moving away from traditional spherical optics. The anticipated benefits are numerous for freeform optics as they provide better aerodynamic characteristics for aircraft, lighter weight for space missions, and smaller size for medical procedures.

Currently the design and utilization of conformal and freeform shapes are costly due to the difficulties introduced with fabrication and metrology of these parts. Techniques for creating these complex optical surfaces are still in development for traditional optical materials. OptiPro has a unique opportunity create manufacturing solutions though computer controlled multi-axis optical generating, polishing, and metrology machines. OptiPro Systems is continuing to develop advanced optical manufacturing technologies. OptiPro has made toric and freeform arch shapes. OptiPro's existing manufacturing platforms include its eSX grinding, UltraForm Finishing, and UltraSurf non-contact surface scanning system, which will be used for grinding, polishing, and measuring conformal and freeform shapes.

Freeform surfaces are initially generated using deterministic microgrinding with diamond bonded tools. Tool paths with up to five axes of simultaneous motion are required to generate and polish the optical figure of conformal surfaces. Sub-aperture corrective polishing will need to vary the amount of time the tool contacts at each location in order to remove the proper amount of material. These locations and dwell times are derived from a surface figure error map provided by OptiPro's UltraSurf. Research and development of the freeform manufacturing process will be presented.

8708-38, Session 8

Interferometric tomography metrology of conformal optics

Mikhail A. Gutin, Olga N. Gutin, Xu-Ming Wang, Dennis Ehlinger, Applied Science Innovations, Inc. (United States)

Conformal windows and domes improve aerodynamic quality of missiles and aircraft but introduce significant optical aberrations. These aberrations can be compensated, provided both window and corrective optics are fabricated to high tolerances. Highly accurate measurement of conformal optics is required for success of the fabrication process. This paper describes the development of the Interferometric Tomography – a new tool for metrology of conformal aspheric optics, including optics with very high aberrations. The metrology system is designed to measure wavefront aberrations as well as the optical figure of both surfaces.

8708-39, Session 8

Advances in freeform optics fabrication for conformal window and dome applications

Jessica DeGroote Nelson, Alan Gould, Nathan Smith, Katherine Medicus, Michael Mandina, Optimax Systems, Inc. (United States)

Freeform optical shapes or optical surfaces that are designed with non-symmetric features are gaining popularity with lens designers and optical system integrators. This enabling technology allows for conformal sensor windows and domes that provide enhanced aerodynamic properties as well as environmental and ballistic protection. In order to provide ballistic and environmental protection, these conformal windows and domes are typically fabricated from hard ceramic materials. 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. This paper will overview a complete freeform optical fabrication process that includes ultrasonic generation of hard ceramic surfaces, high speed VIBE polishing, sub-aperture figure correction of polycrystalline materials and final testing of freeform surfaces. This paper will highlight the progress made to each of the processes as well as the challenges associated with each of them.

8708-40, Session 8

Recent advances in high-performance window fabrication

James B. Taylor, Richard J. Boland, Edward Gowac, Paul D. Stupik, Marc Tricard, Zygo Corporation (United States)

Continuous drive towards higher performance Intelligence Surveillance and Reconnaissance (ISR) and High Energy Laser (HEL) systems has translated into new requirements for high performance windows:

• A wide range of materials needs to be considered ranging from amorphous glass (such as fused silica), polycrystalline materials such as ClearTran or hard ceramics such as AlON, spinel and sapphire

• A wide range of sizes (up to an including meter class optics) and geometries (high aspect ratio plano surfaces remain prevalent of course, but "free-form" shapes are also being envisioned and implemented routinely, including conformal windows)

• Increasingly tighter specifications, driven by lower wavelength IR systems as well as visible and/or multi-spectral systems, require continually more sophisticated metrology techniques to validate

• Development of sophisticated manufacturing processes needed to yield pristine optical surfaces capable of operating at high laser fluences and/or for highly brittle ceramics capable of withstanding a wide range of temperature, operating pressure and stress

• New high durability thin film coatings capable of withstanding increasing harsher environments

• In a defense environment where cost pressures continue to require less expensive manufacturing processes

This paper will present a wide range of examples dealing with these materials, geometries, specifications, metrology and thin film coating developments.

8708-41, Session 8

Patterning and hardening of Gold Black infrared absorber by shadow mask deposition with Ethyl Cyanoacrylate

Deep R. Panjwani, Nima Nader-Esfahani, Doug Maukonen, Imen Rezadad, Javaneh Boroumand, Evan Smith, Janardan Nath, Robert Peale, Univ. of Central Florida (United States)

We report patterning of infrared-absorbing gold-black films by thermal evaporation with shadow-mask stencil lithography, achieving 80 micron feature sizes. To overcome the extreme fragility of these highly porous gold deposits, which are just 2-5% the density of bulk gold, ethyl cyanoacrylate is fumed onto the deposits through the same mask. Transmission and reflection spectroscopy in the range 2.5 to 12 micron wavelength is performed using a Fourier spectrometer with infrared microscope and either a globar or synchrotron IR source. In the latter case, an array detector provides spectral imaging of the film with diffraction-limited spatial resolution. Scanning electron microscopy and optical profilometry characterize the morphology and thickness of the films, and four-point probe measurements determine their resistivity. Measurements are recorded before and after fuming and over a period of weeks to study aging effects. The optimized hardening process strongly reduces the usual aging degradation without reducing the IR absorption relative to fresh unhardened deposits. This work has application to infrared array bolometers.

8709-1, Session 1

Toward a real-time positioning system for a portable EMI sensor

Juan Pablo Fernández, Thayer School of Engineering at Dartmouth (United States); Benjamin E. Barrowes, Kevin A. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States); Irma Shamatava, Fridon Shubitidze, Thayer School of Engineering at Dartmouth (United States)

The Portable Decoupled Electromagnetic Induction Sensor (Pedemis) is a new instrument designed to provide diverse, high-quality data for detection and discrimination of unexploded ordnance in rocky, treed, or otherwise forbidding terrain. It consists of a square array of nine transmitters and a similar arrangement of receivers that measure all three vector components of the time-dependent magnetic field at nine different locations. The receiver assembly can be fixed to the transmitters or detached from them for enhanced flexibility and convenience. The latter mode requires a positioning system that finds the location of the receivers with respect to the transmitters at any time without hampering portability or requiring communication with outside agents (which may be precluded by field conditions). The current system examines the primary field during the transmitters' on-time phase and optimizes to find the location at which it is most likely to obtain the combination of measured values. We have developed an algorithm that computes mutual inductances analytically and exploits their geometric information to predict location. The method does full justice to Faraday's Law from the start and incorporates the fine structure of both transmitters and receivers; it is exact and involves only elementary functions, making it unnecessary to set up and monitor approximations and guaranteeing robustness and stability everywhere; it uses a fraction of the memory and is orders-of-magnitude faster than methods based on numerical quadrature. We have tested the algorithm on the current Pedemis prototype and have obtained encouraging results which we summarize in this paper.

8709-2, Session 1

The Pedemis Instrument: positioning, background subtraction, and APG field results

Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Fridon Shibitidze, Dartmouth College (United States); Tomasz M. Grzegorczyk, Delpsi, LLC (United States); Juan Pablo Fernández, Thayer School of Engineering at Dartmouth (United States) and Fernandez Consulting (United States); Kevin A. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States)

Recent techniques for detecting and discriminating unexploded ordnance (UXO) have centered on electromagnetic induction (EMI) technologies. Recent results from EMI instruments from ESTCP demonstration sites has shown that detection and discrimination rates could mean saving at least three quarters of the money used to excavate targets. Pedemis is a new EMI instrument with nine transmitter coils and nine receiver cubes that can physically decouple the transmitter and receiver arrays. This allows flexible deployment and operational options that can further reduce geophysical data acquisition times at remediation sites.

We have recently finished fabrication of Pedemis and acquired both laboratory and field data. To interpret these data, we present a routine to position the receiver array relative to the transmitter array based on a beacon type positioning system. In addition, we present a background subtraction method that can subtract instrument noise due to the transmitter array for any position of the receiver array. Finally we present inversion results from our laboratory data in from data acquired at Aberdeen Proving Ground.

8709-3, Session 1

Automatic classification of unexploded ordnance applied to Spencer Range live site for 5x5 TEMTADS sensor

John B. Sigman, Fridon Shubitidze, Dartmouth College (United States)

This paper details methods for automatic classification of Unexploded Ordnance (UXO) as applied to sensor data from the Spencer Range live site. The Spencer Range is a former military weapons range, in Spencer, Tennessee. Electromagnetic Induction (EMI) sensing is carried out using the 5x5 Time-domain Electromagnetic Multi-sensor Towed Array Detection System (5x5 TEMTADS), which has 25 receivers and 25 co-located transmitters. Every transmitter is activated sequentially, with each followed by measuring the magnetic field in all 25 receivers, from 100 microseconds to 25 milliseconds. This data is inverted using the Differential Evolution (DE) algorithm for the Combined Advanced EMI Model. The inversion provides x, y, and z locations and a time series of the total ONVMS principal eigenvalues. The eigenvalues are fit to an empirical model, called Pasion-Oldenburg model, providing 3 coefficients -- k, b, and g -- for each object. The objects are grouped geometrically into variably-sized clusters, in the k-b-g space, using clustering algorithms. Clusters matching a priori characteristics are identified as Targets of Interest (TOI), and larger clusters are automatically subclustered. Ground truths at the center of each class are requested, and probability functions are applied to the cluster, based on radial distance from the center of the cluster, and according to a Gaussian Mixture Model. All objects of UXO probability higher than a chosen threshold are placed in a ranked dig list. This prioritized list is submitted to the Institute for Defense Analysis (IDA) for independent scoring, and the results are demonstrated and analyzed.

8709-4, Session 1

Spencer range live-site portable EMI sensors target classification

Irma Shamatava, Juan Pablo Fernández, Dartmouth College (United States); Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Fridon Shubitidze, Dartmouth College (United States)

The Spenser range is second in a series of live-site UXO classification studies in wooded areas, performed by the Environmental Strategic Technology Certification Program (ESTCP), using recently developed portable electromagnetic induction (EMI) systems. The first study was conducted in 2011 at Camp Beale, CA. Our team processed data taken by the 2 ? 2 three-dimensional (3D) man-portable, developed by the NRL and G&G Sciences, and the new version of the Man-Portable Vector (MPV) handheld system developed by ERDC-CRREL, G&G Sciences, and Sky Research, using advanced EMI models. The models, that combine a forward model based on volumetric, discrete, orthonormalized, mutually coupled magnetic dipoles; joint diagonalization (JD) preprocessing; differential evolution (DE) optimization; and classification using library matching and Gaussian mixture models, is suitable for the discrimination of single or multiple targets. The main objective of this work is to further evaluate the classification capabilities of the advanced methods at the Spenser range that is partially wooded site, with a high density of clutter and a mix of munitions types (37mm to 155 mm projectiles). The data from portable sensors are processed independently and targets intrinsic

(i.e. the size, shape and material properties) and extrinsic (location, depth, orientation) parameters are estimated. The intrinsic parameters are then used for classification and sensor-specific, independent dig-lists are generated for each EMI instrument. The dig-lists are submitted to the Institute of Defense Analysis (IDA) for independent scoring, and the classification performances of the advanced models for each of the portable EMI sensors are illustrated and assessed.

8709-5, Session 1

A new EMI system for detection and classification of challenging targets

Fridon Shubitidze, Juan Pablo Fernández, Dartmouth College (United States); Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Irma Shamatava, Sky Research, Inc. (United States); David George, G&G Sciences Inc. (United States)

Advanced electromagnetic induction (EMI) sensors currently feature multi-axis illumination of targets and tri-axial vector sensing (e.g., MetalMapper), or exploit multi-static array data acquisition (e.g., TEMTADS). They produce data of high density, quality, and diversity, and have been combined with advanced EMI models to provide superb classification performance relative to the previous generation of single-axis, monostatic sensors. However, these advances yet have to improve significantly our ability to classify challenging targets, such as small and deep targets. Particularly, recent live-site discrimination studies at Camp Butner, NC and Camp Beale, CA have revealed that it is more challenging to detect and discriminate small munitions (with calibers ranging from 20 mm to 60 mm) than larger ones. In addition, Massachusetts Military Reservation, MA, live-site test highlighted the difficulties for current sensors to classify large deep and overlapping targets with high confidence. To overcome these problems, recently a new EMI system, that consist different size Tx coils, has been developed to improve the detection limits of current sensors. The advanced EMI models has been adapted to the new system data to further to further enhance the discrimination of small and deep targets. In the paper, we will illustrate a combined software and hardware approach that will provide extended detection range and spatial resolution of next-generation EMI systems; will illustrate a fast EMI data inversion and target-discrimination approaches;

8709-6, Session 2

Targets classification approach applied to active UXO sites

Fridon Shubitidze, Dartmouth College (United States); Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Juan Pablo Fernández, Dartmouth College (United States); Irma Shamatava, Sky Research, Inc. (United States)

This study is designed to illustrate discrimination performance of advanced, beyond a simple dipole, electromagnetic induction (EMI) models, such as orthonormalized volume magnetic source (ONVMS), joint diagonalization (JD) and differential evolution (DE) approaches, at Fort Sill, OK and Massachusetts military reservation (MMR), MA active-sites. The Fort Sill site is highly contaminated with a mix of following munitions: 37 mm target practice tracers, 60 mm illumination mortar, 75 mm and 4.5” projectiles, 3.5”, 2.36” and LAAW rockets, antitank mine fuzes with/without hex nut, practice MK2 and M67 grenades, 2.5 inch ballistic windshields, M2A1-mines with/without bases, M19-14 time fuzes, 40 mm practice grenades with/without cartridge. Where-else MMR site consists different size targets. In this work these models are applied to EMI data collected using the Metal Mapper (MM) and 2x2 TEMTADS sensors. The data for each anomaly are inverted and targets’ intrinsic (total volume magnetic source (NVMS i.e. the size, shape and material properties) and extrinsic (location, depth, orientation) parameters are estimated. The estimated intrinsic parameters are used for classification, which is performed using library matching and statistical classification algorithms. Using classification algorithms a prioritized dig-list is generated and submitted to the Institute for Defense Analyses (IDA) for independent scoring. The performances of the advanced models’ classification are illustrated and assessed based on the independently scored results. Particularly, the sources of false positives are analyzed in relation to the target size and time windows of the measured signals.

8709-7, Session 2

Transmitter power efficiency of broadband CW electromagnetic induction sensors

Waymond R. Scott Jr., Georgia Institute of Technology (United States)

Broadband electromagnetic induction (EMI) sensors have been shown to be able to discriminate between certain classes of metallic targets. However, broadband CW systems are not as power efficient as traditional pulsed induction systems. The excitation for a CW system is a multisine that consists of the sum of N sinusoidal signals. The power amplifier used to drive the transmit coil with the multisine signal can require a significant amount of power. Two methods for reducing this power are presented. In the first method, an analog power amplifier is used, and the power is reduced by optimizing the multisine signal to make the amplifier more efficient. In the second method, a switched-mode power amplifier is used in which the coil is connected to the power supply with binary switches that are either fully on or off. A binary signal is developed that controls the switches so the signal generated has essentially all its energy in the desired N sinusoidal signals. The power dissipation in the switched-mode amplifier is significantly less than in a linear amplifier even with the best excitation signal. Proper filtering and compensation must be used or the switched-mode amplifier will introduce noise in the EMI sensor. Results will be shown that demonstrate the power efficiency and noise performance of the switched-mode amplifier.

8709-8, Session 2

Buried explosive hazard characterization using advanced magnetic and electromagnetic induction sensors

Jon Miller, Gregory Schultz, Sky Research, Inc. (United States)

Advanced electromagnetic induction (EMI) arrays that feature multi-axis transmitters and wideband magnetic field receivers provide significant capability enhancement to landmine, unexploded ordnance (UXO), and buried explosives detection applications. Specifically, arrays that are easily and quickly configured for integration with a variety of ground vehicles and mobile platforms offer improved safety and efficiency to personnel conducting detection operations including route clearance, explosive ordnance disposal, and humanitarian demining missions. We present experimental results for a novel sensor concept that incorporates both magnetic and electromagnetic modalities. The sensor features a multi-axis EMI array and an extremely high sensitivity chip scale atomic magnetometer (AM). The use of multi-axis EMI transmitters and receivers enables characterization of target electromagnetic polarizabilities, which describe the physical properties of the buried object. The integration of a radio frequency (RF) tunable AM receiver adds increased sensitivity to lower frequency components of the electromagnetic response. This added sensitivity provides greater capability for detecting deeply buried or low-metal content targets. We evaluate the requirements for incorporating these sensor modalities in forward mounted ground vehicle operations. Specifically, the ability to recover target features in near real-time is critical to non-overpass modes. Additionally, vehicle and motion induced noise reduction can significantly improve target depth sensitivity and reduce requirements for forward vehicle standoff. We also demonstrate the potential for this technology to confirm ground penetrating radar (GPR) decisions by providing target depth and location information.

8709-9, Session 2

In-field quality control of advanced electromagnetic induction data for munitions remediation projects

Jon Miller, Sky Research, Inc. (United States); Leonard R. Pasion, Sky Research, Inc. (Canada)

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 remediation efforts to mitigate the potential environmental and public health hazards posed by these munitions and explosives of concern (MEC). UXO remediation operations typically employ electromagnetic induction (EMI) or magnetometer surveys to identify potential MEC hazards located throughout cleanup sites. A significant cost factor in these operations is the allocation of resources for the excavation of harmless objects associated with fragmentation, scrap, or geological clutter. Recent developments in advanced EMI sensor technologies, i.e., those that employ multi-axis transmitter and receiver configurations, have enabled classification of a vast majority of these non-hazardous objects prior to excavation. One of the key requirements for successfully implementing MEC classification is the acquisition of high quality EMI data prior to analysis. Factors such as improper sensor positioning, low signal-to-noise ratio, or insufficient data sampling can lead to poor performance of classification algorithms. We present results from recent field evaluations of an approach for incorporating an in-field analysis of data quality metrics as part of the EMI survey process. Specifically, this approach applies a dipole inversion routine to the EMI data immediately after acquisition is complete. Data and model parameters are subsequently used to extract quality metrics, which are supplied to the operator in the form of a quality decision. This process provides the operator with high confidence that the data will yield effective classification results.

8709-10, Session 3

Operational field evaluation of the PAC-MAG man-portable magnetometer array

Joe Keranen, Gregory Schultz, Jon Miller, 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 describes an Operational Field Evaluation (OFE) of the PAC-MAG man-portable UXO detection system. The OFE, conducted in Laos and beginning in January 2013, consists of a two week training of indigenous demining personnel by NVESD and Sky Research personnel followed by a period of system use as part of demining operations. The PAC-MAG system is a man-portable magnetometer array for the detection and characterization of ferrous unexploded ordnance (UXO). System hardware includes four Cesium vapor magnetometers for detection, a Real-time Kinematic Global Position System (RTK-GPS) for sensor positioning, an electronics module for data concatenation and wifi communications, and a computer for logging data via wifi. A hipchain encoder is also provided for position information in GPS-denied areas. System software elements include data logging software and post-processing software for detection and characterization of ferrous anomalies. The output of the post-processing software is a dig list containing locations of potential UXO(s), formatted for import into the system GPS equipment for reacquisition of anomalies. Results from the training of indigenous demining personnel on the use of the system and from in-field operations will be described.

8709-11, Session 3

Optimized coils for electromagnetic induction systems

Mark A. Reed, Waymond R. Scott Jr., Georgia Institute of Technology (United States)

Traditional continuous-wave electromagnetic induction (EMI) systems use a dipole transmit coil and quadrupole receive coil to achieve zero mutual coupling. The quadrupole produces a magnetic field that falls off more quickly than that of a dipole, causing the detection depth to be lower than that of a comparable pulsed EMI system, which uses both transmit and receive dipole coils. Therefore, a continuous-wave system with transmit and receive coils that both act like dipoles and yet have zero mutual coupling is desirable. A method of optimizing such coil pairs for EMI systems is presented. A simple model of spiral coils is developed, allowing each of the two coils to be easily represented as a non-constant spiral. The problem of simultaneously optimizing two such spiral coils is partially convex, so an iterative convex optimization method can be used to quickly and accurately find an optimal solution. In the optimization, the energy coupled between the two coils is constrained to be zero and the stored energy in each coil is constrained to avoid infinite current, creating an optimal pair of spiral-wound transmit and receive coils. Results are shown that demonstrate a continuous wave system with the benefits of both dipole-dipole and dipole-quadrupole systems.

8709-12, Session 3

Location and continuous orientation estimation of buried targets using tensor extraction

Kyle R. Krueger, Waymond R. Scott Jr., James H. McClellan, Georgia Institute of Technology (United States)

Dictionary matching techniques have been an effective way to detect the location and orientation of buried targets using electromagnetic induction (EMI) sensors. Two problems with dictionary detection are that they require a large amount of computer storage to enumerate nine dimensions, and fine discretization of the parameter space must be used to reduce modeling error.

The proposed method shrinks the dictionary size by five orders of magnitude, and reduces modeling error by directly solving for the 3[1] x3 tensor model of the target. A robust low-rank matrix approximation algorithm has been implemented which can also account for directional insensitivities in the measurements.

8709-13, Session 3

Constant phase uniform current loop for detection of metallic objects using longitudinal magnetic field projection

Daniel C. Heinz, Adam W. Melber, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Michael L. Brennan, CACI International Inc. (United States)

Currents on remote metallic objects such as landmines can be induced by projecting strong longitudinal magnetic fields. These currents result in electromagnetic fields that can be subsequently detected. The magnetic field varies slowly as it passes from air into the ground but is sufficient to produce a strong magnetic field rotation which excites currents in metallic objects. Traditionally strong magnetic fields are produced using short range transformer–like inductive coupling, or as a component of powerful propagating electromagnetic fields. The strength of the magnetic component of the propagating electromagnetic field is restricted by regulatory limits on the total radiated radio frequency power. There is a need for forward projected strong magnetic field at

medium ranges with low level propagation. This paper reports on a non-radiating loop antenna which maintains a constant amplitude and phase current around the loop. The radiated field is small and results from the relativistic time-of-flight affect from one side of the loop to the other. The result is that a very strong magnetic field is produced in the near- to mid-field region, up to one wavelength away from the loop. Experiments with a prototype antenna and modeling show that the H-field is very high, radiated electromagnetic fields are negligible, and the drop off is around 1/r2. This agreement between experiments and modeling allows for a design based on computer simulations. In the full paper, correlation between measurements and simulations will be presented with a design concept of a forward looking system for detection of metallic objects.

8709-67, Session 3

Computational analysis of “detectability” metrics from an EMI sensor for target detection and discrimination

Isaac S. Chappell, Institute for Defense Analyses (United States)

Many technologies are being developed to improve the detection of threats and to discriminate the threats from clutter in an operational environment. Efforts within IDA have focused on analysis of data from an electromagnetic induction (EMI) sensor developed by Dr. Waymond Scott to improve the detection and discrimination of low-metal mines and of a wider variety of smaller, shallow buried targets from surface clutter. Our objective was to gain a better understanding of the EMI sensor, specifically the physics behind its operation and the data coming out of it with respect to locating and discriminating targets underground. We developed a number of metrics to visualize a subset of the data. We analyzed each metric for various criteria. We found two metrics, KSUMLOG and GSUM, which were good “detectability” metrics. Detectability is defined here as providing a visual difference between locations where there were targets and the background.

8709-14, Session 4

Unsupervised domain transfer of latent Dirichlet allocation derived MLO topics from SAS imagery

Jason C. Isaacs, Naval Surface Warfare Ctr. Panama City Div. (United States)

Identifying the important discriminating information demonstrated by objects in SAS imagery is important for automatic target recognition. We present a method for determining which information is important using a generative model for documents, introduced by Blei, Ng, and Jordan [1] in which each document is generated by choosing a distribution over topics and then choosing each word in the document from a topic selected according to this distribution. We use this algorithm to analyze synthetic aperture sonar data by using Bayesian model selection to establish the number of topics. We show that the extracted topics capture meaningful structure in the SAS data, consistent with the class designations provided, and demonstrate the transfer of this knowledge across sensor domains.

8709-15, Session 4

Multi-Image texton selection for sonar image seabed co-segmentation

James T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States); Alina Zare, University of Missouri (United States)

(For J. T. Cobb’s session on sonar processing and ATR)

This paper deals with the problem of supervised synthetic aperture sonar (SAS) image seabed segmentation using a optimized 2D wavelet packets. Our approach uses 2D local discriminant basis (LDB) on a training set of seabed snippets to learn an optimal filter selection. Once an optimal filter selection is made, the expansion coefficients of the training set is computed and clustered to form our segmentation rule set. New seabed snippets are then segmented by computing their expansion coefficients and applying our determined segmentation rule set.

8709-16, Session 4

Multiresolution statistics as a normalized clutter measure for synthetic aperture sonar imagery

Shawn Johnson, Johns Hopkins Univ. Applied Physics Lab. (United States); Anthony Lyons, Applied Research Lab. (United States)

(For J. T. Cobb’s session on sonar processing and ATR) Given the complexity of many shallow seafloor sites, synthetic aperture sonar (SAS) images often appear heterogeneous or cluttered. This image clutter can cause difficulty for object detection algorithms when it mimics scattering features of real targets. The purpose of this work is to develop an efficient method for determining the complexity of a region of interest (in terms of the density of scattering objects or features with a specific range of sizes), thereby inferring the performance of an object detection algorithm in that particular region of interest and possibly influencing the choice of detector. A proposed technique for estimating a normalized clutter measure from the statistics of multi-resolution images will be demonstrated using data obtained from the MUSCLE SAS operated by the NATO Centre for Maritime Research and Experimentation.

8709-17, Session 4

Automated detection and classification for underwater optical imagery

Jo E. Wilbur, Robert J. McDonald, Michael P. Strand, Naval Surface Warfare Ctr. Panama City Div. (United States)

(For J. T. Cobb’s session on sonar processing and ATR)

This work presents detection/classification results for underwater optical imagery. The study couples optical image data from a laser line scan (LLS) sensor and model based scene generation from a 2D/3D optical imagery based model developed at NSWC, Panama City. An automatic target recognition (ATR) algorithm to locate contacts and extract 2D and 3D object features was developed and tested on range and intensity data sets, both real and synthetic. The ATR system consists of three modules a detector, feature extractor, and classifier. The detector preprocesses the data and locates regions of interest. The feature extractor produces a feature vector which is subsequently input to the classifier. Combinations of real and synthetic data are used to develop and evaluate the effects of clutter, turbidity, and other factors on performance. The data used comprised the Arête Streak Tube Imaging Lidar (STIL) sensor acquired offshore near Panama City, Florida. This available STIL imagery is then supplemented through modeling with “target / false target insertion” to further examine the effect of clutter on performance. NSWC, PC has the capability for 3D/2D optical modeling which includes realistic 3D shapes. The model enabled inclusion of false contacts not provided in the real data, like, rocks, anchors, chains, tires, and other debris. Various blurring filters and scaling operations were applied to the target and false target model images to examine the effect on detection/classification from turbidity and from degradation of the resolution as the imaging altitude increases.

8709-18, Session 4

Estimation of sidescan sonar image quality using shadow contrast

Daniel Cook, Georgia Tech Research Institute (United States); Daniel Brown, The Pennsylvania State Univ. (United States)

(For J. T. Cobb's session on sonar processing and ATR)

Resolution, maximum range, and area coverage rate are the most commonly reported performance metrics for both real and synthetic aperture sidescan sonars. While of primary importance, these are insufficient to adequately describe the image quality achievable by the sonar. Because sidescan imaging is done using very low grazing angles a target's shadow often carries as much, if not more, information than the direct return. We advocate the shadow contrast as a key sidescan image metric and show how it can be predicted from system parameters and environmental conditions. This deeper analysis of image quality has significant implications for system design, deployment, and data processing. For example, shallow-water multipath can obliterate shadows at ranges much shorter than the maximum range of the sensor. Also, certain sediment types such as silt and mud have low backscatter coefficient that can limit the signal-to-noise ratio at long ranges. Such knowledge could be used to develop more effective sonar systems, but perhaps more interesting is the potential for adaptive mission planning. That is, the sensor track and transmit power can be dynamically adjusted so as to ensure that minimum image quality requirements are met throughout the survey area. Such requirements are influenced by both human operators and automatic target recognition algorithms. In addition to deriving the shadow contrast, we apply the metric to several examples of at-sea imagery to demonstrate the utility of a more comprehensive approach to quantifying sidescan image quality.

8709-19, Session 4

Seabed segmentation and environmentally adaptive ATR

Jason C. Isaacs, James T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States)

The automatic detection and classification of underwater objects in synthetic aperture sonar data is complicated due to various factors such as variation in operating and environmental conditions, competing man-made and natural clutter, variations in object shapes, compositions and orientations. In a real-world environment, the decision about the presence and type of an object is usually made based on the properties of the object signature such as highlight and shadow structures. These properties can be displayed by background objects in certain environments and consequently confuse an ATR algorithm. Therefore, the feature extraction process should be adaptable to environmental and operating condition changes. The focus of this work is to analyze the adaptability of a sonar-based ATR system with seabed segmentation used to elicit adaptation.

8709-20, Session 5

Electromagnetic packable (EMPACT) technology for detection and characterization of unexploded ordnance in post-conflict areas

Gregory Schultz, Jon Miller, Sky Research, Inc. (United States)

Land reclamation efforts in post-conflict regions are often hampered by the presence of Unexploded Ordnance (UXO) or other Explosive Remnants of War (ERW). Surface geophysical methods, such as Electromagnetic Induction (EMI) and magnetometry, are typically applied to screen rehabilitation areas for UXO prior to excavation; however, the prevalence of innocuous magnetic clutter related to indigenous scrap, fragmentation, or geology can severely impede the progress and efficiency of these remediation efforts. Additionally, the variability in surface conditions and local topography necessitates the development of sensor technologies that can be applied to a range of sites including those that prohibit the use of vehicle-mounted or large array systems. We present a man-portable EMI sensor known as the Electromagnetic Packable Technology (EMPACT) system that features a multi-axis sensor configuration in a compact form factor. The system is designed for operation in challenging site conditions and can be used in low ground-standoff modes to detect small and low-metal content objects. The EMPACT acquires high spatial density, multi-axis data that enable high resolution of small objects. These high density data can also be used to provide characterization of target physical features, such as size, material content, and shape. We summarize the development of this system for humanitarian demining operations and present results from preliminary system evaluations against a range of target types. Specifically, we assess the general detection capabilities of the EMPACT system and we evaluate the potential for target classification based on analysis of data and target model features.

8709-22, Session 5

Deployment of dual-sensor ALIS for humanitarian demining in Cambodia

Motoyuki Sato, Kazunori Takahashi, Tohoku Univ. (Japan)

Conventional landmine detection depends on highly trained and focused 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 testing simplified but effective signal processing for imaging mines. 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 more than 70 mines in mine fields, and returned more than 13ha cleaned fields to local farmers. We also report the current status of ALIS in Cambodia.

8709-24, Session 6

Stand-off detection of explosives vapors by resonance-enhanced Raman spectroscopy

Ida Johansson, Ema Ceco, Henric Östmark, Swedish Defence Research Agency (Sweden)

This paper describes a system for stand-off vapor detection by Resonant Raman spectroscopy, RRS. The system is a step towards making a RRS LIDAR (Light Detection And Ranging) system, capable of detecting vapors from explosives and explosives precursors at long distances. The current system is an improved version of a previous setup, which has been used to detect the vapor of nitromethane and nitrotoluenes outdoors in the open air, at a stand-off distance of 13 meters. The current setup has a higher extinction ratio and a superior throughput, which enables detection at longer distances. A tunable Optical Parametric Oscillator pumped by an Nd:YAG laser, with a

pulse length of 6 ns, is operated in the UV range of interest , 195-400 nm, illuminating the sample vapor. The backscattered Raman signal is collected by a telescope and a tunable edge filter is used for suppression of backscattered laser light. As tunable filters are yet only available for measurements down to about 310 nm, substances that undergo resonance in that wavelength range are used in this work. A 150 mm long round-to-slit optical fiber is used to transmit collected light to the spectrometer with minimum losses, and a gated intensified charge-coupled device (ICCD) registers the spectra.

8709-25, Session 6

Infrared photothermal imaging of trace explosives on relevant substrates

Christopher A. Kendziora, Robert Furstenberg, Michael R. Papantonakis, Viet Q. Nguyen, James Borchert, Jeff M. Byers, R. Andrew McGill, U.S. Naval Research Lab. (United States)

We are developing a technique for the stand-off detection of trace explosives on relevant substrate surfaces using photo-thermal infrared (IR) imaging spectroscopy (PT-IRIS). This approach leverages one or more compact IR quantum cascade lasers, tuned to strong absorption bands in the analytes and directed to illuminate an area on a surface of interest. An IR focal plane array is used to image the surface and detect small increases in thermal emission upon laser illumination. The PT-IRIS signal is processed as a hyperspectral image cube comprised of spatial, spectral and temporal dimensions as vectors within a detection algorithm. Increased sensitivity to explosives and selectivity between different analyte types is achieved by narrow bandpass IR filters in the collection path. We have demonstrated 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. This talk will include an overview of the approach and recent experimental results for different explosives and possible interferents on relevant substrates including metal, plastic, glass and painted car panels.

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8709-26, Session 6

Sensitive NQR techniques for explosive detection

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Nuclear Quadrupole Resonance (NQR) on 14N nuclei (I=1) is one of the most prospective methods for “bulk” detection of explosives, because the NQR spectrum is like a “fingerprint” of chemical compound. We presents below the results of our studies for development of double resonance and multifrequency NQR techniques for the explosive detection with primary goal to increase NQR sensitivity in low frequency range (< 1MHz).

Experiments were performed using Tecmag Apollo/Redstone NMR/NQR console in combination with Tomco pulse amplifiers, home-made preamplifiers, Q-spoilers and probes. We also tested home-made two-frequency probe for human body and Supracon SQUID-sensor based system as model setup for development of a luggage scanner.

The application of double resonance methods in NQR based on use of the presence of hydrogen atoms of 1H with magnetic interaction of 14N nitrogen atom. Our cross-relaxation experiments revealed that it is possible to use the low pulse magnetic field (< 4mT) both for increasing the amplitude of the NQR signal in the multipulse sequence and for shortening the time of the detection.

Another prospective approach is based on use of two (three) frequency methods for explosives detection. The two-frequency hand-held body sensor has been developed. We proposed a scheme two-frequency excitation with the SQUID detection at the third frequency. We have shown that multifrequency and double NQR are prospective methods with respect practical applications. Further work is planned to adapt these detection technique for a specific (explosive or illicit) substance.

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8709-66, Session 6

Low-power stimulated emission nuclear quadrupole resonance detection system utilizing Rabi transitions

John Apostolos, William Mouyos, AMI Research and Development, LLC (United States); Judy Feng, AMI Research & Development, LLC (United States); Walter Chase, AMI Research and Development, LLC (United States)

The application of CW radar techniques to Nuclear Quadrupole Resonance (NQR) detection of nitrogen based explosives and chlorine based narcotics enables the use of low power levels, in the range of 10’s of watts, to yield high signal strengths. By utilizing Rabi transitions the nucleus oscillates between states one and two under the time dependent incident electromagnetic field and alternately absorbs energy from the incident field while emitting coherent energy via stimulated emission. Through the application of a cancellation algorithm the incident field is eliminated from the NQR response, allowing the receive signal to be measured while transmitting. The response signal is processed using matched filters of the NQR response which enables the direct detection of explosives. This technology has applicability to the direct detection of explosives and narcotics for security screening, all at safe low power levels, opposed to the current X-Ray and Millimeter wave screening systems that detect objects that may contain explosives and utilize high power. The quantum mechanics theoretical basis for the approach and an application for a system for security screening are described with empirical results presented to show the effects observed.

8709-27, Session 7

Fast and sensitive recognition of various explosive compounds using Raman spectroscopy and principal component analysis

Joonki Hwang, Hanyang Univ. (Korea, Republic of); Aaron Park, Chonnam Univ. (Korea, Republic of); Jin Hyuk Chung, Agency for Defense Development (Korea, Republic of); Namhyun Choi, Hanyang Univ. (Korea, Republic of); Jun-Qyu Park, Chonnam Univ. (Korea, Republic of); Soo Gyeong Cho, Agency for Defense Development (Korea, Republic of); Sung-June Baek, Chonnam Univ. (Korea, Republic of); Jaebum Choo, Hanyang Univ. (Korea, Republic of)

Recently, the development of methods for the identification of explosive materials that are faster, more sensitive, easier to use, and more cost-effective has become a very important issue for homeland security and

counter-terrorism applications. However, limited applicability of several analytical methods such as, the incapability of detecting explosives in a sealed container, the limited portability of instruments, and false alarms due to the inherent lack of selectivity, have motivated the increased interest in the application of Raman spectroscopy for the rapid detection and identification of explosive materials. Raman spectroscopy has received a growing interest due to its stand-off capacity, which allows samples to be analyzed at a distance from the instrument. In addition, Raman spectroscopy has the capability to detect explosives in sealed containers such as glass or plastic bottles. We report a rapid and sensitive recognition technique for explosive compounds using Raman spectroscopy and principal component analysis (PCA). Seven hundreds of Raman spectra (50 measurements per sample) for 14 selected explosives were collected, and were pretreated with noise suppression and baseline elimination methods. PCA, a well-known multivariate statistical method, was applied for the proper evaluation, feature extraction, and identification of measured spectra. A broad wavenumber range (200-3500 cm-1) on the collected spectra set was used for the classification of the explosive samples into separate classes. It was found that three principal components achieved 99.3 % classification rates in the sample set. The results show that Raman spectroscopy in combination with PCA is well suited for the identification and differentiation of explosives in the field.

8709-28, Session 7

Standoff detection of explosive molecules using nanosecond gated Raman spectroscopy

Jin Hyuk Chung, Soo Gyeong Cho, Agency for Defense Development (Korea, Republic of)

Recently, improvised explosive devices (IEDs) has been a serious threat for many countries. One of the approaches to alleviate this threat is standoff detection of ingredients used in IEDs, including explosive molecules. Raman spectroscopy is a prospective method among many technological measures under research to achieve this goal. It can provide unique information of the target material, through which the ingredients used in IEDs can be analyzed and identified. The main problem of standoff Raman spectroscopy detection is the large background noise hindering weak Raman signal from the target samples. Typical background noise comes from both ambient fluorescent lights indoor and sunlight outdoor whose intensity is usually much larger than that of Raman scattering from the sample. Under the proper condition using pulse laser and ICCD camera with nanosecond pulse width and gating technology, we succeed to separate and remove these background noises from Raman signals. For this experiment, we build an optical system for standoff detection of explosive molecules, and are able to identify various ingredients of IEDs including TNT, RDX, and HMX which are located 10 ~ 54 meters away from our detection system. Using 532nm, 10Hz, Q-switching Nd:YAG laser as light source, and ICCD camera synchronized with laser Q-switching time with proper gate delay regarding the flight time of Raman from target materials, more than 20 ingredients used in IEDs frequently are successfully identified.

8709-30, Session 8

Laser driven X-ray sources, their potential for through barrier/obscured object imaging

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When a high power laser is focussed onto a material at intensities of 10^18 -10^20 Wcm^-2 it can produce energetic beams of relativistic (up to 10’s MeV) electrons which can then be converted into Bremsstrahlung X-ray beams, in a suitable convertor. These X-rays have unique properties in terms of their short (few ps) duration, directionality and small source size which potentially make them suitable as a source for high resolution through barrier imaging.

In a recent experiment conducted with the Vulcan glass laser at the Rutherford Appleton laboratory, the source characteristics in the 50 KeV-5 MeV range have been investigated and optimised. Using a range of targets from low to high Z, the conversion efficiency and spectral emission have been characterised. A range of target thicknesses were investigated from a starting point where refluxing effects were present, to thicknesses much greater than the hot electron range, comparing the X-ray scaling observed to simulations. Additional methods to increase the absorbed laser energy were also investigated and the improved conversion efficiency will be discussed. As well as X-ray flux measurements, images from test samples demonstrating the optimum resolution deliverable will be presented.

With the development of higher repetition rate diode driven laser systems, the requirements and potential for laser driven sources to be used for buried object detection and security screening applications will be presented

8709-31, Session 8

Construction of a ultra-nanocrystalline diamond-based field emitter arrays for a flat-panel x-ray source

Edwin J. Grant, Chrystian M. Posada, Missouri Univ. of Science and Technology (United States); Ralu Divan, Anirudha V. Sumant, Argonne National Lab. (United States); D. Rosenmann, Argonne National Lab. (United States) and Argonne National Laboratory (United States); L. Stan, Argonne National Lab. (United States); Aashiesh Avachat, Carlos H. Castano, Hyoung Koo Lee, Missouri Univ. of Science and Technology (United States)

A novel cold cathode field emission array (FEA) X-ray source based on ultra-nanocrystalline diamonds (UNCD) field emitters is being constructed as an alternative for detection of obscured objects and material. Depending on the geometry of the given situation the flat-panel X-ray source could be used in tomography, radiography or tomosynthesis. Furthermore, the unit could be used as a portable X-ray scanner or an integral part of an existing detection system. UNCD field emitters show great field emission output and can be deposited over large areas as the case with carbon nanotube “forest” (CNT) cathodes. Furthermore, UNCDs have better mechanical and thermal properties as compared to CNT tips which further extend the lifetime of UNCD based FEA. This work includes the first generation of the UNCD based FEA prototype which is being manufactured at the Center of Nanoscale Material within Argonne National Laboratory with standard microfabrication techniques. The prototype is a 3x3 pixel FEA, with a pixel pitch of 500 ?m, where each pixel is individually controllable.which could break off and disrupt the electron emission over the lifetime of the FEA. From our previous simulation study the technical feasibility of the flat-panel X-ray source was demonstrated, and present work includes design and fabrication of the prototype of the UNCD FEA, in collaboration with the Center for Nanoscale Materials at Argonne National Laboratory. The prototype is an array of 3x3 FEA, with a pixel pitch of 500 µm, where each pixel is individually controllable. We present experimental results including the electron emission current, turn-on voltage and other electron emission characteristics from each cathode.

8709-32, Session 8

A vehicle threat detection system using correlation analysis and synthesized x-ray images

Yufeng Zheng, Alcorn State Univ. (United States); Adel Elmaghraby, University of Louisville (United States)

The goal of the proposed research is to automate the vehicle threat detection with X-ray images when a vehicle crosses the country border or the gateway of a secured facility (military base). The proposed detection system requires two inputs: probe images (from X-ray machine) and gallery images (from database). For each vehicle, the gallery images include the X-ray images of fully-loaded (with typical cargo) and unloaded (empty) vehicle. The proposed system produces two types of outputs for threat detection: the detected anomalies and the synthesized images (e.g., grayscale fusion, color fusion, and differential images). The anomalies are automatically detected with the block-wise correlation analysis between two temporally aligned images (probe versus gallery). The locations of detected anomalies can be marked with small rectangles on the probe X-ray images. The several side-view images can be combined into one fused image in gray scale and in colors (color fusion) that provides more comprehensive information to the operator. The fused images are suitable for human analysis and decision. We analyzed several samples of vehicle X-ray images, each of which consists of 4 images generated from AS&E OmniView GantryTM. The preliminary results of detected anomalies and synthesized images are very promising; meanwhile the processing speed is very fast.

8709-33, Session 8

Quasi-static high-resolution magnetic-field detection based on dielectric optical resonators

Tindaro Ioppolo, Edoardo Rubino, Southern Methodist Univ. (United States)

In this paper we present a high resolution magnetic field sensor that is based on the perturbation of the of the optical modes of cylindrical and spherical dielectric resonator. The optical resonator is side coupled to a tapered single mode optical fiber. One side of the optical fiber is coupled to a distribute feedback laser while the other end is coupled to a photodiode. The optical modes of the dielectric cavity are perturbed using a metglas beam that is in conatct with the resonator. When the metglas beam is exposed to an external magnetic field it will elongate perturbing the optical modes of the dielectric cavity. Different sensor configurations are under investigation to optimize the sensor resolution.

8709-34, Session 8

Detection of tunnel excavation using fiber optic reflectometry: experimental validation

Raphael Linker, Assaf Klar, Technion-Israel Institute of Technology (Israel)

Cross-border smuggling tunnels enable unmonitored movement of people and goods, and pose a severe threat to homeland security. In recent years, we have been working on the development of a system based on fiber-optic Brillouin time domain reflectometry (BOTDR) for detecting tunnel excavation. The system is based on the observation that the excavation of an underground cavity induces strains in the soil, which can be detected in a fiber optic cable buried at a shallow depth. In two previous presentations (SPIE publications 731603 and 76662A) we have reported the initial development of the system as well as its validation using small-scale experiments which were conducted in a large centrifuge. In this presentation we will report for the first time results of full-scale experiments and further discuss the system's performance. We will also show how the soil strain measurements enable not only detection and localization of the tunnel but also estimation of its depth and size, and in some cases the rate at which it approaches the fiber optic cable.

8709-35, Session 8

Underwater surveillance system for inspection of strategic coastal installations

Vladivoj Valkovic, Analysis and Control Technologies, Ltd. (Croatia); Davor Sudac, Jasmina Obhodas, Institut Ruder Bo?kovic (Croatia)

Recently thousands of structures for the production of oil, gas and electricity have been erected in the coastal seas around the Globe. Those are not the only structures in the sea; sea floor is intertwined by pipes providing water, electricity, gas and communication to the islanders. In addition infrastructure objects like bridges, power stations, ports and dams have critical underwater components. They all need to be inspected for the service, repaired when malfunctioning and kept in the environmentally accepted conditions.

A new addition to the underwater NDT family is fast neutron activation analysis induced by tagged 14 MeV neutrons. It has been shown that a sealed tube 14 MeV neutron generator can be successfully used underwater when mounted together with gamma detector and associated electronics inside a specially designed ROV.

We have shown that such a system can be used to study problems related to integrity and stability of coastal and underwater constructions namely underwater parts of infrastructure objects like bridges, dams, etc. The problems which have been elaborated include:

- Mechanism of corrosion of steel reinforcement in concrete immersed in the sea water.

- Influence of environment, stress and materials on corrosion of reinforcement in concrete.

Devices which can perform without cleaning the structure could substantially reduce time and, ultimately, costs. The described neutron based system is capable to obtain information about the composition and state of the surfaces covered with 4-6 cm thick layer of marine organisms.

8709-69, Session 8

The development of an 'on-belt tomosynthesis' system for cost-effective (3D) baggage screening.

Selina Kolokytha, Robert Speller, Stuart Robson, Univ. College London (United Kingdom)

This study describes a cost-effective check-in baggage screening system, based on 'on-belt tomosynthesis' (ObT) and close-range photogrammetry, that is designed to address the limitations of the most common method of baggage screening, conventional projection radiography:

1) Superimposition of the projections of the individual items within baggage

2) Distorted image information due to disparity in x-ray absorption properties among individual items within baggage

These effects can lead to loss of information and an increase in baggage handling time, as baggage is manually searched or screened with more advanced systems, most frequently a CT scanner. CT is more advanced than conventional x-ray systems, however, slower, more complex, and costly.

This project proposes a system that overcomes the limitations of the former systems, creating a cost-effective fully automated pseudo-3D

imaging system, by combining x-ray and optical imaging to form digital tomograms. Tomosynthesis is the creation of pseudo-3D images from a number of 2D projections which are acquired at a range of orientations around a static object. In the ObT system, instead of moving the source and detectors around the object, as in conventional CT, the movement of bags around bends in the baggage transport system provides the required relative motion between source, object and a fan configuration of strip-detectors. For image reconstruction it is necessary to accurately establish the sequential position and orientation of each bag as it is imaged. For this, a low-cost photogrammetric solution is used, based on geometrically calibrated web–cameras positioned around the bends where the bags are imaged.

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8709-36, Session 9

Modeling of currents induced in linear conducting objects located at a dielectric interface

Scott E. Irvine, Defence Research and Development Canada, Suffield (Canada); Pradiv Sooriyadevan, Quality Engineering Test Establishment (Canada)

Sensing of linear conductors is essential for avoiding utilities both in free-space (cable avoidance for aircraft) and underground (excavation). The latter of these two is arguably more important as burying utilities have become more favourable than placing them overhead. Sensing buried utilities is not only important in order to reduce the number of accidents associated with excavating, but also to be able to map the continuously expanding infrastructure beneath cities and densely populated areas.

This presentation will discuss ongoing investigations into currents induced within linear conductors. The induced current is a useful indicator of the amount of scattering an electromagnetic field encounters in the presence of a linear conductor, and hence, the ease with which such a linear conductor could be sensed using electromagnetic radiation. To begin the geometry of the problem is discussed. In general, the linear conductor can be considered to be placed in one of three different dielectric spaces: free-space or vacuum, a full-space having dielectric properties different from those of vacuum, or a dielectric half-space. The analysis begins with the simplest case of vacuum and assesses the variation of induced current with several parameters using Method of Moment calculations. The parameters include frequency of excitation, size of conductor, and type of excitation field (dipole vs. planewave). The analysis is extended to include the dielectric full-space and half-spaces, as well as additional parameters including permittivity and conductivity. The final portion of the presentation will involve a comparison of the modeling results with acquired experimental data. Such comparisons are important for benchmarking theoretical models and will undoubtedly stimulate ongoing research.

8709-37, Session 9

Response of RF targets to a microwave source

David C. Heberlein, John Biddle, Bohdan Balko, Institute for Defense Analyses (United States)

This research was undertaken to predict the vulnerability of different RF target types to the electric field pulses projected by a source mounted on a moving platform. Three approaches were used to predict target effects. The first approach assumed each "shot", i.e. a short sequence of pulses, is an independent attempt to neutralize the target such that the probability of neutralization depends on both the platform speed and the time between "shots". The second approach assumes that each target has a random but fixed "threshold" which is virtually a static problem. The third approach assumes a summation of pulses adding to a heating effect that leads to a breakdown of sensitive and critical elements of a circuit. The results are used to predict the estimated probability of neutralization for different target heights above the ground, the standoff distance, the effect of time between microwave pulses at specified platform speeds for the three different approaches identified above.

8709-38, Session 9

Polarimetric antenna for ground penetrating radar based on the resistive-vee dipole

James W. Sustman, Waymond R. Scott Jr., Georgia Institute of Technology (United States)

A broadband antenna system has been developed to use polarization diversity for ground penetrating radar (GPR) applications. The antenna system uses four, crossed, resistive-vee dipole (RVD) antennas operating bistaticly to measure the simultaneous transmission and reception of multiple polarizations. The RVD was selected because it has low self clutter, low radar cross section and wideband performance. The RVD is linearly polarized, but other polarizations can be synthesized through the use of two orthogonal RVDs to transmit or receive orthogonal field components. The antenna system is able to distinguish rotationally symmetric and linear targets with its ability to transmit right-hand circularly polarized (RHCP) fields and receive both left-hand circularly polarized (LHCP) and RHCP scattered fields. A target's type can be identified by comparing the relative amplitudes of the received LHCP fields and RHCP fields. For example, the polarimetric antenna will be able to identify linear targets such as wires or pipes because linear targets scatter LHCP and RHCP fields in equal amounts. The configuration of the RVDs was optimized through simulation to achieve good circular polarization at close range and low coupling between the RVDs. Further simulations were performed which demonstrate that the polarimetric antenna provides sufficient information to identify linear targets from nonlinear ones, even at different target orientations. The polarimetric antenna was constructed and has been shown to also correctly detect and identify linear targets.

8709-39, Session 10

Millimeter-wave detection of landmines

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Millimeter wave absorption relative to background soil can be used for detection landmines with little or no metal content. At these frequencies, soil and landmine absorb electromagnetic energy differently. Stepped frequency measurements from 40 GHz to 60 GHz were used to detect buried surrogate landmines in the soil. The targets were 3 cm beneath the soil surface and coherent transmission and reflection was used in the experimental setup. The measurement set-up was mounted on a handheld portable device, and this device was on a rail for accurate displacement such that the rail could move freely along the scan axis. Each measurement was performed from 40 to 60 GHz and scattering data in frequency domain were recorded for processing, namely for inverse Fourier Transform and background subtraction. Background subtraction was performed through a numerical filter to achieve higher contrast ratio. Although the numerical filter used was a simple routine with minimal computational burden, a specific detection method was applied to the background subtracted GPR data, which was based on correlation summation of consecutive A-scan signals in a predefined

window length. We will show the positive and negative sides of millimeter wave imaging for landmine detection.

8709-40, Session 10

A parametric analysis of time and frequency domain GPR scattering signatures from buried landmine-like targets

Fabio Giovanneschi, Maria Antonia Gonzalez Huici, Udo Uschkerat, Fraunhofer FHR (Germany)

The detection and efficient classification of buried antipersonnel (AP) landmines remains nowadays a complex scientific and technical issue. Ultra wideband (UWB) Ground Penetrating Radar (GPR) is a promising alternative and/or complementary technology to tackle this serious problem since it can sense any dielectric anomaly present in soil in a non-invasive way.

In this work we present a comprehensive study of the scattered signals by small buried targets via Finite Difference Time Domain (FDTD) numerical modeling of the GPR response for diverse antenna-soil-target scenarios. These simulations evidence that to include the real antenna in the model is crucial to obtain accurate target responses.

From the aforementioned one-dimensional signatures, we extract several scattering features in time and frequency domain. The acquired knowledge may be useful to better understand the scattering mechanisms of subsurface objects as well as to be incorporated within target recognition procedures. In particular, we focus on characteristics such as the target top and bottom scattering amplitude ratio against the dielectric contrast between scatterer and soil for different target geometries and depths. We also investigate the spectral behavior in terms of the number and positions of the resonances present in the signatures for a series of target electrical sizes and soil permittivities. Moreover, a short two-dimensional analysis of the scattering responses is also made applying a time-frequency transformation to the simulated GPR data.

Finally, a brief theoretical interpretation of the results is provided together with a detailed summary of the most relevant temporal and spectral features encountered.

8709-42, Session 11

Optical detection of buried explosive threats: Longitudinal comparison of visible, SWIR, and TIR signal strengths

James J. Staszewski, Carnegie Mellon Univ. (United States); Charles A. Hibbitts, Johns Hopkins Univ. Applied Physics Lab. (United States); Luke Davis, Carnegie Mellon Univ. (United States)

Vision is an effective, but imperfect way of detecting buried explosive threats. This work quantifies observer sensitivity to optical information produced by burial of anti-tank and small anti-personnel landmines, asking ‘How detectable are soil signatures captured in visible, short wave infrared, and thermal infrared bands?’ and “How long do they remain detectable?’ Signature imagery in each band from the same mines was collected over a 6-week period. “Best in band” images were sampled for each week-long time epoch. Images on the other bands collected at the same time as each “best” were used as incidental “signal” controls. Images showing adjacent undisturbed areas and matched in time to each “signal” signature in each band served as controls. Signal and control images were presented to adult observers in a binary choice task. Signal detection measures (d’ and A’) were used to quantify signature detectability. Results suggest negligible declines in signal strength over the period sampled. Strength for “Best” signatures was generally superior to incidental signatures in each band. Aggregated results suggest the superiority of SWIR imagery over visible and TIR, showing greatest advantage and strength for the small signature of an anti-personnel mine. Strengths for visible and SWIR were roughly equivalent for best and incidentals for anti-tank targets. Strengths varied substantially for each band over time epochs and more so for incidentals than “bests” in each band. The variability and complementary among the bands suggests that each support detection under appropriate conditions. Investigation of environmental conditions that predict when each band yields the strongest signals is warranted.

8709-43, Session 11

Comparison of broadband and hyperspectral thermal infrared imaging of buried threat objects

John E. McFee, Defence Research and Development Canada, Suffield (Canada); Stephen Achal, Alejandra U. Diaz, ITRES Research Ltd. (Canada); Anthony A. Faust, Defence Research and Development Canada, Suffield (Canada)

Previous research by many groups has shown that broadband thermal infrared (TIR) imagers can detect buried explosive threat devices, such as landmines and improvised explosive devices (IEDs). Broadband detection measures the apparent temperature – an average over the waveband of the product of the true soil surface temperature and the emissivity. Broadband detection suffers from inconsistent performance (low signal, high clutter rates), due in part to diurnal variations, environmental and meteorological conditions and soil surface effects. It has been suggested that hyperspectral TIR imaging might have improved performance since it can, in principle, allow extraction of the wavelength-dependent emissivity and the true soil surface temperature. This would allow the surface disturbance effects to be separated from the soil column (bulk) effects. A significant, and as yet unanswered, question is whether hyperspectral TIR images provide better detection capability (higher probability of detection and/or lower false alarm rate) than broadband thermal images.

TIR hyperspectral image data of threat objects, buried and surface-laid in bare soil, were obtained in arid, desert-like conditions over full diurnal cycles for several days. Regions of interest containing threat objects and backgrounds were extracted throughout the time period. Simulated broadband images were derived from the hyperspectral images. The time evolution of the images was studied. Various metrics were used to compare the ability of the broadband and hyperspectral images to discriminate objects from background. Hyperspectral was found to provide some improvement over broadband imaging in detection of threat objects for the limited set of data studied.

8709-44, Session 11

A broad-band field portable reflectometer to characterize soils and chemical samples

Eldon Puckrin, Defence Research and Development Canada, Valcartier (Canada); Louis Moreau, Hugo A. Bourque, Real Ouellet, Florent M. Prel, Claude B. Roy, Christian A. Vallieres, Guillaume Thériault, ABB Analytical Measurement (Canada)

The developments of optical methods to characterize soils and various surface contaminants require complete and reliable databases of spectral signatures of various objects, including chemical and representative background surfaces. Ideally, the databases should be acquired in the field to properly consider the chemical mixing and heterogeneity of the surfaces. Spectral characterization instruments are common in the visible and the short-wave infrared but there are few solutions in the mid-wave and thermal infrared.

ABB recently developed a broad band spectrometer based on a small FTIR spectrometer. It is capable of measuring diffuse spectral reflectance from various surfaces in the infrared from 0.7 to 13.5 microns. This sensor has been developed to be operated in the field by one person. It is lightweight (about 12 kg); it is battery powered and ruggedized

for operation in harsh environments. Its operation does not require sophisticated training; it has been designed to be operated by a non-specialist. The sensor can be used to generate spectral libraries or to perform material identification if a spectral library already exists.

Examples of measurements in the field will be presented.

8709-45, Session 11

Thermal inertia mapping of below ground objects and voids

Nancy K. Del Grande, Brian M. Ascough, Geo-Temp Corp. (United States); Richard L. Rumpf, Rumpf Associates International (United States)

Thermal inertia (effusivity) contrast marks the borders of naturally heated below ground object and void sites. The Dual Infrared Effusivity Computed Tomography (DIRECT) method, patent pending, detects and locates the presence of enhanced heat flows from below ground object and void sites at a given area. DIRECT maps view contrasting surface temperature differences between sites with normal soil and sites with soil disturbed by subsurface, hollow or semi-empty object voids (or air gaps) at varying depths. DIRECT utilizes an empirical database created to optimize the scheduling of daily airborne thermal surveys to view and characterize unseen object and void types, depths and volumes in "blind" areas.

8709-46, Session 12

Buried target detection in forward looking IR (FLIR) images using Shearlet features

Mihail Popescu, Alexander T. Paino, Brian Thomson, James M. Keller, Univ. of Missouri-Columbia (United States)

In this paper we investigate a new approach for representing objects in FLIR images based on shearlets. Similar to wavelets, shearlets represent an affine system for image representation obtained by scaling and translation of a generating function called mother shearlet. Unlike wavelets, the mother shearlet has an extra parameter called shear that allows the shearlet transform to be anisotropic. We believe that the anisotropic property of the shearlet transform will allow for a better representation of objects with irregular shape and will better account for image perspective.

We test our representation methodology on FLIR images obtained from an IR camera installed on a moving vehicle. Objects of interested (spots) are detected in each frame using a methodology based on mathematical morphology. Each spot is then represented using its shearlet features and assigned a confidence using a support vector machine classifier.

We compare our approach to a methodology that uses traditional features such as local binary patterns (LPB) and histogram of gradients (HOG). The comparison is performed on a dataset that consists of multiple 1 kilometer runs.

8709-47, Session 12

Using evolutionary computation to optimize an SVM used in detecting buried objects in FLIR imagery

Alexander T. Paino, Mihail Popescu, James M. Keller, Kevin E. Stone, Univ. of Missouri-Columbia (United States)

In this paper we will describe an approach for optimizing the parameters of a Support Vector Machine (SVM) as part of an algorithm used to detect buried objects in forward looking infrared (FLIR) imagery captured by a camera installed on a moving vehicle. The overall algorithm consists of a spot-finding procedure (to look for potential targets) followed by the extraction of several features from the neighborhood of each spot. The features include local binary pattern (LBP) and histogram of oriented gradients (HOG) as these are good at detecting texture classes Finally, we project and sum each hit into UTM space along with its confidence value (obtained from the SVM), producing a confidence map for ROC analysis. In this work, we use an Evolutionary Computation Algorithm (ECA) to optimize various parameters involved in the system, such as the combination of features used, parameters on the Canny edge detector, the SVM kernel, and various HOG and LBP parameters. To validate our approach, we compare results obtained from an SVM using parameters obtained through our ECA technique with those previously selected by hand through several iterations of "guess and check".

8709-48, Session 12

Automatic detection system for buried explosive hazards in FL-LWIR based on soft feature extraction using a bank of Gabor energy filters

Stanton R. Price, Derek T. Anderson, Mississippi State Univ. (United States); Robert H. Luke, U.S. Army RDECOM CERDEC, Night Vision & Electronic Sensors Directorate (United States); Kevin E. Stone, James M. Keller, Univ. of Missouri-Columbia (United States)

There is a strong need to develop an automatic buried [i]explosive hazards detection[/i] (EHD) system for purposes such as route clearance. In this article, we put forth a new automatic detection system, which consists of keypoint identi cation, feature extraction, classi cation, and clustering. In particular, we focus on a new [i]soft feature extraction process[/i] from [i]forward-looking long-wave infrared[/i] (FL-LWIR) imagery based on the use of an importance map derived from a bank of Gabor energy lters. Experiments are conducted using a variety of target types buried at varying depths at a U.S. Army test site. An uncooled LWIR camera is used and the collected data spans multiple lanes and times of day (due to diurnal temperature variation that occurs in IR). Our experiments illustrate the performance at di erent stages in the system and sensitivity of some of the algorithm parameters. The reported [i]Receiver Operating Characteristic[/i] (ROC) curve performance is extremely encouraging for FL EHD.

8709-49, Session 12

Moving beyond flat earth: dense 3D scene reconstruction from a single FL-LWIR camera

Kevin E. Stone, James M. Keller, Univ. of Missouri-Columbia (United States); Derek T. Anderson, Mississippi State Univ. (United States)

In previous work an automatic detection system for locating buried explosive hazards in forward-looking long-wave infrared (FL-LWIR) and forward-looking ground penetrating radar (FL-GPR) data was presented. This system consists of an ensemble of trainable size-contrast filters prescreener coupled with a secondary classification step which extracts cell-structured image space features, such as local binary patterns (LBP), histogram of oriented gradients (HOG), and edge histogram descriptors (EHD), from multiple looks and classifies the resulting feature vectors using a support vector machine. Previously, this system performed image space to UTM coordinate mapping under a flat earth assumption. This limited its applicability to flat terrain and short standoff distances.

This paper demonstrates a technique for dense 3D scene reconstruction from a single vehicle mounted FL-LWIR camera. This technique utilizes multiple views and standard stereo vision algorithms such as polar rectification and optimal correction. Results for the detection algorithm using this 3D scene reconstruction approach on data from recent collections at an arid US Army test site are presented. These results are compared to those obtained under the flat earth assumption, with special focus on rougher terrain and longer standoff distance than in previous experiments. The most recent collection also allowed comparison between uncooled and cooled FL-LWIR cameras for buried explosive hazard detection.

8709-51, Session 12

A novel framework for processing forward looking infrared imagery with application to buried threat detection

Jordan M. Malof, Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

Forward Looking Infrared (FLIR) cameras have recently been studied as a sensing modality for use in buried threat detection systems. FLIR-based detection systems benefit from larger standoff distances and faster rates of advance than other sensing modalities, but they also present significant signal processing challenges. FLIR imagery typically yields multiple looks at each subsurface area, each of which is obtained from a different relative camera pose and position. This multi-look imagery can be exploited for improved performance, however open questions remain as to the best ways to process and fuse such data. Further, the utility of each look in the multi-look imagery is also unclear: How many looks are needed? From what poses? Etc. In this work we propose a general framework for processing FLIR imagery wherein FLIR imagery is partitioned according to the particular relative camera pose from which it was collected. Each partition is then projected into a common spatial coordinate system resulting in several distinct images of the subsurface area. Buried threat detection algorithms can then be applied to each of these resulting images independently, or in aggregate. The proposed framework is evaluated using several detection algorithms on an FLIR dataset collected at a Western US test site and the results indicate that the framework offers significant improvement over detection in the original FLIR imagery. Further experiments using this framework suggest that additional looks by the FLIR imagery can be used to improve detection performance, and that detection can be performed at greater standoff distances without significant loss in performance.

8709-52, Session 13

Sparse model inversion and processing of spatial frequency-domain electromagnetic induction sensor array data for improved landmine discrimination

Stacy L. Tantum, Kenneth A. Colwell, Duke Univ. (United States); Waymond R. Scott Jr., Georgia Institute of Technology (United States); Peter A. Torrione, Leslie M. Collins, Kenneth D. Morton Jr., Duke Univ. (United States)

Frequency-domain electromagnetic induction (EMI) sensors have been shown to provide target signatures which enable discrimination of landmines from harmless clutter. In particular, frequency-domain EMI sensors are well-suited for target characterization by inverting a physics-based signal model. In many model-based signal processing paradigms, the target signatures can be decomposed into a weighted sum of parameterized basis functions, where the basis functions are intrinsic to the target under consideration and the associated weights are a function of the target sensor orientation. When sensor array data is available, the spatial diversity of the measured signals may provide more information for estimating the basis function parameters. After model inversion, the basis function parameters can form the foundation of a generative model for model-based classification of the target as landmine or clutter. In this work, sparse model inversion of spatial frequency-domain EMI sensor array data followed by target classification using a generative statistical model is investigated. 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 from spatial frequency-domain EMI sensor array data followed by statistical classification provides an effective approach for classifying targets as landmine or clutter.

[This work is supported by the US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) and the Army Research Office (ARO).]

8709-53, Session 13

Landmine Classification Using Possibilistic K-Nearest Neighbors with Wideband Electromagnetic Induction Data

Josephine Dula, Univ. of Missouri (United States); Alina Zare, Dominic K. Ho, Univ. of Missouri-Columbia (United States); Paul D. Gader, Univ. of Florida (United States)

A K-Nearest Neighbor classifier is presented to classify mine and non-mine objects in data obtained from wide-band electromagnetic induction sensors. The proposed classifier is motivated by the observation that different buried object types often have consistent signatures depending on their metal content, size, shape, and depth. Given a joint orthogonal matching pursuits (JOMP) sparse representation, particular target types consistently selected the same dictionary elements. The proposed classifier distinguishes between particular target types using the frequency of dictionary elements selected by an alarm. Possibilistic weights are assigned for each alarm for sixteen landmine target classes as well as a false alarm class. The advantage of the use of possibilistic weights is that the proposed classifier can indicate that none of the trained target types are match a pruticular alarm. The proposed method is compared to several state-of-art methods and shows improvement in discrimination results.

8709-54, Session 13

Sweep detection & alignment in handheld GPR detection devices

Peter J. Dobbins, Joseph N Wilson, Jeremy Bolton, Univ. of Florida (United States)

Handheld ground penetrating radar (GPR) devices, such as the AN/PSS-14, produce image data for a detection sequence. Sequences contain sweeps of left to right and right to left swings of the device. By smoothing the image scan and examining local minima, we can determine the sweep ranges and turn around points contained within the data. Different filters are used to determine the interval between sweeps and approximate the exact turn around point for each sweep. Images are then annotated with the start and end of sweep locations. Results presented are both qualitative, based on comparison to labeling by humans, and quantitative, based on robot-collected data. Dynamic Time Warping (DTW) helps us align overlapping regions of a left to right sweep with its corresponding right to left sweep.

8709-55, Session 13

Material identification reflectivity kernel (MIRK), real-time processing for in-stride sea mine countermeasures

John D. Pearson, Prometheus Inc. (United States)

Algorithms have been derived to solve the equation: signal return (f(t)) equals the integral of the product of a value K (t, t') and s(t, t')dt' plus noise. Given the signal return to the sensor, f(t) and knowing the characteristics of the transmitted signal s(t'), the algorithm solves for the value k(t, t') and provides information necessary to identify the signal

return as target or non-target. The algorithm is tunable for different transmitted signals in different sensor applications.

The signal processing technique has improved classification and reduced false target rates in several undersea sonar sytems to a significant degree (95+% in one operational defense sonar system). The technique only requires a software patch to an operating system. This technique has been successful, in its original application with synthetic aperture radar.

8709-56, Session 14

Detection of shallow buried objects using an autoregressive model on the ground penetrating radar signal

Daniel Nabelek, Dominic K. Ho, Univ. of Missouri-Columbia (United States)

The detection of shallow buried low-metal content objects using ground penetrating radar (GPR) is a challenging task. This is because these targets are just underneath the ground and the ground bounce reflection interferes with their detections. They do not produce much hyperbolic signatures as required by most existing GPR detection algorithms due to their special geometric shapes and low metal content. This paper proposes the use of the Autoregressive (AR) modeling method for the detection of these targets. We fit an A-scan of the GPR data to an AR model. It is found that the fitting error will be small when such a target is present and large when it is absent. The ratio of the energy in an A-scan before and after AR model fitting is used as the confidence value for detection. Using the data collected from a government test site, the proposed method can improve the detection of this kind of targets by 30% compared to the pre-screener, at a false alarm rate of 0.002/m2.

8709-57, Session 14

Evaluation of landmine detection performance applying two different algorithms to GPR field data

Roi Mendez Rial, Udo Uschkerat, Fernando Rial, Maria Antonia Gonzalez Huici, Fraunhofer FHR (Germany)

In this paper we evaluate and compare the performance of two different algorithms that have previously demonstrated their potential in underground target detection. One of the algorithms is based on a Likelihood Ratio Test, where the unknown model parameters of the clutter are estimated using a Maximum Likelihood approach (Generalized Likelihood Ratio Test). The other method is a basic energy-based detection algorithm where a noise (clutter) level is established according to the average amount of scattered energy per time instant (depth). Since both methods act on a pixel by pixel basis, we apply morphology operators as final step in order to remove isolated single-pixel alarms and cluster detection pixels.

Field data was obtained on specially prepared test fields at the Joint Research Center (JRC) in Ispra (IT), where various mine simulants, reference objects and mine-like clutter where placed at precise locations in different soil types. An additional test site of Leibnitz Institute for Applied Geophysics (LIAG) in Hannover with different mine simulants and inhomogeneous soil is also considered.

The efficiency of both algorithms in terms of detection accuracies (ROC curves) and computational burden is compared, and the impact of preprocessing algorithms (such as background removal and different focusing techniques) is also evaluated.

Based on the results, we discuss the convenience of both methods to be integrated in a real-time signal processing system considering their advantages and drawbacks.

8709-58, Session 14

Performance of imaging techniques for explosive hazard detection using forward-looking ground-penetrating radar

Timothy C. Havens, Michigan Technological Univ. (United States); James M. Keller, Dominic K. Ho, Univ. of Missouri-Columbia (United States)

This paper presents a comparison of FLGPR imaging techniques for the task of detecting explosive hazards. The challenges in detecting these hazards with FLGPR are that there are multiple types of targets buried at different depths in a highly-cluttered environment. A wide array of target and clutter signatures exist, which makes detection algorithm design difficult. Recent work in this application has focused on fusion methods, including fusion of multiple modalities of sensors (e.g., FLGPR and infrared), fusion of multiple frequency sub-band images in FLGPR, and feature-level fusion using multiple kernel learning. For this paper, we will examine the effectiveness of different imaging techniques, including conventional delay-and-sum based methods and adaptive imaging methods based on amplitude and phase estimation and robust Capon beamforming. Using FLGPR data collected at a US Army test site, we compare the performance of several imaging techniques using a common set of previously developed detection algorithms

8709-59, Session 14

A run packing technique for multiple sensor fusion

Taylor Glenn, Joseph N. Wilson, Univ. of Florida (United States); Paul Gader, Brandon Smock, Univ of Florida (United States)

The Run Packing (RP) fusion method is a novel algorithm that addresses the confidence level fusion problem when M different sensors (or alarm sources) produce alarms independently. The goal of such a fusion method is to map the output confidence range of each alarm source to a global range shared by all of the alarm sources. The shared global confidence range allows a single receiver operating characteristics (ROC) curve to be created, and this ROC then shows the global system performance trade-offs across all alarm sources. We explain the run packing algorithm, show its application to a multi-sensor buried explosive object detection system, and compare its performance to other fusion techniques.

8709-60, Session 14

Multiple Instance Hidden Markov Models for GPR-based Landmine Detection

Achut Manandhar, Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

Ground Penetrating Radar (GPR) is a widely used technology for the detection of subsurface buried threats. Although GPR data contains a representation of 3D space, object truth (target/false alarm location) is usually only available in 2D space along the surface of the earth. To overcome uncertainty in target depth location, many algorithms simply extract features from multiple depth regions which are then independently used to make mine/non-mine decisions. A similar technique is employed in Hidden Markov Model (HMM) based landmine detection. In this approach, sequences of downtrack GPR responses over multiple depth regions are utilized to train an HMM, which learns the probability of a particular sequence of GPR responses being generated by a buried target. However, the uncertainty in object depth complicates learning for discriminating targets/non-targets since features at the (unknown) target depth can be significantly different from features at other depths but in the same volume. To mitigate the negative impact of the uncertainty in object depth, mixture models based on Multiple

Instance Learning (MIL) have previously been developed. MIL is also applicable in the landmine detection problem using HMMs because features that are extracted independently from sequences of GPR signals over several depth bins can be viewed as a set of unlabeled time series, where the entire set either corresponds to a buried threat or a false alarm. In this work, a novel HMM-MIL framework is developed. We show that the performance of the proposed approach for discriminating targets from non-targets in GPR data is promising.

8709-61, Session 15

Multiple instance learning for hidden Markov models: application to landmine detection

Jeremy Bolton, Univ. of Florida (United States); Seniha Yuksel, Univ of Florida (United States); Paul D. Gader, Univ. of Florida (United States)

In standard learning techniques, an algorithm is typically presented with exemplar samples from some number of classes, and its goal is to construct a characterization for each class. However, in some learning scenarios, class labels are not readily available for each sample in the training data. Multiple Instance Learning is a learning paradigm that explicitly accounts for learning from ambiguous data. It accomplishes this task by learning from sets of data rather than samples.

A novel Multiple Instance Hidden Markov Model (MI-HMM) is developed for classification of ambiguous time-series data. Without introducing any additional parameters, the MI-HMM provides an elegant and simple way to learn the parameters of an HMM in a Multiple Instance Learning (MIL) framework. The efficacy of the model is shown on a real landmine data set. Experiments on the landmine data set show that MI-HMM learning is very effective, and outperforms the state-of-the-art models that are currently being used in the field for landmine detection.

8709-62, Session 15

Robust entropy-guided image segmentation for ground detection in GPR

John W. Roberts, Yakov P. Shkolnikov, Jonathan Varsanik, Timothy Chevalier, Exponent, Inc. (United States)

Identifying the ground within a ground penetrating radar (GPR) image is a critical component of automatic and assisted target detection systems. As these systems are deployed to more challenging environments they encounter rougher terrain and less-ideal data, both of which can cause standard ground detection methods to fail. This paper presents a means of improving the robustness of ground detection by adapting a technique from image processing in which images are segmented by local entropy. This segmentation provides the rough location of the air-ground interface, which can then act as a "guide" for more precise but fragile techniques. The effectiveness of this two-step "coarse/fine" entropy-guided detection strategy is demonstrated on GPR data from very rough terrain, and its application beyond the realm of GPR data processing is discussed.

8709-63, Session 15

GPR preprocessing optimization with signal-to-clutter metrics

Jonathan Varsanik, John W. Roberts, Timothy Chevalier, Adam D. Mulliken, Exponent, Inc. (United States)

Prior to the calculation of target detection features, ground penetrating radar (GPR) data typically requires extensive preprocessing to suppress clutter artifacts and enhance signals corresponding to weaker targets. Optimization of this GPR signal preprocessing pipeline is necessary to provide the best opportunity at visual detection and automatic target recognition. Manual, independent adjustment of the many configuration parameters in the data preprocessing pipeline is inefficient and not guaranteed to find an optimal result. In this paper, the authors present a new metric for GPR processed data quality and demonstrate its utility in an automated parameter sweep optimization of a large set of algorithm configuration parameters. The observed costs and benefits of using automated preprocessing optimization are presented and discussed.

For preprocessing optimization and evaluation, a cost function was desired that is independent of the target detection features – to enable independent evaluation of the various components of the GPR target detection software. The proposed cost function, JSUM, is a signal-to-clutter ratio (SCR) metric, derived from the known KSUM metric. JSUM was developed to be sensitive to a particular type of noise in GPR data not captured by KSUM. The response of JSUM and KSUM to different common types of noise was explored to qualify the usefulness of the metric.

JSUM was used as the cost function for a parameter sweep optimization across a set of preprocessing parameters. The outcomes of this optimization are presented for discussion.

8709-64, Session 15

Application of image categorization methods for buried threat detection in GPR data

Rayn T. Sakaguchi, Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

Utilizing methods from the image processing and computer vision fields has led to advances in high resolution Ground Penetrating Radar (GPR) based threat detection. By analyzing 2-D slices of GPR data and applying various image processing algorithms, it is possible to discriminate between threat and non-threat. In initial attempts to utilize such approaches, object instance-matching algorithms were applied to GPR images, but only limited success was obtained when utilizing feature point methods to identify patches of data which displayed landmine-like characteristics. While the approach worked well under some conditions, the instance-matching method of classification was not designed to identify a type of class, only reproductions of a specific instance. In contrast, our current approach is focused on identifying methods that can account for within-class variation that results from changing target types and varying operating conditions that a GPR system regularly encounters. Image category recognition is an area of research which attempts to account for the in-class variation of objects within visual images. Instead of finding a reproduction of a particular known object within an image, algorithms for image categorization are designed to learn the qualities of images that contain an instance belonging to a known class. The results illustrate how image category recognition algorithms can be successfully applied to threat identification in GPR data.

8709-65, Session 15

Embedding the multiple instance problem: applications to landmine detection with ground penetrating radar

Jeremy Bolton, Paul Gader, Univ. of Florida (United States); Hichem Frigui, University of Louisville (United States)

Multiple Instance Learning (MIL) is a recently researched learning paradigm in machine intelligence. MIL provides for learning target concepts from data with uncertain class labels also known as ambiguous data. It accomplishes this task by performing inference over a set of data rather than a single sample by utilizing the noisy-OR gate. Although this approach permits learning in this highly ambiguous environment, optimization procedures are cumbersome due to the final inference step using the noisy-OR gate, which is a non-linear mapping from a set of probabilities to a single probability.

Rather than performing this non-linear mapping last, the proposed

research investigates the benefits of performing a non-linear mapping first by embedding the MI scenario into a simple classifier, thus eliminating cumbersome optimization steps. Preliminary classification results on ground penetrating radar data for the purposes of landmine detection show that this method is comparable in classification accuracy to existing MI methods; yet there is a significant reduction in computation time during the training period. Furthermore, this method is more amenable to online training.

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8710-1, Session 1

Mid- and short- wave infrared hyperspectral imaging of hazardous liquids *(Invited Paper)*

Chris R. Howle, Rhea Clewes, Defence Science and Technology Lab. (United Kingdom); Keith Ruxton, M Squared Lasers Ltd. (United Kingdom); Jason A. Guicheteau, Darren K. Emge, U.S. Army Edgewood Chemical Biological Ctr. (United States); Bill Miller, Gordon Robertson, Graeme A. Malcolm P., Gareth T. Maker, M Squared Lasers Ltd. (United Kingdom)

The ability for the accurate detection and identification of hazardous agents including chemical warfare agents (CWAs), biological warfare agents (BWAs) and volatile organic compounds (VOCs) is a priority for the protection of personnel in both military and domestic environments. Active infrared (IR) hyperspectral imaging is a technology that has great potential for successful agent detection and identification. This imaging technique uses an infrared source, in this case an optical parametric oscillator (OPO) with broad tunability, operating at 1.5 μm to 1.7 μm in the short wave IR (SWIR) and 2.7μm to 3.6 μm in the mid wave IR (MWIR). The laser beam is raster scanned across the scene of interest using a pair of galvanometric mirrors with the backscattered light being de-scanned and focussed onto point detectors generating IR images of the scene. If the agent is present and the wavelength is tuned to an absorption feature, the agent will absorb the laser light through molecular vibrations. Absorptions will appear as a dark area in the generated image, giving the user the spatial information of the agent. The output wavelength is tuned to on and off absorption features of the target agent, in order to build its absorption spectrum. The recorded spectrum can then be compared to spectral reference data to obtain identification. This work presents a selection of results where active hyperspectral imaging was performed in the SWIR and MWIR on a number of agents used as simulants in the field of CWA detection.

8710-2, Session 1

Standoff chemical D&Id with extended LWIR hyperspectral imaging spectroradiometer

Florent M. Prel, Louis Moreau, ABB Analytical Measurement (Canada); Hugo Lavoie, François Bouffard, Jean-Marc Thériault, Defence Research and Development Canada, Valcartier (Canada); Christian A. Vallieres, Claude B. Roy, ABB Analytical Measurement (Canada); Denis Dubé, Defence Research and Development Canada, Valcartier (Canada)

Standoff detection and identification (D&Id) of unknown volatile chemicals has been increasingly desired for homeland security, first responders and environmental monitoring such as chemical warfare and consequences of industrial incidents. On site gas detection sensors are commercially available and several of them can even detect more than one chemical species, however only few of them have the capabilities of detecting a wide variety of gases at long distances.

The ABB Hyperspectral Imaging Spectroradiometer (MR-i), configured for the needs of the Defense Research and Development Canada, detects and identifies a wide variety of chemical species including toxic industrial chemicals (TICs) and chemical warfare agents (CWA) up to several kilometers away from the sensor. This configuration is called iCATSI for improved Compact Atmospheric Sounding Interferometer. iCATSI is a stand-off passive system.

The modularity of the MR-i platform allows optimization of the detection configuration with a 256 x 256 Focal Plane Array imager (cut off 13.6 μm) or a line scanning imager (cut off 14 μm) both covering the long wave IR atmospheric window. The uniqueness of their extended LWIR cut off enables to detect more chemicals than usual LWIR sensors.

Lab and field chemicals measurements results will be presented in this paper.

8710-6, Session 1

Stand-off identification and mapping of liquid surface contaminations by passive hyperspectral imaging

René Braun, Roland Harig, Bruker Optik GmbH (Germany)

Stand-off identification of potentially hazardous liquid surface contaminations and the visualisation of the contaminated area enable first responders to rapidly assess emergency situations. Hyperspectral imaging allows the detection and mapping of a huge variety of liquid compounds in real time even without the active illumination of the sample. The approach that is presented in this study uses the contrast of the brightness temperature of the investigated sample and of the surrounding hemisphere. The liquid compounds are identified by the comparison of the reflection spectrum that is measured and synthetic in-situ reflection spectra for various liquid compounds. These synthetic in-situ spectra are calculated using the optical properties of the various target compounds that are stored in a library and data characterizing the measurement conditions. That is the spectrum of the radiation incident to the investigated sample and the reflection spectrum of the uncontaminated background surface, both of which are acquired along with the measurement. In this work passive measurements of liquid surface contaminations are presented. The comparison to modelled spectra proves the feasibility of passive stand-off detection and mapping of liquid compounds.

8710-7, Session 2

Video-rate spectral imaging of gas leaks in the longwave infrared

Nathan A. Hagen, Robert T. Kester, Christopher Morlier, Rebellion Photonics (United States)

We have recently constructed a gas cloud imager (GCI) which demonstrates the first-ever video-rate detection (15 frames/sec) of gas leaks using an uncooled LWIR detector array. Laboratory and outdoor measurements, taken in collaboration with BP, show capabilities that exceed the current state of the art both in detection sensitivity and in the ability to detect and quantify multiple gases simultaneously. Gases imaged for these experiments include methane, propane, propylene, ethane, ethylene, butane, and iso-butylene, but any gases with absorption features in the LWIR band can be detected, such as sarin and other toxic gases. These results show that practical continuous monitoring of gas leaks is now possible.

8710-8, Session 2

Improved detection and false alarm rejection for chemical vapors using passive hyperspectral imaging

William J. Marinelli, Physical Sciences Inc. (United States); Rex K. Miyashiro, Research Support Instruments, Inc. (United States); Christopher M. Gittins, Daisei Konno, Shing D. Chang, Physical Sciences Inc. (United States); Brad Perkins, Matt Farr, Smiths Detection Edgewood (United States)

Two AIRIS sensors were deployed to Dugway Proving Grounds for testing against chemical agent vapor simulants. The primary objectives of the test were to: 1) assess performance of algorithm improvements designed to reduce false alarm rates with a special emphasis on solar effects, and 3) evaluate performance in target detection at 5 km.

The tests included 66 total releases comprising alternating 120 kg glacial acetic acid (GAA) and 60 kg triethyl phosphate (TEP) events. The AIRIS sensors had common algorithms, detection thresholds, and sensor parameters. The sensors used the target set defined for the Joint Service Lightweight Chemical Agent Detector (JSLSCAD) with TEP substituted for GA and GAA substituted for VX. They were exercised at two sites located at either 3 km or 5 km from the release point.

Data from the tests will be presented showing that: 1) excellent detection capability was obtained at both ranges with significantly shorter alarm times at 5 km, 2) inter-sensor comparison revealed very comparable performance, 3) false alarm rates < 1 incident per 10 hours running time over 143 hours of sensor operations were achieved, 4) algorithm improvements eliminated both solar and cloud false alarms. The algorithms enabling the improved false alarm rejection will be discussed.

The sensor technology has recently been extended to address the problem of detection of liquid and solid chemical agents and toxic industrial chemical on surfaces. The phenomenology and applicability of passive infrared hyperspectral imaging to this problem will be discussed and demonstrated.

8710-9, Session 2

Standoff chemical detection with a parts per million level calibrated detection sensitivity

Xing Chen, Fow-Sen Choa, Univ. of Maryland, Baltimore County (United States); Ellen L. Holthoff, Paul M. Pellegrino, U.S. Army Research Lab. (United States); Jenyu Fan, Adtech Optics Inc. (United States)

Photoacoustic (PA) sensing is a highly sensitive chemical and biological detection technique. Chemical sensing using quantum cascade lasers (QCLs) and the PA effect has achieved parts-per-trillion level detection sensitivity for in situ measurements in PA cells. However, to detect chemicals such as explosives and nerve agents, a safe standoff distance is required. To achieve that, recently we demonstrated standoff chemical detection at a distance of more than 41 feet using the PA effect, QCLs, and other very light weight components, including a microphone, sound reflector, and electronics. In this work, we have further calibrated the sensitivity of such a standoff detection system. In our experiments, a QCL was operated under pulsed conditions with a repetition rate of ~1.5kHz and pulse width of ~300 µs with an average power of more than 150 mW. To calibrate the sensitivity, a commercial gas vapor generator was used. Permeation tubes containing nerve agent simulants were the gas sources. Nitrogen was used as the carrier gas and varying calibrated flow rates provided ppm level chemical concentrations. When the laser output light was focused on the nerve agent in an open environment, photoacoustic signals were generated and could be detected by an ultra-sensitive microphone at a standoff distance. In order to increase the detection distance, a parabolic sound reflector was added to the system for better sound collection. With the help of the sound reflector, the standoff detection distance was extended up to 2 feet with the nerve agent concentration calibrated at 2 ppm.

8710-10, Session 2

CWA stand-off detection, a new figure-of-merit: the field surface scanning rate

Philippe F. Bernascolle, Bertin Technologies (France)

All the manufacturers of stand-off CWA detector communicate on the “same” characteristics. And one can find these parameters in the comparison table published between all the different products. These characteristics are for example the maximum detection range, the number of different detectable compounds, the weight, the price, etc…

All these parameters are good to compare products between them, but they omit one very important point: the reaction time in case of an unexpected incoming chemical threat, in the case of the surveillance application.

To answer this important question, we imagine a new parameter: the Field Surface Scanning Rate (FSSR). This value is a classical parameter in astronomical survey, use by astronomers to compare the performance of different telescopes, they compute the quantity of sky (in sky square degrees) analyzed per unit of time by the system.

In this paper we will compare this new figure-of-merit, the FSSR, of some on the shelf stand-off detector.

We will present for different surveillance scenario and for each analyzed detector the FSSR value.

The comparison between classical FTIR system and gas imaging system in term of FSSR will be presented.

8710-12, Session 3

Performance comparison of microphone and reflector array structures for real-time and outdoor photoacoustic chemical sensing

Joshua A. Lay, Univ. of Maryland, Baltimore (United States); Xing Chen, Fow-Sen Choa, Univ. of Maryland, Baltimore County (United States)

Standoff chemical sensing using QCL and photoacoustic techniques recently has been demonstrated at a distance of more than 41 feet. To operate such a system outdoor, the system needs to be capable of rejecting other acoustic sources in the field. In this work, we experimentally compare two different implementations of beam forming array systems. One structure uses 4 microphones placing at the 4 foci of 4 parabolic reflectors. The other structure uses an array of 4x4 microphones placing at the focal point of one parabolic reflector. Two acoustic sources were used to represent the signal (at 3kHz) and noise (at 4kHz). Using a multi-channel A to D system we can adjust delays of all the channels to make sure the signals from each phone were added in phase, which can enhance the signal and at the same time suppress the noise source. the system is then ready for real time operations. The measured results in Fourier domain shows that the signal and noise spectra of the 4 microphone/4 reflector system with a combined SNR of 12.48 dB. For the 16-microphone/1-reflector case, an SNR of 17.82 was achieved. The worse SNR result of the 4-phone/4-reflector system may not simply due to the other system has 16 microphones. It also because of the average effect of the full reflector area, which can play the role to blur the phase of each element in the beam forming system. With reflectors the phase canceling of noise at the microphone location cannot be exact.

8710-13, Session 3

LIBS plasma model validation

Steven T. Griffin, Brandon Dent, Univ. of Memphis (United States)

An engineering thermodynamic approach to the plasma description associated with Laser Induced Breakdown Spectroscopy (LIBS) has been previously published. In the prior work, a non-traditional modeling approach was made to reduce the modeling system to a configuration compatible with incorporation into a TI6701. This modeling technique was necessitated by the extreme limitations that portability and robustness place on the physical size and power consumption of the computer for data processing and classification. The new modeling approach was previously reported. This presentation reports on the finalization of this and the validation of the result through comparison to more established models such as detailed balance, via the solution to a system of Boltzmann Equations. The emphasis is on the engineering

modeling and its' system implications - not a physics tutorial. Implications of the modeling approximations for the accuracy and repeatability of the complete sensor system will be presented. Possible utilization of newer, larger scale processors and the impact that would have on the model and associate sensor performance is addressed

8710-14, Session 3

Methodology for the passive detection and discrimination of chemical and biological aerosols

William J. Marinelli, Kirill N. Shokhirev, Daisei Konno, David C. Rossi, Physical Sciences, Inc. (United States); Martin B. Richardson, BAE Systems, Inc. (United States)

The standoff detection and discrimination of aerosolized biological and chemical agents has traditionally been addressed through LIDAR approaches, but sensor systems using these methods have yet to be deployed. We discuss the development and testing of an approach to detect these aerosols using the deployed base of passive infrared hyperspectral sensors used for chemical vapor detection.

The detection of aerosols requires the inclusion of down welling sky and up welling ground radiation in the description of the radiative transfer process. The wavelength and size dependent ratio of absorption to scattering provides much of the discrimination capability. The approach to the detection of aerosols utilizes much of the same phenomenology employed in vapor detection; however, the sensor system must acquire information on non-line-of-sight sources of radiation contributing to the scattering process.

We describe the general methodology developed to detect chemical or biological aerosols, including justifications for the simplifying assumptions that enable the development of a real-time sensor system. Mie scattering calculations, aerosol size distribution dependence, and the angular dependence of the scattering on the aerosol signature will be discussed.

This methodology will then be applied to two test cases: the ground level release of a biological aerosol (BG) and a non-biological confuser (kaolin clay) as well as the debris field resulting from the intercept of a cruise missile carrying a thickened VX warhead. A field measurement, conducted at the Utah Test and Training Range will be used to illustrate the issues associated with the use of the method.

8710-15, Session 4

Sampling and analysis of chemical particulates on surfaces.

Kenneth J. Ewing, Jas S. Sanghera, Daniel Gibson, U.S. Naval Research Lab. (United States); Fritz Miklos, Sotera Defense Solutions, Inc. (United States)

Almost all chemical detectors are designed to collect and analyze vapors or gasses in the ambient air. For example ion mobility spectrometers, mass spectrometers, and gas chromatographs are routinely used to detect various toxic chemicals such as chemical warfare agents and toxic industrial chemicals in the vapor phase. However, low volatility toxic chemicals such as pesticides are dispersed as a solid particulate, and in many cases the pesticide is immobilized into an inert carrier material to enable uniform dissemination of the material. Such low vapor pressure materials are not efficiently collected using vapor phase collection methods. Therefore, there is a need for the development of sampling techniques for low vapor pressure chemical particulates. The current work describes a sampling approach for collection of chemical particulates from surfaces with subsequent analysis using thermal desorption ion trap mass spectrometry.

8710-16, Session 4

Smart phones: platform enabling modular, chemical, biological, and explosives sensing

Amethist S. Finch, Justin R. Bickford, Marvin A. Conn, Thomas J. Proctor, Dimitra N. Stratis-Cullum, U.S. Army Research Lab. (United States)

Reliable, robust, and portable technologies are needed for the rapid identification and detection of chemical, biological, and explosive (CBE) materials. A key to addressing the persistent threat to U.S. troops in the current war on terror is the rapid detection and identification of the precursor materials used in development of improvised explosive devices, homemade explosives, and bio-warfare agents. However, a universal methodology for detection and prevention of CBE materials in the use of these devices has proven difficult. Herein, we discuss our efforts towards the development of a modular, robust, inexpensive, pervasive, archival, and compact platform (android based smart phone) enabling the rapid detection of these materials. Preliminary results focus integration of detection methodologies based on the use of commercially available colorimetric assays for chemical and explosives identification.

8710-17, Session 4

Paper SERS chromatography for detection of trace analytes in complex samples

Wei W. Yu, Ian M. White, Univ. of Maryland, College Park (United States)

Recently, we reported on the fabrication of inkjet-printed paper SERS substrates and demonstrated their applications for the detection of food contaminants, pesticides and illicit drugs in the forms of spot-on assays, swabs and dipsticks. These inexpensive and highly sensitive paper SERS substrates eliminate the high costs associated with conventional SERS substrates created through microfabrication. Paper SERS substrates represent a significant advancement for point-of-sample analytics, liberating surface enhanced Raman spectroscopy from the confines of a traditional laboratory setting and enabling the application of this highly sensitive analytical technique in the field.

In this work, we report the application of paper SERS substrates in the form of paper chromatography for the detection of trace quantities of multiple analytes in a complex sample. Paper chromatography facilitates the separation of different analytes from a complex sample into distinct sections in the chromatogram, which can then be uniquely identified using SERS. Specific applications such as the separation and detection of contaminants in foods, and the identification of narcotics in street drugs will be demonstrated. This simple but highly sensitive technique requires no complex equipment apart from a portable Raman system and the inexpensive paper SERS substrates. Paper SERS chromatography has obvious applications, including law enforcement, food safety, and border protection, and facilitates the rapid detection of chemical and biological threats at the point of sample.

8710-18, Session 4

New SERS substrates enabled by confining gold nanoparticles in mesopores of SBA-15 for sensitive chemical detections

Yongheng Zhu, Univ. of Washington (United States) and Shanghai Univ. (China); Jiaqiang Xu, Shanghai Univ. (China); Shaoyi Jiang, Qiuming Yu, Univ. of Washington (United States)

Surface-enhanced Raman scattering (SERS) spectroscopy has immerged as a powerful analytical and sensing tool for use in chemical and biological threat detections. Gold and silver colloid nanoparticles and nanostructures are commonly used as SERS-active substrates. Here,

we reported a new type of SERS-active substrates realized by in-situ growing gold nanoparticles in mesoporous sillca materials SBA-15. The high surface area of SBA-15 and the narrow gap formed by gold nanoparticles inside the mesopores make this new SERS material very sensitive for detecting a variety of chemical markers. We first synthesized hexagonal lamelliform SBA-15 with the plane size of ~6 μm and the thickness of ~ 400 nm. The mesopores of ~7 nm diameter are hexagonally arranged forming vertical channels. Polydopamine were coated on the inner wall of mesopores of SBA-15 particles and promoted the reduction of gold precursors (AuCl4-) at room temperature. TEM images confirm that gold nanoparticles are formed inside the mesopores. In addition, X-ray diffraction patterns show that gold nanoparticles are crystalline and mesopores structure of SBA-15 is retained. Using 4-mercaptopyridine (4-Mpy) as SERS reporter molecule, strong SERS signals were obtained and the spectra also indicated that gold nanoparticles were confined in mesopores. We functionalized the gold nanoparticle surfaces with cysteine for specific detection of TNT because of the formation of Meisenheimer complex between TNT and cysteine. The excellent detection limit and selectivity over DNT and other nitrocompound were demonstrated.

8710-19, Session 4

Development of SERS monitoring of fuel markers to prevent fraud

Timothy G. Wilkinson, John Clarkson, Peter C. White, Nicholas Meakin, DeCipher Pte Ltd. (United Kingdom); Ken McDonald, Ocean Optics (United Kingdom)

Governments often tax or subsidise fuel products to generate revenues, or stimulate their economies and both of these practices are subject to fraud. Fuel marking has been shown to be effective in controlling illegal activity. DeCipher has developed SERS as its lead technology for measuring markers in fuel to identify and control malpractice. SERS instruments are portable and give high specificity for fuel markers and the analysis is quick, clear and decisive. We will present results of our development of a stable silver colloid as a SER substrate to measure fuel markers at ppb levels.

8710-20, Session 4

Ppb detection of Sarin surrogate in liquid solutions

Matthieu Hamel, Jennifer Hamoniaux, Licinio Rocha, Stéphane Normand, Commissariat à l'Énergie Atomique (France)

Organophosphorus molecules are well known to be highly toxic compounds. In particular, Sarin is toxic for concentrations as low as 0.03 ppm in the air (Immediately Dangerous to Life or Health value). Numerous methods could be used to detect sub-ppm concentrations of Sarin. A technology providing easy-to-use, low cost, sensitivity and selectivity "on board" could be emission spectroscopy.

To this aim, we have developed a new, cheap and extremely sensitive method for the detection of Diethyl Chlorophosphate (DCP), a Sarin surrogate. This method provides in a few seconds a turn-off fluorescence response where the sensor is able to provide a response for ppb levels. For instance, a I/I0 = 0.68 (fluorescence quenching) was obtained when the sensor was affected by 16 ppb of DCP.

An example of our sensors is composed of a xanthene derivative (fluorescein, resorufin and so on) highly diluted in DMSO or ethanol. This presentation will show the results and compare the sensors in terms of quenching effect, response linearity and limit of detection. An extension to a solid, potable system will also be presented. It is probable that these simple systems with so outstanding detection levels will find industrial applications.

8710-64, Session PTues

CN, C2 emission studies of methyl- and dinitro-imidazoles using femtosecond LIBS technique

Soma Venugopal Rao, Nageswar Rao Epuru, Sreedhar Sunku, Manoj Kumar Gundawar, Surya Prakash Tewari, Univ. of Hyderabad (India)

We present some of our initial experimental results from the laser induced breakdown spectroscopic studies of 1, 4-dinitroimidazole and 2-methyl-4(5)-nitroimidazole using femtosecond laser pulses. The molecular emission spectra of CN violet band and C2 swan band along with elemental (C, H, N, O) features have been investigated in plasmas generated in air, argon, and nitrogen atmospheres at different time delays (40 ns to 690 ns). The variations in ratios of molecular CN (388.2 nm), C2 (516.5 nm) intensities to that of elemental of C (247.8 nm) and N (868.65 nm) have been evaluated. We observed that CN/C and C2/C ratios were constant from 40 ns to 200 ns (in all atmospheres and for both the molecules). For delays beyond 200 ns the ratios were higher (than that at 200 ns) and oscillating in air, nitrogen atmospheres but remained almost constant in argon atmosphere. This could be due to the secondary reactions occurring in plasma (with external atmospheric constituents) leading to higher number of molecular species. The spectral intensities of the CN molecular bands were observed to be stronger in nitrogen than in air and argon. However, C and C2 peaks were observed to be intense in argon atmosphere than ambient air and nitrogen. In the case of air and nitrogen atmospheres contribution from nitrogen atoms surrounding plasma leads to higher probability of CN formation. The intensity decay constants of CN, C2 molecular and carbon peaks were also calculated.

8710-65, Session PTues

Femtosecond LIBS studies of Nitropyrazoles

Soma Venugopal Rao, Nageswara Rao Epuru, Sreedhar Sunku, Manoj Kumar Gundawar, Surya Prakash Tewari, Univ. of Hyderabad (India)

We present our initial experimental results from LIBS studies of 1-nitropyrazole, 3-nitropyrazole, 3,4-dinitropyrazole and 1-methyl-3,4,5 trinitro pyrazoles using femtosecond pulses performed in argon atmosphere. CN molecular bands in three different spectral regions of 357 nm-360 nm, 384 nm-389 nm and 414 nm -423 nm, C2 swan bands near 460 nm-475 nm, 510 nm– 520 nm and 550 nm-565 nm were observed. The C peak at 247.82 nm, H peak at 656.2 nm also have been observed along with several peaks of O and N. CN/C2, CN/C, C2/C and C2/N ratios were measured from the average of 25 spectra obtained in argon. The effect of number of nitro groups on the atomic and molecular emission has been evaluated. A gate delay of 100 ns and a gate width of 800 ns were used.

8710-66, Session PTues

Controls characterization of predictor corrector-based LIBS data collection

Steven T. Griffin, Alex Sanders, Univ. of Memphis (United States)

Portable LIBS sensor communication bandwidth limitations favor local material classification for low power consumption. Partial Least Squares - Discriminant Analysis (PLS-DA) and Principle Component Analysis (PCA) have been implementation via general purpose computers and are accepted for some Department of Defense applications. Prior publications address the creation of a low mass, low power, robust hardware spectra classifier for a limited set of predetermined materials in an atmospheric matrix. The incorporation of a PCA or a PLS-DA classifier into a predictor-corrector implementation on a TI6701 has been developed. The performance modeling of the control system with

an emphasis on further optimization needs addressing. This paper characterizes, from a control system standpoint, the predictor-corrector architecture applied to LIBS data collection. In addition, the application of this as a material classifier is presented. Updates in the model implemented on a low power multi-core DSP will be presented as well. Performance comparisons to alternative control system structures will be considered.

8710-67, Session PTues

An apparatus for the measurement of re-suspension of particles from realistic surfaces

Jonathan M. Richardson, Trina R. Vian, Benjamin L. Ervin, Jason J. Han, MIT Lincoln Lab. (United States)

Particles deposited on surfaces can be re-suspended readily by various transient airflows (e.g., passing vehicles, pedestrian movement). Measuring re-suspension properties is of particular interest for hazardous particles that could present a persistent aerosol hazard in a particular location. MIT Lincoln Lab has developed an apparatus for determining the relative re-suspension probabilities of various particle classes due to transient airflow. The apparatus is designed to accommodate a wide range of substrates and includes a method for exposing the substrates to a range of particle classes in a well-controlled manner. This poster will describe our exposure and re-suspension measurement methods, presenting recent results. We acknowledge the support of Teresa Lustig at the Department of Homeland Security for this work.

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8710-22, Session 5

Infrared hyperspectral standoff detection of explosives

Frank Fuchs, Stefan Hugger, Jan P. Jarvis, Verena Blattmann, Michel Kinzer, Quankui K. Yang, Ralf Ostendorf, Wolfgang Bronner, Rachid Driad, Rolf Aidam, Joachim H. Wagner, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

In this work we demonstrate imaging standoff detection of traces of explosives using infrared laser spectroscopy. The system relies on active laser illumination, synchronized with the collection of the backscattered radiation by a high performance infrared camera. The key component is an external cavity quantum cascade laser with a tuning range of 300 cm-1 that enables us to scan the illumination wavelength over several of the characteristic absorption features of a large number of different explosives using a single source. For the hyperspectral image analysis we combine an Adaptive Matched Subspace Detection (AMSD) algorithm with an Adaptive Target Generation Process (ATGP). In such a two-step process the algorithm separates the uncontaminated area from contaminated area and identifies the chemical species. In our experiments this approach yields high detection performances while keeping the false alarm rates at a very low level.

We investigated traces of various explosives including e.g. PETN, TNT and RDX on different real-world target-materials. For medium distances (< 3 m) particles below 1 µg can be detected. For larger quantities we demonstrate detection distances exceeding to 25 m. The large tuning range of the laser proved to be crucial both for the ability to identify most of the relevant explosives as well as for reliable suppression of cross-sensitivity to other substances.

8710-23, Session 5

Quantum cascade laser (QCL) FM spectroscopy of explosives

Zach Gutmann, Trocia Clasp, Taylor Ingle, Roger Buchanan, Scott Reeve, Arkansas State Univ. (United States)

Polyisobutylene is a widely used polymer used in a number of applications including the manufacture of military grade explosives. We have examined the vapor emanating from a low molecular weight (2800 g/mol) sample of polyisobutylene using high resolution QCL FM spectroscopy. The spectra exhibit a rovibrational structure in both the 11 and 7.5 micron regions similar to that for the gas phase isobutylene molecule. We have assigned the structure in the 7.5 micron range as the isobutylene v7 fundamental band. In addition, a series of GCMS measurements were used to detect the signature fractioning pattern of isobutylene collected using solid phase microextraction (SPME) from the same sample of polyisobutylene. The base ion peak 41 m/z (99%) as well as the molecular ion 55 m/z (16%) and 39 m/z (45%) peaks were used for confirmation. Finally, we re-examined SPME samples collected in the presence of C4 explosives using this same GCMS method. Here we will describe the optically based measurements as well as the series of GCMS measurements that unambiguously identifies isobutylene as an explosive bouquet compound in RDX-based C4 explosives.

8710-24, Session 5

Active infrared hyperspectral imaging of solid particles on surfaces

Anish K. Goyal, Travis Myers, Melissa Spencer, Matthew Aernecke, Rod R. Kunz, Stella Park, Bryan E. Tipton, Michael W. Kelly, MIT Lincoln Lab. (United States); Ellen L. Holthoff, Mikella E. Farrell, Paul M. Pellegrino, U.S. Army Research Lab. (United States)

Active long-wave-infrared (LWIR) hyperspectral imaging is a promising technique for the standoff detection and mapping of chemicals on surfaces. In this work, we investigate the phenomenology of LWIR reflectance from surfaces that are contaminated with solid particulates. The illumination source consisted of two wavelength-tunable external-cavity quantum-cascade lasers (EC-QCLs) that span the wavelength range from 9.1 to 10.8-microns. The diffusely reflected radiation from the sample was captured by a HgCdTe focal-plane array (FPA). The resulting hyperspectral image (HSI) cubes of 164 wavelengths were analyzed for spectral features that are indicative of the target material. For these experiments, the solid particles consisted of KClO3. These were measured as bulk powders, as a sparse distribution of particles, as single particles dispensed from a microdrop generator into a regular array, and as fingerprint residue. The particles and residues were deposited on a variety of surfaces such as aluminum, glass, and car panels, and their reflection spectra were characterized under various illumination geometries. It was found that the reflection spectrum from individual particles and residues was similar to that for bulk powders but with a dependence on the illumination geometry. By applying detection algorithms to the HSI cubes, it was possible to detect KClO3 at concentrations of <100 micrograms/cm2 at a ground sampling distance (GSD) of 0.6 mm. Single particles having a mass of 10's of nanograms could be detected at GSD = 0.3 mm. We will present the experimental results and compare with theoretical calculations.

8710-25, Session 5

Hazardous material analysis using mid-wave infrared hyperspectral imaging techniques

Keith Ruxton, Gordon Robertson, Bill Miller, Graeme P. A. Malcolm, Gareth T. Maker, M Squared Lasers Ltd. (United

Kingdom)

The detection and identification of hazardous material is required in a wide range of application environments including military and domestic. Infrared (IR) absorption spectroscopy is a technique that can be used for material identification through comparing absorption spectra with reference data from a library. The absorption spectrum of a compound is the result of light at certain wavelengths being absorbed through molecular vibrations of the compound. To build on this hyperspectral imaging can be used to add spatial information of the absorber. In this case the IR source output, an optical parametric oscillator (OPO) operating at 1.5 μm to 1.7 μm in the short wave IR (SWIR) and 2.7μm to 3.6 μm in the mid wave IR (MWIR), is raster scanned using a galvanometric mirror pair across a scene of interest. The resulting backscattered light is de-scanned through the same mirror pair and focussed onto point detectors and images in the IR are generated. This hyperspectral imaging instrument is a prototype that is currently being developed for a wide range of applications. If an absorber is present and the OPO wavelength is tuned to an absorption feature this will be appear as a dark area in the generated image. With the broad tunability of the OPO a detailed absorption spectrum of the target compound can be recorded and used to aid identification. This work presents a selection of results where explosive simulants and explosive materials were investigated and analysed using the prototype instrument.

8710-26, Session 5

Thz Raman spectroscopy for explosives, chemical, and biological detection

James T. Carriere, Frank Havermeyer, Randy A. Heyler, Ondax, Inc. (United States)

Raman and Terahertz spectroscopy are both widely used for their ability to safely and remotely identify unknown materials. Each approach has its advantages and disadvantages. Traditional Raman spectroscopy typically measures molecular energy transitions in the 200-5000 cm-1 region corresponding to sub-molecular stretching or bending transitions, while Terahertz spectroscopy measures molecular energy transitions in the 1-200 cm-1 region (30GHz-6THz) that correspond to low energy rotational modes or vibrational modes of the entire molecule.

Many difficult to detect explosives and other hazardous chemicals are known to have multiple relatively strong transitions in this “Terahertz” (<200cm-1, <6THz) regime, suggesting this method as a powerful complementary approach for identification. However, THz signal generation is often expensive, many THz spectroscopy systems are limited to just a few THz range, and strong water absorption bands in this region can act to mask certain transitions if great care isn’t taken during sample preparation. Alternatively, low-frequency or “THz-Raman™” spectroscopy, which covers the 10cm-1 to 200 cm-1 (300GHz-6 THz) regions and beyond, offers a powerful, compact and economical alternative to probe these low energy transitions.

We present results from a new approach for extending the range of Raman spectroscopy into the Terahertz regime using an ultra narrow-band volume holographic grating (VHG) based notch filter system. An integrated, compact Raman system is demonstrated utilizing a single stage spectrometer to show both Stokes and anti-Stokes measurements down to <10cm-1 on traditionally difficult to detect explosives, as well as other chemical and biological samples.

Many difficult to detect explosives (including HMTD and TATP) and other hazardous chemicals are known to have multiple relatively strong transitions in this “Terahertz” (<200cm-1) regime, suggesting this method as a powerful complementary approach for identification. However, THz signal generation is often expensive, many THz spectroscopy systems are limited to just a few THz range, and strong water absorption bands in this region can act to mask certain transitions if great care isn’t taken during sample preparation. Alternatively, “low-frequency” Raman spectroscopy, which covers the 10cm-1 to 200 cm-1 (300GHz-6 THz) regions and beyond, offers a powerful, compact and economical alternative to probe these low energy transitions.

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8710-27, Session 5

Quantum Cascade Laser Intracavity Absorption Sensor

Andrey V. Muraviev, Doug Maukonen, Christopher J. Fredricksen, Gautam Medhi, EMX International, LLC (United States); Robert E. Peale, Univ. of Central Florida (United States)

We describe a compact Chemical Explosives Threat Analyzer (ChETA), which detects and identifies trace vapors. ChETA is a mid-infrared intracavity laser absorption spectrometer based on an external cavity multi-mode quantum cascade laser. A scanning Fabry-Perot interferometer is used as tunable narrow band transmission filter to analyze the laser emission spectrum. Sensitivity to date has been demonstrated at the level 1 ppm using the test gas ethyl acetate, which corresponds to the vapor absorption coefficient of 5*10^-6 cm^-1. The sensitivity to a weak sharp absorption line of the test gas ammonia has been shown to significantly exceed that of usual Fourier spectroscopy with a 10 meter path length. Sensitivity to the absorption coefficients of 10^-7 cm^-1 and vapor concentrations in the low ppb range is well within ChETA’s theoretical limits, which is comparable to that for the strongest lines of saturated TNT vapor.

8710-28, Session 6

LightGuard: hyperspectral imaging detector for explosives, chemical threats, and narcotics

Matthew P. Nelson, ChemImage Corp. (United States)

ChemImage has developed a LightGuard sensor which uses hyperspectral imaging (HSI) for wide area surveillance and standoff detection of explosives, chemical threats, and narcotics. Existing detection technologies often require close proximity for sensing or detecting, endangering operators and costly equipment. Furthermore, most of the existing sensors do not support autonomous, real-time, on-the-move (OTM) detection of threats.

The LightGuard sensor provides real-time standoff detection of explosives, chemical threats and narcotics. The LightGuard sensor provides wide area surveillance and HSI capability enabled by liquid crystal tunable filter technology. Easy-to-use detection software with a simple, intuitive user interface produces automated alarms and real-time display of threat and type. The system has an extensive library of military and homemade explosives, chemical threats and illicit drug substances and allows for easy threat library updates in the field for detection of new hazardous materials.

LightGuard technology could be used by law enforcement for standoff screening of suspicious locations and vehicles in pursuit of illegal labs or combat engineers to support route-clearance applications, as well as site reconnaissance and explosive ordnance disposal (EOD) missions - ultimately to save the lives of soldiers and civilians.

In this paper, results from a LightGuard sensor, which include detection of various materials in bulk form, as well as residue amounts on vehicles, people and other surfaces, will be discussed.

8710-29, Session 6

Investigation of short cavity CRDS noise terms by optical correlation

Steven T. Griffin, Jason Fathi, Univ. of Memphis (United States)

Cavity Ring Down Spectroscopy (CRDS) has been identified as having significant potential for Department of Defense security and sensing applications. Significant factors in the development of new sensor architectures are portability, robustness and economy. A significant factor in new CRDS sensor architectures is cavity length. Prior publication has examined the role of cavity length in sensing modality both from the standpoint of the system's design and the identification of potential difficulties presented by novel approaches. Two of interest here are new noise terms that have been designated turbulence-like and speckle-like in prior publication. In the prior publication the theoretical and some empirical data was presented. This presentation addresses the automation of the experimental apparatus, new data analysis, and implications regarding the significance of the two noise terms. This is accomplished through an Analog-to-Digital Conversion (ADC) from the output of a custom designed optical correlator. Details of the unique application of the developed instrument and implications for short cavity (portable) CRDS applications are presented.

8710-30, Session 6

Next-generation hazard detection via ultrafast coherent anti-Stokes Raman spectroscopy

John J. Brady, Paul M. Pellegrino, U.S. Army Research Lab. (United States)

The diversity of possible signature molecules and their inherent low vapor pressures make the detection of hazardous materials (e.g. biological, chemical or explosive) in an asymmetric threat scenario a great challenge. As a result, there still exists a need to detect such materials on surfaces and in the aerosolized state at a variety of ranges dependent on the concept of operation. It has long been believed that spectroscopic methods are the most likely candidates to fill this critical gap for soldier protection. Studies utilizing the multiplex coherent anti-Stokes Raman scattering (CARS) technique suggests that the broadband nature of the femtosecond laser pulse could enable discrimination of threat signatures in complex backgrounds. The spectral bandwidth of the femtosecond laser pulse used in these studies is board enough to coherently and simultaneously excite all the vibrational modes in the molecule of interest. The research performed here demonstrates that CARS has the capability to detect hazardous materials such as dimethyl methyl phosphonate and 2-chloroethyl ethylsulfide (a Sarin and a Mustard chemical warfare stimulant, respectively) with high specificity. Further, evidence shows that CARS is capable of overcoming common sensitivity limitations of spontaneous Raman thus allowing for the detection of material in milliseconds with standard USB spectrometers, as opposed to seconds with intensified spectrometers. The exponential increase in scattered photons suggests that the CARS technique may be capable of overcoming range detection issues found with spontaneous Raman.

8710-31, Session 6

Rejection of fluorescence from Raman spectra of explosives by picosecond optical Kerr gating

Ida Johansson, Markus Nordberg, Henric Östmark, Swedish Defence Research Agency (Sweden)

This paper describes how optical Kerr gating can be used for effective rejection of fluorescence from Raman spectra of explosives and explosives precursors. Several explosives are highly fluorescent, and this method enables Raman detection of explosives materials that would else complicate or inhibit identification. Where electronic cameras (intensified charge-coupled devices, ICCDs) have showed not yet to be sufficiently fast to be used for rejection of this fluorescence, Kerr gating is here proved to be an efficient alternative, demonstrated by measurements on plastic explosives. Results are obtained using a gating time of ~30 ps. The Kerr gate is driven by the fundamental mode of an Nd:YAG laser, at 1064 nm, with pulses of ~10 mJ, 50 Hz and 30 ps. CS2 is used as a Kerr medium and Glan polarizing prisms are important features of the system. Raman spectra are obtained using a 532 nm probe wavelength, from the same Nd:YAG laser being frequency doubled, with ~10 mJ pulse energy.

8710-32, Session 6

Spatiotemporal evolution of plasma molecular emission following laser ablation of explosive analogs

Jonathan A. Merten, Arkansas State Univ. (United States); Christian G. Parigger, The Univ. of Tennessee Space Institute (United States); Cheyenne J. Sheppard, Matthew P. Jones, Arkansas State Univ. (United States); Susan D. Allen, Embry-Riddle Aeronautical Univ. (United States)

LIBS has been investigated extensively for the detection of explosives, normally by the measurement of N, O and C lines and their ratios. There have been fewer studies on the potential of molecular fragments (e.g. CN, C2, NO) for explosive identification. Even less information is available regarding the temporal evolution of these molecules' emission within the plasma. We have investigated the early (first microsecond) evolution of the CN and C2 spectra from LIBS plasmas formed on 3-nitrobenzoic acid, a simulant for energetic nitro compounds. This compound was chosen because it is available in pure, solid form and contains a nitro-substituted benzene ring. It should be noted that molecular LIBS is interesting for other applications such as detection of biological samples, isotopic analysis, etc.

Images were taken of the inhomogeneous LIBS plasma using bandpass filters at emission maxima for C2 (462-472 nm), CN (379-389 nm) and continuum (400-410 nm) at various times starting 50 ns after the 355 nm ablation pulse at several laser energies. The images are complemented with time-resolved spectra. The spatially integrated C2 data shows a continuous exponential decay from the earliest time measured. The CN emission, on the other hand, increased slightly up to a laser energy-dependent maximum, with an exponential decrease thereafter.

The temperature of the molecular species at early times has been estimated from vibrational fits using BESP software and compared to the excitation temperature of metals doped into the sample.

8710-33, Session 7

Real-world particulate explosives test coupons for optical detection applications

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Trace or residue explosives detection typically involves monitoring explosives present as solid particulates on a solid substrate. Different optical spectroscopy techniques have been developed to detect these explosives by probing how light interacts with the explosives particles in-situ. Depending on the specific optical detection technique, the particle size, how the particle contacts the surface, solvent inclusion in the crystals formed and variables which are specific for material deposited by solution-based techniques, can all influence the spectra. This generally places an increased level of importance on how test coupons are fabricated and highlights the need to fabricate explosives particulate test coupons which best mimic "real world" particulate coated surfaces.

Sieving dry materials avoids many of the complications produced by

solvent-based techniques and more closely exhibit “real world” like particle properties relevant for trace detection, e.g., those generated by fingerprint transfer. We have investigated how sieved material compares with more common solvent-based techniques such as ink-jetting, aerosol sprays and spin coating with ammonium nitrate, TNT, RDX, and sucrose. The solution-based techniques tended to produce particles with uneven particle sizes and spatial distributions, and often result in crystals with solvent inclusions, and importantly, yield crystals which intimately contact the substrate. This can influence the performance of optical detection techniques and is not representative of trace explosives for forensic applications. In contrast we have found the simple application of sieving can produce particulate explosives-coated test coupons with relevant size distributions and more realistic contact with surfaces. Additionally we describe our efforts to quantify the samples using profilometery and image processing.

8710-35, Session 7

Optimized aerodynamic sampling of shoes to support trace explosives detection

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The ongoing development and characterization of an aerodynamic shoe sampling system is presented. Shoe screening technology is of particular interest given the inconvenience of removing shoes at aviation checkpoints. This system emphasizes a non-contact approach to trace explosives sampling that exploits fluid mechanics for micro-particle release and transport. The prototype shoe sampler uses a series of high-pressure air jets and air blades to dislodge particulate contamination from the surfaces of shoes. A large blower establishes a bulk flow field within the system domain that guarantees all liberated particles are transported to a collection device, rather than being blown away from the particle collector. In this talk, we will present a series of flow visualization tools and metrology techniques used to help with design optimization and evaluation of our prototype system. These include schlieren imaging, laser light-sheet flow visualization, and high-speed video microscopy. Lessons learned during the ongoing development of this system will be used to develop future shoe screeners that are based on trace detection.

8710-36, Session 7

Infrared (1-10 um) atomic and molecular emission signatures from energetic materials using laser induced breakdown spectroscopy

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Laser-induced breakdown spectroscopy (LIBS) has shown great promise for applications in chemical, biological, and explosives (CBE) sensing and has significant potential for real time standoff detection and analysis. In this work conventional LIBS covering the UV-VIS-NIR region was extended to the IR spectral region from 1 - 12 um. A Q-switched Nd: YAG laser operating at 1064nm was employed as the excitation source and was focused onto several chlorate and nitrate compounds (e.g. $KClO_3$, $NaClO_3$, KNO_3, $NaNO_3$) to produce intense plasma at the target surface. Comparative IR LIBS studies on KCl and NaCl were also performed. The IR LIBS emissions within the hot plasma were focused onto the entrance slit of a 0.15m grating spectrometer and detected by a liquid nitrogen cooled Mercury Cadmium Telluride (MCT) detector. A gated detection scheme employing a boxcar averager was used to separate the continuum radiation in the plasma plume from the atomic and molecular IR LIBS signals. Narrow-band atomic emission lines were observed from all the compounds and assigned to transitions of neutral potassium and sodium atoms as published in the NIST atomic database [1, 3]. In addition, first evidence of broad-band molecular LIBS emission signatures was observed for chlorate and nitrate compounds at ~10μm and at ~7.2 μm respectively. The observed molecular emission bands show strong correlation with FTIR absorption spectra of the investigated materials.

8710-37, Session 8

Feasibility studies on explosive detection and homeland security applications using a combined neutron and x-ray computed tomography system

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The successful creation and operation of a neutron and X-ray combined computed tomography (NXCT) system has been demonstrated by researchers at the Missouri University of Science and Technology. The NXCT system has numerous applications in the field of material characterization and object identification in materials with a mixture of atomic numbers represented. Presently, the feasibility studies have been performed for explosive detection and homeland security applications, particularly in concealed material detection and the determination of light atomic materials. These materials cannot be detected using traditional X-ray imaging. The new system has the capability to provide complete structural and compositional information due to the complimentary nature of X-ray and neutron interactions with materials. The design of the NXCT system facilitates simultaneous and instantaneous imaging operation, promising enhanced detection capabilities of explosive materials, concealed weapons and similar materials for homeland security applications. In addition, a feasible design of a sample positioning system which allows the user to remotely and automatically manipulate the sample make system viable for commercial applications has been developed. In the present research, several explosives (TNT, Dynamite, Nitrocellulose, Lead Azide, Semtex etc.) and weapon (Bullet, Screw Drivers, Plastic Guns) simulants have been imaged and the results will be provided. The fusion algorithms which combine the data from the neutron and X-ray imaging provide a superior image for detection. Furthermore, the possibility of neutron activation in target materials will be described. This paper will be a complete overview of the NXCT system for feasibilities studies on explosive detection and homeland security applications. The design of the system, operation, algorithm development, and detection schemes will be narrated in detail.

8710-38, Session 8

A review of sensor data fusion for explosives and weapons detection

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The combination or fusion of data from multiple complementary sensors can potentially improve system performance in many explosives and weapons detection applications. The motivations for fusion can include improved probability of detection; reduced false alarms; detection of an increased range of threats; higher throughput and better resilience to adversary countermeasures. This paper presents the conclusions of a study which surveyed a wide range of data fusion techniques and examples of the research, development and practical use of fusion in explosives detection. Different applications types such as aviation checkpoint, checked baggage and stand-off detection are compared and contrasted, and the degree to which sensors can be regarded as ‘orthogonal’ is explored. Whilst data fusion is frequently cited as an opportunity, there are fewer examples of its operational deployment. Blockers to the wider use of data fusion include the difficulty of predicting the performance gains that are likely to be achieved in practice, as well as a number of cost, commercial, integration, test and evaluation issues

surrounding multiple sensor 'systems-of-systems'. The paper suggests some tentative ways forward and makes a number of recommendations for future research work.

8710-39, Session 8

A simulation study of detection of weapon of mass destruction based on radar

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Typical systems used for detection of Weapon of Mass Destruction (WMD) are based on sensing objects using gamma rays or neutrons. Nonetheless, depending on environmental conditions, current methods for detecting fissile materials have limited distance of effectiveness. Moreover, radiation related to gamma- rays can be easily shielded.

Here, detecting concealed WMD from a distance is simulated and studied based on radar, especially WideBand (WB) technology. The WB-based method capitalizes on the fact that electromagnetic waves penetrate through different materials at different rates. While low-frequency waves can pass through objects more easily, high-frequency waves have a higher rate of absorption by objects, making the object recognition easier.

During simulation, radar waves and propagation area including free space, shielding materials, and WMD are modeled. In fact, an object is modeled as different layers with different thicknesses. As an example, the materials under test can be air, wood, steel, beryllium, plutonium. Therefore, four layers except plutonium are defined. For each layer, field parameters, attenuation, transmission and reflection coefficients are considered.

At start of simulation, a modeled radar wave is radiated toward the layers. The average power density of the transmitted and reflected waves are calculated for each layer. Moreover, reflection loss and absorption loss are calculated for each layer. At the receiver side, based on the received signal from each layer and the time of reception, each layer can be identified. When an electromagnetic wave passes through an object, the wave's power will be subject to a certain level of attenuation depending of the object's characteristics. For instance, the total loss, combination of absorption and reflection losses, for 0.03mil Iron at frequencies 30MHz, 300MHz, 3GHz are calculated as 62dB, 64dB, 108dB, respectively. Matlab simulation is performed using radar signals with different frequencies and powers (frequency ranges KHz to GHz) to identify different layers.

8710-40, Session 8

Dual-excitation-wavelength resonance-Raman explosives detector

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Deep-ultraviolet resonance Raman spectroscopy (DUVRRS) is a promising approach to stand-off detection of explosive traces due to: 1) resonant enhancement of Raman cross-section, 2) λ-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 are developing a stand-off explosive sensor using DUVRRS with two simultaneous 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 an orthogonal signature that complements the traditional Raman signature to improve specificity relative to single-excitation-wavelength techniques. As part of this effort, we are developing two novel CW DUV lasers, which have potential to be compact, and a compact dual-band high throughput DUV spectrometer, capable of simultaneous detection of Raman spectra in two spectral windows. We have also developed a highly sensitive algorithm for the detection of explosives under low signal-to-noise situations.

8710-41, Session 8

Explosives detection using quantum cascade laser spectroscopy

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Infrared spectroscopy based explosives detection systems using quantum cascade lasers (QCL) and thermal (Globar) sources were used to record mid infrared spectral signals of highly energetic materials (HEM) on travel baggage and cardboard. Different deposition methods such as sample smearing, spin coating, spray deposition and partial immersion were evaluated for preparing samples and standards. Chemometrics statistical routines such as principal component analysis regression (PCA) with pre-treatments were applied to the recorded infrared spectra. The results show that the infrared vibrational techniques investigated are useful for detection of explosives in the types of substrates studied.

8710-42, Session 8

Explosive vapor detection payload for small robots

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Detection of explosive hazards is a critical component of enabling and improving operational mobility and protection of US Forces. The Autonomous Mine Detection System (AMDS) developed by the US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) is addressing this challenge for dismounted soldiers. Under the AMDS program, ARA has developed a vapor sampling system that enhances the detection of explosive residues using commercial-off-the-shelf sensors. The "sniffer" payload is designed for plug-and-play installation and autonomous operation on small robotic platforms, addressing critical Army needs for more safely detecting concealed or exposed explosives in areas such as culverts, walls and vehicles. This presentation will describe the development, integration and testing of the explosive vapor sampling system, which consists of a sampling "head," vapor transport tube and extendable boom. The sampling head and transport tube are integrated with the extendable boom, which allows samples to be collected from targeted surfaces up to 7-ft away from the robotic platform. During sample collection, an IR lamp in the sampling head is used to heat a suspected object/surface and the vapors are drawn through the heated vapor transport tube to an ion mobility spectrometer for detection. The sampling system is capable of quickly (less than 60 seconds) detecting common explosives (e.g., TNT, PETN, and RDX) at nanogram levels on common surfaces (brick, concrete, wood, glass, etc.).

8710-43, Session 8

Investigation of molecular and elemental species dynamics in NTO, TNT, and ANTA using femtosecond LIBS

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In this paper we present the results from our recent efforts to study the elemental and molecular species dynamics in high energy materials (HEMs) using the technique of laser induced breakdown spectroscopy (LIBS) with ultrashort laser pulses [1-5]. Spectral emission behavior of atomic and molecular species of HEMs such as NTO, TNT and ANTA were studied in different atmospheres of Argon, Nitrogen, and ambient air. We used a femtosecond (fs) laser with pulse width of ~40 fs, 2.5 mJ energy delivering 1 KHz repetition rate pulses for creating the breakdown. CN and C2 molecular species were formed when these organic molecules during the breakdown. These molecular species are key signatures of organics substances for identification of organic HEMs. The formation of these species will be either from the ejection of molecular radicals owing to direct vaporization of sample or due to the recombination reaction occurring between the constituent atomic species present in the plasma. The surrounding atmosphere, therefore, has a significant impact in the formation of these molecular radicals. Especially in the case of CN molecular fragments, the probability of CN formation is more when atmospheric nitrogen interacts with C and C2. A precise kinetic study of molecular band intensities evolving in time allows us to differentiate the contribution of native CN bonds released by the sample from those formed due to Carbon recombination with atmospheric Nitrogen. The present work attempted to understand the sources of formation of these molecular fragments from different HEMs under diverse surrounding atmospheres. The decay rates of various atomic lines have also been examined.

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8710-44, Session 9

Models to support active sensing of biological aerosol clouds

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Elastic backscatter lidar is a promising approach for stand-off detection of biological aerosol clouds. Comprehensive models that explain the scattering behavior from the aerosol cloud are needed to understand and predict the scattering signatures of biological aerosols under varying atmospheric conditions and against different aerosol backgrounds. Elastic signatures are dependent on many parameters of the aerosol cloud, with two major components being the size distribution and refractive index of the aerosols. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has been in a unique position to measure the size distributions of released biological simulant clouds using a wide assortment of aerosol characterization systems that are available on the commercial market. In conjunction with the size distribution measurements, JHU/APL has also been making a dedicated effort to properly measure the refractive indices of the released materials using a thin-film absorption technique and laboratory characterization of the released materials. Intimate knowledge of the size distributions and refractive indices of the biological aerosols provides JHU/APL with powerful tools to build elastic scattering models, with the purpose of understanding, and ultimately, predicting the active signatures of biological clouds.

8710-45, Session 9

System to study the effects of atmospheric environmental conditions on bioaerosol viability and fluorescence spectra

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A system to measure the effects of atmospheric environmental conditions, such as gases, sunlight, and humidity on the UV-laser-induced fluorescence spectra and viability of bioaerosols was designed, built and tested. The overall system will be referred to as the System for Atmospheric Effects on Bioaerosols (SAEB). The SAEB system includes two rotating drums, each with a volume of approximately 1.5 m3. The drums are made from UV transparent Teflon, and rotate at 1 rpm to help keep particles aloft for long-term aging. The two drums are on a platform that rotates during the day tracking the sun for maximizing exposure to sunlight without shading. The ends of the inner volume of each drum (i.e., the drum heads) is a membrane of porous expanded tetrafluoroethylene (ePTFE) which prevents any particles larger than about 20 nm from entering or leaving the drum, but allows gases to pass into and out of the drums. In one operation mode, both drums are injected with the same bioaerosol simultaneously, while one of the drums is allowed to equilibrate with atmospheric gases, and the other drum equilibrates with highly cleaned atmospheric air (with humidity adjusted back to atmospheric level) in which volatile organics, ozone, NOx, and other trace gases have been removed. Several newly developed and commercial instruments are used to monitor the aerosol properties sampled from the drums including: 1) a UV-LIF spectrometer for measuring single particle fluorescence spectra excited by a 263-nm or a 351-nm laser; 2) a TSI UVAPS for particle size, concentration and total fluorescence by 355 nm excitation; 3) two DMAs for monitoring the growth of small particles injected into the chamber (for indication of secondary organic aerosol formation); 3) Solar pyrometer, ozone, humidity, and temperature sensors for continuously recording atmospheric environmental conditions; and 4) bioaerosol viability measurement, where aerosol particles, at different times, are collected into water by all-glass impingers (AGI) and analyzed for colony forming units (in the case of bacteria) or plaque-forming-units (in the case of virus), as well as for total bacteria (live+dead) or virus (infectious+noninfectious) using q-PCR. The measurements period for this study was from September 27th through October 19th, 2012 at Adelphi, MD, USA.

Fluorescence spectra from single bioaerosol particles were observed to vary at different time affected by various atmospheric environmental conditions. The preliminary results obtained with this SAEB system during the Sept-Oct field measurements will be analyzed and presented in the conference.

Acknowledgements

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8710-46, Session 9

The multiwavelength aerosol signature testbed for BSL3 (MAST-3)

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Biological attack remains a clear and present threat to our military and homeland. Detection of bio-aerosol threats by optical means has the advantages of being rapid and low maintenance, require no reagents. Such methods rely on the optical properties of the bio-aerosols themselves, which depend primarily on the class (spore, virus, toxin, etc.) and comingled materials (residual growth media, etc.) present. In the case of wet-generated aerosols, the environmental conditions (e.g., relative humidity) are also important. This work will describe an apparatus for measuring the optical properties of benign and malignant bio-aerosols under a wide range of growth and environmental conditions called the Multi-wavelength Aerosol Signature Testbed (MAST). A demonstration version of MAST has been fielded at the Edgewood Chemical and Biological Center (ECBC), where it is located in a secure biosafety level 3 laboratory. This version of the MAST includes 355nm and 1550nm polarimetric scatter and 355nm spectroscopic fluorescence channels, all fiber-coupled. The apparatus fully contains the aerosol challenges and can be decontaminated in-place for periodic maintenance. In this presentation, we will describe the aerosol generation and optical systems and present results from our measurements program.

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8710-47, Session 9

Spectroscopic detection of microorganisms

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This work was motivated by the need of rapid analysis of potential biological threats. Development of capabilities for the detection, identification and discrimination of biological agents using adequate simulants is at the very top of defense and security agencies. That involves the study of commonly known bacteria, using vibrational spectroscopic techniques such as FT-IR, Raman, and surface enhanced Raman scattering (SERS) spectroscopy. Various substrates were used in order to test and compare the results obtained. These included the preparation of various SERS active substrates, including polymer/metal thin films spin coated on 1 cm x 1 cm pieces of glass and onto IR windows materials barium fluoride and zinc selenide. Bacterial suspensions were deposited on these substrates, allowed to dry in air and analyzed. The systems used to determine to detect microorganisms were Thermo-Ahura TruDefender™ which is based on a 785 nm laser, Thermo-Ahura FirstDefender™ (ATR FT-IR) and Block Engineering LaserScanner™ (a quantum cascade mid-infrared laser). All substrates were used for analysis of three types of bacteria: Escherichia coli, Staphylococcus epidermis and Bacillus thuringiensis. The spectra suggest that FT-IR spectroscopy can determine whether these microorganisms are present, in addition to confirming that they can be discriminated based on spectral differences of the bacterial membrane that can be detected in the spectral windows of the various instruments evaluated.

8710-48, Session 9

Understanding water uptake in bioaerosols using laboratory measurements, field tests, and modeling

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Uptake of water by bioaerosols can impact their physical and chemical characteristics. The water content in a bioaerosol particle can affect the backscatter cross-section as measured by LIDAR systems. Better understanding of the water content in controlled-release clouds of biosimulants can aid in the development of improved standoff detection systems. This study includes three components to further understanding of how bioaerosols take up water. The laboratory component measures hygroscopic growth of biosimulant material after it is aerosolized and dried. The humidity is increased in small steps to observe the efflourescence point, then the humidity is decreased to observe the deliquescence point. Full hygrocopicity curves are created. The field component of the study measures particle size distributions of biosimulant material disseminated into a large, humidified chamber. Measurements are made with a Twin-Aerodynamic Particle Sizer(APS, TSI, Inc), -Relative Humidity apparatus. Two APSs, operated side-by-side, were chosen for this study. The first operated under dry conditions by sampling downstream of dessicant dryers, the second operated under ambient conditions. The relative humidity was measured within the sampling systems to determine the difference in the aerosol water content between the two sampling trains. The water content of the bioaerosols was calculated from the twin APS units following Khlystov et al. 2005. Simulant material is measured dried and wet and compared to laboratory curves of the same material. Lastly, theoretical curves are constructed from literature values for components of the biosimulant material.

8710-49, Session 9

Wavelength resolved polarized elastic scatter measurements from micron-sized single particles

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The goal of this project is to investigate the polarimetric scattering signatures of aerosol particles and correlate these signature patterns to the structure and composition of the particles, providing a basis for discrimination between man-made and natural occurring aerosol particles. If we are successful, this could potentially lead to a parallel technique in BW detection for non-fluorescent threat agents. We have developed an experimental arrangement to measure multi-angle, multi-wavelength polarized scatter from single aerosol particles on-the-fly. Our novel technique is a radical departure from conventional polarimetric approaches, a key element being the use of a multiple-order retarder that creates different light source polarization states depending on the wavelength of the incident light. We will describe in detail our experimental approach based on a super-continuum light source, an array of optical fibers, an imaging spectrometer and EMCCD camera to simultaneously acquire a two-dimensional snapshot of scattering data.

Initially Mueller matrix measurements have been made from individual particles held in an optical trap (at 405 nm). Since particles can be stably trapped for long periods (hours), we were able to change the optical configuration to acquire multiple Muller matrix element measurements on a single particle. We have done initial modeling for these measurements at specific angles and the comparison with experimental measurements shows good agreement. Similar measurements have been made on slowly drifting particles, and our current concentration is on improving experimental parameters that will allow us to transition towards making such measurements on slowly flowing particles.

8710-50, Session 10

Micro-organisms detection on different substrates using quantum cascade laser spectroscopy

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Infrared spectroscopy based detection systems using quantum cascade lasers sources were used to record mid infrared spectral signals of bacteria: Escherichia coli, Staphylococcus epidermis and Bacillus thuringiensis on different substrates such as glass, card board, travel baggage, tags, aluminum and stainless steel. The experiments were carried out in both modes reflection and transmittance. Chemometrics statistical routines such as principal component analysis (PCA) regression and partial least squares-discriminant analysis (PLS-DA) hyphenated chemometrics techniques were applied to the recorded infrared spectra. The results show that the infrared vibrational techniques investigated are useful for classification/detection theses microorganisms in the types of substrates studied.

8710-51, Session 10

Metaproteomics analyses as diagnostic tool for differentiation of Escherichia coli strains in outbreaks

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The recent fatal outbreak of food borne illness in Europe caused by the enterohemorrhagic strain of Escherichia coli (EHEC) dictates the improvement and development of effective rapid detection and reliable strain-identification techniques to ensure timely and efficient medical countermeasures. The secreted proteins of the enterohemorrhagic E. coli (EHEC) strains are the most common cause of hemorrhagic colitis, which can lead to life threatening hemolytic-uremic syndrome (HUS). We are reporting a metaproteomics approach as an effective diagnostic tool and complimentary technique to the genomic-based approaches. This metaproteomics approach will evaluate the secreted proteins utilize their signatures as biomarkers for the differentiation of EHEC strains.

The extracted EHEC and EPEC secretome proteins were reduced and then digested by trypsin. The tryptic peptides were separated on a reverse phase LC column and electrosprayed into an LTQ-XL-ETD (ThermoFisher) instrument. The mass spectrometry (MS) analytical cycle consisted of a broad m/z range survey scan which was always followed by five MS/MS scans of the most intense peaks.

The results identified several peptides that correlate with virulence factor proteins. The distribution of strain-unique peptides was affected by the type of biological matrix the bacterial strains were grown in. The EHEC O157:H7 had less number of secretome proteins than that of the EHEC H104:O4 . Taxonomic classification showed strain-differentiation between the studied E. coli strains which are the common ones found in outbreaks. Overall, the preliminary data showed that metaproteomics analyses can provide complimentary and effective diagnostic tool to those of genomic based ones.

8710-52, Session 10

Advances in synthetic peptides reagent discovery

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Bacterial display technology offers a number of advantages over competing display technologies (e.g, phage) for the rapid discovery and development of peptides with interaction targeted to materials ranging from biological hazards through inorganic metals. We have previously shown that bacterial display technology is relatively simple and rapid to perform making laboratory automation possible. This included extensive study of the protective antigen system of Bacillus anthracis, including development of discovery, characterization, and computational biology capabilities for in-silico optimization. Although the benefits towards CBD goals are evident, the impact is far-reaching due to our ability to understand and harness peptide interactions that are ultimately extendable to the hybrid biomaterials of the future. In this paper, we describe advances in peptide discovery including, new target systems including non-biological materials, advanced library development and clone analysis including integrated reporting.

8710-54, Session 11

The MODES_SNM project

Alessandro Curioni, ETH Zurich (Switzerland)

MODES_SNM is a collaborative project (funded under the FP7 - Security program), aimed at developing a prototype for a mobile, modular detection system for radioactive and Special Nuclear Materials (SNM). To maximize the detection capability for SNM, the prototype will combine detectors for fast and thermal neutrons, as well as for gamma-rays. The key detector technology in the development is high pressure scintillation cells filled with noble gases, as recently developed by ARKTIS. The project started officially at the beginning of 2012, for a duration of 30 months. The goal of the project is to deliver a fully integrated and field tested prototype of a modular mobile system capable of passively detecting weak or shielded radioactive sources with accuracy higher than currently available systems. We will present the status of the project, preliminary results and future prospects.

8710-55, Session 11

Combined, solid-state molecular property and gamma spectrometers for CBRNE detection

Ben S. Rogers, Nevada Nanotech Systems, Inc. (United States); Jay W. Grate, Pacific Northwest National Lab. (United States); Brett Pearson, Nevada Nanotech Systems, Inc. (United States); Neal B. Gallagher, Barry M. Wise, Eigenvector Research, Inc. (United States); Ralph Whitten, Jesse D. Adams, Nevada Nanotech Systems, Inc. (United States)

Nevada Nanotech Systems, Inc. is developing a multi-sensor CBRN&E solution utilizing Molecular Property Spectrometer™ technology—a micro-electro-mechanical chip-based technology capable of measuring a variety of thermodynamic and electrostatic molecular properties of sampled vapors and particles—and a compact, high-resolution, solid-state gamma spectrometer module for identifying radioactive materials, including isotopes used in dirty bombs and nuclear weapons.

By carrying out a variety of measurement processes, the system can provide a more complete characterization of an unknown sample, leading to a more accurate identification. Positive identifications of threats are

communicated using an integrated wireless module. Currently, system development is focused on detection of commercial, military and improvised explosives, radioactive materials, and chemical threats.

The system can be configured for a variety of CBRN&E scenarios, including handheld wands and swab-type threat detection scenarios requiring short sample times, and scenarios in which longer sampling times are used. Here we provide an overview of the system design and operation and present results from preliminary testing.

8710-56, Session 11

Design and performance of the radiation observations with communications (ROC) sensor

Dimosthenis C. Katsis, Athena Energy Corp. (United States); David A. Burns, Marc S. Litz, John A. Russo, James J. Carroll, U.S. Army Research Lab. (United States)

A network of compact, low cost gamma radiation sensors composed of bismuth germinate (BGO) scintillators and avalanche photodiodes (APD) has been developed to detect radiation levels in the energy range 400 keV to 2 MeV. These sensors can detect a 20 µCi source of 137Cs from a distance of three meters. Sensitivity increased 30% by modification of the rectangular scintillator shape. Our philosophy however is that several individual sensors meshed in a data network is the most effective way to increase detection area. We present the design and development of the low-power wireless link and associated software to process and present the data from a large network of independent GPS-enabled sensors. The most recent design supports spectroscopic mode in addition to the original Geiger mode. Design challenges included developing a way to measure data while accounting for the temperature sensitivity of the avalanche photodiode gain. We used our characterization of detector sensitivity to support real-time adjustments allowing accurate operation through a one-hour warm-up period.

8710-57, Session 11

Study and understanding of n/? discrimination processes in organic plastic scintillators

Matthieu Hamel, Pauline Blanc, Licinio Rocha, Stéphane Normand, Commissariat à l'Énergie Atomique (France); Robert B. Pansu, Ecole Normale Supérieure de Cachan (France)

This paper lies in the context of nuclear detection through fast neutron for nondestructive assay (NDA) applications to characterize radioactive materials. This study specifically evaluates organic plastic scintillators abilities to discriminate gamma from neutrons in comparison with other organic media. It also explores different approaches that would explain photophysical processes brought into play after nuclear interactions.

Liquid and crystal scintillators discriminate efficiently gamma unlike plastics. Neutron/gamma discrimination proceeds by luminescent components separation after ionization leading to either singlet (S) or triplet (T) excited states. γ and n are respectively responsible for populating S and T and from those to generate prompt and delayed luminescence.

After γ-interactions electrons produced originate the prompt component emitted from S1 -> S0 direct de-excitation whereas protons recoil after n-interactions lead to T-T annihilations processes (TTA) consisting in T1 + T1 -> S0 + S1 followed by a S1 -> S0 delayed de-excitation. Higher the TTA rate is better the separation.

During 50 years, it was assumed that plastic scintillators were not able to discriminate neutrons from gamma. In this work, we will demonstrate that such TTA can occur even in plastic scintillators, following certain conditions. Thus, the presentation will deal with the chemical preparation, the characterization and the comparison of n/γ pulse shape discrimination of various plastic scintillators.

8710-58, Session 11

Probing the gamma-scintillation process in semiconductor nanomaterials using ultrafast transient cathodoluminescence

Jeffrey M. Pietryga, Lazaro A. Padilha, Wan Ki Bae, Victor I. Klimov, Los Alamos National Lab. (United States); Richard D. Schaller, Argonne National Lab. (United States) and Northwestern Univ. (United States)

Energy-resolving gamma-ray detectors are of particular interest for the detection of illicit radioactive materials at border crossings and other portals because they offer fast, contactless screening that can discriminate between dangerous and benign materials. Among detector classes, scintillators offer an intriguing balance between cost and performance, but current technologies rely on single-crystal materials that are not scalable to portal-relevant detector sizes. Thus, there is a recognized need for novel, processible, high-performance scintillating materials or composites. Composites based on semiconductor nanocrystal quantum dots (NQDs) are of interest because of their potentially high gamma-stopping power, high emission quantum yields, and low-cost solution synthesis and processing. Yet the performance of these and other granular nanomaterials has not met expectations. We suggest that this is due to the general lack of insight into the gamma-to-photons transduction process within these inherently more complex materials, which reduces the development and refinement of candidates to simple trial-and-error. Here, we describe the development of ultrafast transient cathodoluminescence as a unique spectroscopic tool for probing the population of excited states formed within a material during scintillation, and thus determining the major sources of energy loss. Our analysis shows that in the case of CdSe/ZnS core/shell NQDs, any efficiency loss due to previously blamed factors of low-stopping power and high reabsorptive losses are likely dwarfed by the losses attributable to efficient, non-radiative Auger recombination. We examine how we reached this conclusion, and how this insight defines the characteristics needed in the next generation of scintillating NQD composites.

8710-59, Session 12

Understanding the polymorphic nature of UO3 to infer process history

Lucas E. Sweet, Thomas A. Blake, James E. Szecsody, David E. Meier, Jon M. Schwantes, Timothy J. Johnson, Pacific Northwest National Lab. (United States)

Uranium trioxide is produced in the chemical conversion steps of the refinement of uranium-containing ores and it is also generated as an output from the reprocessing of spent nuclear fuel. This work focuses on how the different conditions used in the production of UO3 influence the distribution of polymorphic forms in the UO3 product. By using X-ray diffraction, along with infrared, UV/Vis, and Raman spectroscopies we have correlated spectroscopic signatures of the UO3 product to production conditions. One of the more complex production pathways studied was the conversion of (NH4)4UO2(CO3)3 to UO3. These studies have revealed that this conversion results in three different phases of UO3: amorphous-UO3, α-UO3 and β-UO3. The distribution of phases in this conversion process is dictated by the heating conditions used. Understanding the polymorphic nature of UO3 and developing spectroscopic signatures for industrially relevant production pathways can be a powerful tool for establishing and confirming the origin of this component in the uranium fuel cycle.

8710-60, Session 12

Large-area high-efficiency self-powered solid state neutron detector

Rajendra Dahal, Kuan-Chih Huang, James J. Q. Lu, Yaron Danon, Ishwara Bhat, Rensselaer Polytechnic Institute (United States)

The development of high efficiency large area solid state neutron detectors is urgent for a wide range of civilian and defense applications. The applications of present neutron detector system are limited by the cost, size, weight, power requirements, and performance of the system. The self-powered or very low power consuming highly efficient solid state neutron detector using highly matured silicon technology would provide significant benefits in terms of cost and volume, as well as allow for wafer level integration with charge preamplifier and readout electronics. In this paper, we will present our research advances on the fabrication, and characterization of large area solid state thermal neutron detector module with thermal neutron detection efficiency exceeding 30%. The detector utilizes three dimensional honeycomb silicon micro-structures with continuous p+-n junction diode filled with enriched boron (99% of 10B) as a converter material for thermal neutron detection. The very low leakage current density of the fabricated device helps to increase the detector surface area greater than 8 cm2. Further, these detector modules operate under no external bias, showing the promise of achieving highly efficient large area solid state thermal neutron detectors with low gamma sensitivity at low cost using matured silicon processing technology for future applications.

8710-61, Session 12

Continuous p-n junction with extremely low leakage current for micro-structured solid-state neutron detector applications

Kuan-Chih Huang, Rajendra Dahal, James J. Q. Lu, Yaron Danon, Ishwara Bhat, Rensselaer Polytechnic Institute (United States)

As neutrons are a very specific indicator of fissile materials, efficient solid-state neutron detectors with large detecting surface area and low gamma sensitivity are urgently needed for border security and illicit nuclear material detection.

Detectors made in silicon enable the fabrication of low-cost and large-area detectors. To detect neutrons, boron was deposited into a silicon 3-D structure having high aspect ratio honeycomb holes in such a way that boron is thick enough for neutrons to interact with and at the same time thin enough for alpha and lithium-7 particles to escape sideways. Boron deposition process followed by boron diffusion process using low-pressure chemical vapor deposition was conducted to form a conformal p-n junction on the entire surface of the patterned detector. The formation of continuous p-n junction not only removes the surface states created by the fabrication of honeycomb holes for reducing the leakage current to the level of planar detector but also fully depletes the silicon walls for enabling the operation of neutron detector without any bias. TSUPREM-4 and MEDICI were used to simulate the thickness and surface doping concentration of p+-Si layers and the depletion width within p+-n diodes to optimize the boron diffusion process. With an optimized fabrication process, the leakage current of an enriched boron filled honeycomb type detector is reduced to an order of ~1E-9 A/cm2 and the device noise level is below 100 KeV, allowing the connection of multiple detectors into a large area detector without the loss of detection efficiency. Without the need of bias, the low amount of depleted silicon reduces gamma sensitivity, which still maintains optimal neutron sensitivity.

8710-62, Session 12

Neutron/gamma pulse shape discrimination (PSD) in plastic scintillators with digital PSD electronics

Duane L. Simonson, Anthony L. Hutcheson, Marc Christophersen, Bernard F. Phlips, Nicholas A. Charipar, Alberto Piqué, U.S. Naval Research Lab. (United States)

Pulse shape discrimination (PSD) is a common method to distinguish between pulses produced by gamma rays and neutrons in scintillation detectors. This technique takes advantage of the property of many scintillators that excitations by recoil protons and electrons produce pulses with different characteristic shapes. Unfortunately, many scintillating materials with good PSD properties have other, undesirable properties such as flammability, toxicity, low availability, high cost, and/or limited size. In contrast, plastic scintillator detectors are relatively low-cost, and are easily handled and mass-produced. Recent studies have demonstrated efficient PSD in plastic scintillators using a high concentration of fluorescent dyes. To further investigate the PSD properties of such systems, mixed plastic scintillator samples were produced and tested. The addition of up to 30 wt. % diphenyloxazole (DPO) and other chromophores in polyvinyltoluene (PVT) results in efficient detection with commercial detectors. These plastic scintillators are produced in large diameters up to 4 inches by melt blending directly in a container suitable for in-line detector use. This allows recycling and reuse of materials while varying the compositions. This strategy also avoids additional sample handling and polishing steps required when using removable molds. In this presentation, results will be presented for different mixed-plastic compositions and compared with known scintillating materials.

8710-63, Session 12

An imaging neutron/gamma-ray spectrometer

Amanda Madden, Peter F. Bloser, The Univ. of New Hampshire (United States); Dominique Fourguette, Liane Larocque, Michigan Aerospace Corp. (United States); Jason S. Legere, The Univ. of New Hampshire (United States); Matt Lewis, Michigan Aerospace Corp. (United States); Mark L. McConnell, Marissa Rousseau, James M. Ryan, The Univ. of New Hampshire (United States)

We present the test results of a neutron/gamma-ray imaging spectrometer for the identification and location of radioactive and special nuclear materials. Radioactive materials that could be fashioned into a radiation dispersal device typically emit gamma rays, while fissile materials such as uranium and plutonium emit both neutrons and gamma rays via spontaneous or induced fission. The simultaneous detection of neutrons and gamma rays is a clear indication of the presence of fissile material. The instrument works as a double-scatter telescope, requiring a neutron or gamma ray to undergo an interaction in two detectors to be considered a valid event. While this requirement reduces the detector efficiency, it yields information about the direction and energy of the incident particle which is used to reconstruct an image of the emitting source, thereby greatly improving its sensitivity. The gamma rays interact with the detector via a Compton scatter in an organic scintillator followed by photoelectric absorption in a dense inorganic scintillator. A valid neutron event requires two neutron-proton interactions in each of two organic scintillators. Because of the instrument's ability to form a coherent image of the source, background events can be subtracted, decreasing the number of events required for high confidence detection. The instrument is optimized for the detection of neutrons with energies from 1-20 MeV and gamma rays from 0.4 to 10 MeV. Images and energy spectra for neutron and gamma rays are reported for several sources including enriched and depleted uranium, and plutonium. In addition, the effect of neutron source shielding is investigated. Laboratory results are compared to simulations where possible.

8710-68, Session 12

Progress in the development of CdMnTe nuclear radiation detectors

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CdMnTe is a promising compound semiconductor. Its distinct advantage of excellent compositional homogeneity compared to CdZnTe, which has been the leading room temperature detector candidate for over three decades, enables the growth of large-volume uniform CdMnTe crystals. Inhomogeneity of CdZnTe crystals continues to limit the industrial yields of usable material to 10% or lower, resulting in very high material costs. An international collaboration investigates CdMnTe crystal growth, detector fabrication and detector performance1,2,3,4. Major obstacles towards realizing CdMnTe crystals that are advantageous in nuclear radiation detector applications have been high levels of residual impurities in the manganese source material and high concentrations of tellurium inclusions which are known to act as charge trapping centres. These issues have recently been overcome in the growth of generation II CdMnTe crystals.

Uniform charge-carrier transport is critical to the spectroscopic performance of CdMnTe detectors. Ion beam induced charge (IBIC) measurements, utilising 4He2+ beams from the ANTARES heavy ion accelerator, have revealed the spatial distribution of charge transport in these devices down to micron scale resolution. IBIC measurements on generation II detectors show for the first time uniform large-area charge collection at a value of 100%.

Generation II detectors are currently the world's most advanced CdMnTe radiation detectors and their charge transport properties are approaching commercially available CdZnTe. With the increased demand for compound semiconductor nuclear radiation detectors, higher yield advanced CdMnTe sensors may define the economical way forward.

1R. Rafiei et al., "Investigation of the charge collection efficiency of CdMnTe radiation detectors", IEEE Trans. Nucl. Sci. 59 (2012) 634-641.

2R. Rafiei et al., "Charge Transport Properties of CdMnTe radiation detectors", EPJ Web of Conferences 35 (2012) 02005.

3K. Kim et al., "New approaches for making large-volume and uniform CdZnTe and CdMnTe detectors", IEEE Trans. Nucl. Sci., 59 (2012) 1510.

4R. Rafiei et al., "High-purity CdMnTe radiation detectors: A high-resolution spectroscopic evaluation", IEEE Trans. Nucl. Sci., (2013) DOI 10.1109/TNS.2013.2243167.

8711-1, Session 1

Superhydrophobic materials for homeland security applications *(Keynote Presentation)*

Panos George Datskos, Oak Ridge National Lab. (United States)

No Abstract Available.

8711-2, Session 2

Real-time algorithms for human versus animal classification using a pyroelectric sensor

Jakir Hossen, Eddie L. Jacobs, Srikant Chari, Univ. of Memphis (United States)

Classification of human and animal targets imaged by a linear pyroelectic array senor presents some unique challenges. In this paper, we apply two approaches to address this problem. Both techniques start with the variational energy functional level set segmentation technique to separate the object from background. After segmentation, in the first technique, we extract features like texture, invariant moments, edge, shape information, and spectral contents of the segmented object. These features are fed to classifiers such as Naïve Bayesian (NB), and Support Vector machine (SVM) for human against animal classification. In the second technique, the speeded up robust feature (SURF) extraction algorithm is applied to the segmented objects. A code book technique is used to classify objects based on SURF features. Human and animal data acquired, using the pyroelectric in different terrains, are used for performance evaluation of the algorithms. The evaluation indicates that the features extracted in the first technique in conjunction with the NB classifier provide the highest classification rates. Though, the SURF feature plus code book approach provides a slightly lower classification rate, it provides better computational efficiency lending itself for real time implementation.

8711-3, Session 2

Applying matching pursuit decomposition to UGS footstep classification

Brett W. Larsen, Hugh Chung, Alfonso Dominguez, Jacob Sciacca, Narayan Kovvali, Antonia Papandreou, David R. Allee, Arizona State Univ. (United States)

The challenge of rapid footstep detection and classification in remote locations has long been an important area of study for defense technology and national security. In addition, as military institutions seek to create effective and disposable unattended ground sensors (UGS), power consumption becomes an essential consideration in the development of classification techniques. In response to these issues, an undergraduate research project at ASU's Flexible Display Center has experimented with the application of matching pursuit decomposition time-frequency (TF) analysis to footstep classification. The algorithm iteratively matches components of an input signal to those stored in a TF dictionary, producing a TF representation of the input signal that can be used to obtain distinctive features for classifying specific categories of footsteps, such as those of several people walking and those of an animal. The approximation of the signal in terms of known footstep patterns is then classified using standard Bayesian detection methods. In addition, we considered the fusion of information from multiple sensor modalities for maximizing footstep classification performance.

In order to obtain footstep data, a prototype of a basic, low-cost UGS was created. Using an FPGA and several low-cost sensors, including seismic and acoustic, data was recorded from footsteps in various environments. This data is currently processed in MATLAB, but will be transferred at a later stage to an FPGA and possibly a small microcontroller. This combination of low-power hardware design and advanced signal processing has the potential to result in practical and disposable unattended ground sensors for military use.

8711-4, Session 2

Integrated algorithm for footstep detection in countermeasures conditions and in complicated tactical situations

Alexander A. Pakhomov, General Sensing Systems LLC (United States)

Common walking/running person makes periodic impacts on the earth surface and generate periodic footstep signal. Security&Defense Research, LLC (S&DR) has designed corresponding algorithm for detection and identification of such signals in extremely heavy background noise conditions. Today "bad guys" are very smart, well-educated and trained. They use various countermeasure techniques to reduce our seismic security systems efficiency. One of the ways of the effective countermeasure is using unstable footstep and moving with variable speed. Moving with variable speed also can be a result of walking in a mountain area. Modern S&DR's algorithms have special modification that can detect a person moving that way.

As a result S&DR has created in fact integrated algorithm for detecting both regular and irregular footstep. This paper describes performance characteristics of the integrated algorithm in various conditions. This algorithm allows to create essentially new generation of the seismic security systems that can reliably work in conditions of active countermeasures.

This paper also presents and discusses the abilities of designed integrated footstep detection algorithm in passive IR and active ultrasonic security systems. This ability is based on deep similarity of the pattern of the footstep signals in seismic, IR and ultrasonic systems. Corresponding S&DR's proprietary solutions can be used in various security systems such as wireless and wired systems, perimeter protection and field and road monitoring systems, unattended ground sensors and fixed systems etc. This fact allows to achieve absolutely new and much higher level of security.

8711-5, Session 2

Evaluation of sensor hardware and signal processing algorithms jointly for human/animal discrimination

Ranga Narayanaswami, Scientific Systems Co., Inc. (United States)

The Department of Homeland Security needs a low cost reliable automated system to detect illegal border crossings across the Southern and Northern borders of the United States. Seismic Unattended Ground Sensors (UGS) without cameras are considered low cost, and are also covert, making them a suitable candidate for border patrol. However, current seismic UGS systems use cadence-based intrusion detection algorithms and are easily confused between humans and animals. The

poor discrimination ability between humans and animals results in missed detections as well as higher false alarm rates. False alarms reduce the trustworthiness of the system and also lead to unnecessary actions which may be costly. In order for seismic UGS systems to be deployed successfully, new signal processing algorithms with better discrimination ability between humans and animals are needed.

We have developed novel signal processing algorithms that utilize spectral, wavelet and entropy based features. We have validated our algorithms against real data collected using our data collection nodes that can sample data at high frequency rate and also has multiple axes on the sensors for data collection. These data collection nodes were purposely designed with the capability for higher sampling rate and multiple axes (accelerometer and geophone). The idea is to collect data at these high sampling rates and multiple sensor axes and run through the signal processing algorithms to determine the most optimal hardware configuration.

SSCI has also developed a hardware independent data interface (HIDI) in order to evaluate different sensor configurations, sampling rates axes and sensor types. By clicking on suitable icons on the HIDI the signal processing algorithms will be run only on the chosen configuration. The HIDI offers a common ground to evaluate signal processing algorithms and hardware configurations simultaneously and allows one to visualize the best case scenario.

In this paper we will present our research on signal processing algorithm development, data collection with humans and animals, and the development of the HIDI interface and testing of the signal processing algorithms, and tradeoffs with hardware configurations.

8711-6, Session 3

Optimization of phase mask-based iris imaging system through the optical characteristics

Yuqing He, Jiaqi Li, Jing Pan, Yingjiao Li, Beijing Institute of Technology (China)

Iris recognition is the most reliable method in personal identification. However, the drawback of current fixed-focus iris imaging system is that the depth of field(DOF) is too small, which limits the distinct imaging range. In order to acquire the proper iris images, user should cooperate accurately and stand in the specific area where the iris can be imaged clearly. This slows the recognition speed and limits the wide application of the iris recognition system. The cost of the autofocus iris imaging system is much higher than the fixed-focus system. This paper presents the design method of a phase mask based iris imaging system. Through wavefront coding, it can extend the DOF and enhance the convenience of iris image acquisition.

This paper analyzes the fundamental principle for the generation of the great DoF in optical system, which means that the modulation transfer function of wavefront coding system is defocus-independent under a special condition. According to study the evaluation function of the optical imaging system, combining with the ambiguity function and the stationary phase method, we deduce the cubic phase mask's mathematical expression which is defocus-independent. Through adding the cubic phase mask on the specific iris imaging lens, which means replace one of the lens' surface into the cubic phase mask's surface, we optimize the parameters of the cubic phase mask to get a large DOF. Through putting the phase mask in the position of traditional fixed-focus system's aperture diaphragm, it can make the imaging system insensitive to defocus and the DOF of the system can be extended about 7 times. But it may brings difficulties in aspheric manufacturing. Therefore, we adjust the position of the aperture diaphragm and add a separated phase mask on the system, which is easy to install the phase mask. Optimization is also done to get good imaging quality and better DOF extension. Experimental results show that the optimization can get 6 times of the DoF extension, which is close to the optimal value of 7 times. Experimental results also show that the extension characteristics of the cubic phase mask is better than the quartic phase mask in iris imaging system.

8711-7, Session 3

Angular dependence of source-target-detector in active mode standoff infrared detection

Leonardo C. Pacheco-Londoño, John R. Castro-Suarez, Univ. de Puerto Rico Mayagüez (United States); Joaquín A. Aparicio-Bolanos, Univ. Puerto Rico (United States); Carlos A. Ortega-Zúñiga, Samuel P. Hernandez-Rivera, Univ. de Puerto Rico Mayagüez (United States)

In active mode standoff sensing using infrared spectroscopy the back reflected intensity is extremely dependent on the alignment between the source, the target and the detector. In this study we considered the effect of having the source out of alignment at small to relatively large angular deviations from back reflection. The angle of the target with respect to the source and the detector was varied from 0 (back reflection) to 70. The experiments were made using three infrared sources/modalities: Fourier transform infrared spectroscopy using a modulated source (MOD FT-IR), a non-modulated Globar (SiC) source (NON-MOD FT-IR) external to the interferometer and a dispersive scanning Quantum Cascade Laser based spectrometer and detector (QCL-IRS). The targets consisted of 200 ug/cm2 PENT deposited on aluminum plates (25.4 cm x 25.4 cm) placed at 1 meter from the sources. The evaluation of the three modalities was aimed at verifying the influence of the highly collimated laser beam (QCL) in the detection in comparison with other sources. The MOD FT-IR performed better than the QCL source in terms of the intensity fall with increasing angle. This performance is influenced by the fact that the QCL source is polarized and this influences the scattering observed from PETN particles deposited on the AL plates, depending critically on the alignment between the surface and the electric field vector of the IR laser beam. A better detection is expected from the higher intensity QCL source, but this decreases rapidly with angle in the case of the laser source.

8711-8, Session 3

A multiband spectral subtraction based algorithm for real-time noise cancellation applied to gunshot acoustics

Antonio L. Ramos, Hogskolen i Buskerud (Norway)

Acoustical sniper positioning systems rely on the detection and direction-of-arrival (DOA) estimation of the shockwave and the muzzle blast in order to estimate the sniper's location. In real life situations, the presence of background noise sources, e.g., vehicle noise, results in non-negligible inaccuracies in the detection and estimation processes which impacts the system's performance and reliability negatively, specially when detecting the muzzle sound under long range distances and absorbing terrains. This paper introduces a multi-band spectral subtraction based algorithm for real-time noise reduction, applied to gunshot acoustical signals. When denoising short-time or impulsive events such as gunshot signals, the background noise can be considered as short-time stationary. Moreover, owing to the fact that relatively long periods of noise only occur in real situations, the noise spectrum can be estimated effectively using a recursive method over successive overlapping frames of predefined length and controlled by a smoothing parameter. The shockwave and the muzzle blast signals exhibit distinct frequency contents and are affected differently by the noise component. Thus, a multi-band spectral subtraction approach is used to reduce the presence of artifacts in the resulting denoised signals. The proposed algorithm is tested using a dataset generated by combining signals from real gunshots and real vehicle noise. The noise component was generated using a steel tracked military tank running on asphalt and includes, therefore, the sound from the vehicle engine, which varies slightly in frequency over time according to the engine's rpm, and the sound from the steel tracks as the vehicle moves.

8711-9, Session 3

The multipath propagation effect in gunshot acoustics and its impact on the design of sniper positioning systems

Antonio L. Ramos, Hogskolen i Buskerud (Norway)

Counter sniper systems rely on the detection and parameter estimation of the sockwave and the muzzle blast in order to determine the sniper location. In real-world situations, these acoustical signals can be disturbed by natural phenomena like weather and climate conditions, multipath propagation effect, and background noise. The latter has been addressed in previous work by the author and partially presented at the 2012 edition of this conference. To the best of the author's knowledge, the remaining topics have not been discussed in details in the technical literature with application to gunshot acoustics. That is particularly true in the case of the multipath propagation phenomenon whose effect can not be neglected, specially in urban environments. Indeed, propagating sound waves are reflected at boundaries in the vicinity of sound sources or receivers, whenever there is a difference in acoustical impedance between the reflective material and the air. Thus, in multipath propagation environments, the received signal is generally composed of a direct path signal, which is not always present, plus M scaled delayed copies of the direct path signal. The scaling factors are dependent on the characteristics of reflective surfaces, whereas the time delays are determined by the respective angles-of-arrival. This paper presents a discussion of the multipath propagation effect and its impact on the performance and reliability of sniper positioning systems. In our formulation, propagation models for both the shockwave and the muzzle blast are considered and analyzed. Supporting simulation results are based on a dataset generated from actual gunshots signals.

8711-10, Session 4

Recognition and localization of relevant human behavior in videos

Henri Bouma, Gertjan Burghouts, Leo de Penning, Patrick Hanckmann, Johan-Martijn ten Hove, Sanne Korzec, Maarten Kruithof, Sander Landsmeer, Coen van Leeuwen, Sebastiaan van den Broek, Arvid Halma, Richard J. den Hollander, Klamer Schutte, TNO Defence, Security and Safety (Netherlands)

Ground surveillance is a mission normally performed by human assets. Military forces would like to shift this mission to unmanned autonomous systems, to reduce risks. However, unmanned systems lack a capability that currently exists only in humans: visual intelligence. The Defense Advanced Research Projects Agency (DARPA) is addressing this problem with Mind's Eye, a program aiming to develop a visual-intelligence capability for unmanned systems, in which we developed the CORTEX system.

In this paper, we present our improved CORTEX system, which can recognize, localize and describe the most relevant actions of a human and interactions between multiple humans in video. The central element in our approach is an agent-based architecture, which allows activity analysis of multiple persons (agents) in a single scene. Furthermore, we use a filtering mechanism for selecting the most relevant relations and computing multi-entity properties for them in order to describe interactions effectively.

The system is trained on thousands of videos and evaluated on realistic persistent surveillance data in the DARPA Mind's Eye program, which includes hours of videos showing significant scene complexity with realistic backgrounds, different camera positions, occlusion and multiple people with a variety of clothing performing actions simultaneously. In the paper, we show that our system is able to track the people, detect and localize events, and discriminate between different behaviors, such as approach, carry and exchange.

8711-11, Session 4

Advanced low-power personnel/vehicle detecting radar for smart unattended ground sensor/munitions systems

Mark A. Winston, Thomas Plummer, Steven W. Brady, Robert Raines, McQ, Inc. (United States)

McQ has developed a micro radar for unattended ground sensor (UGS) and smart munitions systems. The micro radar is designed to be a small battery powered activity sensor that requires no operator adjustments to provide reliable detection of people and vehicles with virtually no false alarms. The micro radar has the ability to detect, classify, and track human and vehicular targets. Target characteristics such as 2D position (range and azimuth) and velocity are computed. Most novel about this radar is its uniquely small size, low cost, and low power consumption. McQ will present an overview of this radar and test results.

8711-12, Session 4

Detection of dismounts from ground-based surveillance systems

William D. Reynolds Jr., Kenji Tashiro, Teledyne Scientific Co. (United States)

Automated detection of dismounts and their activities in rural areas continues to be a primary challenge for illegal border crossings, trafficking and drug activity. While ground-based surveillance systems are often deployed to provide early warnings, these systems traditionally fail to overcome operational difficulties inherent to the natural surroundings. Scene and background clutter due to, for example, trees, forests and wild-life often hinders detection performance, particularly in thermal bands. Thus, this research paper investigates the problem of long-range human detection in infrared video from a ground-based surveillance system.

Common approaches to human detection and classification include spatial feature (e.g., HOG) extraction followed by supervised classification to determine the presence/absence of a dismount. Typically, spatial features such as the Histogram of Oriented Gradients (HOG) are extracted from each video frame, which depend on the viewpoint and scale. Our approach exploits the spatial-temporal characteristics of human dismounts to improve the detection. We propose the Multiple Instance Learning (MIL) framework to combine both spatial and temporal features where each feature is considered as an instance of the target. The advantage of the MIL approach helps address the target variability due to pose, occlusion and background clutter. We present quantitative results from sample thermal infrared video to demonstrate feasibility of the proposed approach. The results show that the MIL approach provides a robust framework for combining multiple features for human detection in cluttered environments.

8711-13, Session 4

Swot Analysis of Using Aerostats for Surveillance in Counter Terrorism

Huseyin Cetin, Turkish Air Force Academy (Turkey)

In today's conjuncture, the terrorist activities are the most compelling issue for the defence forces in order to maintain homeland security. Especially, the terrorist elements that penetrate the homeland may give harm. This harm can be minimized by preventing the terrorist penetrations from homeland borders. In counter terrorism, having intelligence, surveillance and reconnaissance (ISR) capability and using this capability by twentyfour hours is a deterrence for the terrorist groups.

Aerostats emerge as the ideal platform which can provide this capability. Aerostats are different from the other manned and unmanned air vehicles

because of their high altitude, long endurance and hig-resolution image capabilities. Especially having uninterrupted image transmission and surveillance capabilities are important for having advantages in counter terrorism.

In this article, , the operational enviroment has been imagined by giving a brief definition and features of terrorism. In addition, “what are the technical capabilities, the usage areas and the purposes of aerostats?” questions will be introduced as a result of literature search. Finally the strengths and weaknesses of aerostats, opportunities and threats for the close future will be introduced by “SWOT” analysis method.

8711-14, Session 4

The cross-border exchange of hyperspectral materials in anti-terroristic and forensic investigations

Jaana R. Kuula, Univ. of Jyvaskyla (Finland); Tapani Reinikainen, National Bureau of Investigation (Finland)

The usage of hyperspectral imaging and other digital research methods are increasing rapidly in forensic investigation. The speed of developing new hyperspectral investigation methods can however not beat the speed of committing new crimes. According to the European wide study which the University of Jyväskylä and the National Bureau of Investigation have carried out in Finland, new hyperspectral methods could be taken in use faster in forensic investigation by increasing the electronic cross-border exchange of hyperspectral materials between forensic investigators. By joining forces in analysing hyperspectral data in different countries, more of the police officers´ and investigators´ time could be addressed in operational work of preventing ordinary and organized crime. Cooperation would also release more resources in developing better investigation methods. In the survey that was addressed to forensic investigators in 36 European countries 70 percent of respondents indicated that it would be necessary to exchange hyperspectral data between forensic investigation units in European and other countries. The survey indicated also that 50 percentage of forensic investigators would like to analyse hyperspectral data immediately at the crime scene. This is however difficult, because proper on-site analysing methods are missing and because many wireless telecommunication networks do not support transferring confidential data or big data files from the crime scene into the forensic analysing laboratories. The Finnish research group is developing solutions for these questions.

8711-15, Session 4

OptaSense® distributed acoustic and seismic sensing using COTS fiber optic cables for infrastructure protection and counter terrorism

Gregory L. Duckworth, Emery M. Ku, OptaSense (United States)

The OptaSense® Distributed Acoustic Sensing (DAS) technology can turn any single mode fiber optic cable (new or pre-existing) into a very large and high sensor density acoustic/seismic sensor array—covering up to 50 km aperture per system with “virtual” sensor separations as small as 1 meter on the unmodified cable. The system uses Rayleigh scattering from the imperfections in the fiber to return the optical signals measuring local fiber strain from seismic or air and water acoustic signals. The scalable system architecture can provide high-security perimeter and linear asset protection from nuclear facilities to oil and gas pipelines and borders. This paper presents various application architectures and system performance examples for detection, localization, and classification of personnel footsteps, vehicles, digging and tunneling, gunshots, artillery, explosions, aircraft, and earthquakes. The DAS technology can provide a cost-effective alternative to unattended ground sensors and geophone arrays, and a complement or alternative to imaging and radar sensors in many applications. The transduction, signal processing, and operator control and display technology will be described, and performance examples will be given from research and development testing and for operational systems on pipelines, critical infrastructure perimeters, railroads, and roadways. Potential new applications will be discussed that can take advantage of existing fiber-optic telecommunications infrastructure as “the sensor”—leading to low-cost and high-coverage systems.

8711-43, Session 4

Assessment of risks of electromagnetic interference for personal medical electronic devices (PMEDs) from emissions of millimeter-wave security screening systems

Don Witters, Howard Bassen, Joshua Guag, U.S. Food and Drug Administration (United States)

An increasing number of body worn and implanted personal medical electronic devices (PMEDs) are being used by the traveling public for a wide range of medical conditions. Those who chose to fly are required to undergo security screening at airports that can include screening with millimeter wave (mmW) advanced imaging technology (AIT) security systems. While high priority PMEDs such as implantable cardiac pacemakers, ICDs, neurostimulators and insulin pumps are designed and tested for susceptibility to electromagnetic interference (EMI) the present standards for medical device electromagnetic compatibility (EMC) do not address exposure to the much higher frequency fields that are emitted by mmW security systems. In the present study the FDA performed an analysis, measurements, testing, and simulations (including development of a novel exposure simulation system) to assess the EMI related risks for these high priority PMEDs when exposed to the emissions from the mmW AIT system. This presentation will report on this work and findings for the sample PMEDs. No effects on the medical devices from the exposure to the mmW security system were observed.

8711-44, Session 4

A field test of mobile x-ray back-scattering screening system for joint multi-agency operation for detection of IED and other dangerous organic substances in the nordic conditions

Andre Samberg, Sec-Control Finland Ltd. (Finland)

No Abstract Available.

8711-46, Session 4

Dynamic data-driven sensor network adaptation for border control

Doina Bein, The Pennsylvania State Univ., ARL (United States); Bharat B Madan, Old Dominion University (United States); Shashi Phoha, Sarah M Rajtmajer, The Pennsylvania State Univ., ARL (United States); Anna C. Rish, The Pennsylvania State Univ. (United States)

Given a specific scenario for the border control problem, we propose a dynamic data-driven adaptation of the associated sensor network via embedded software agents which make sensor network control, adaptation and collaboration decisions based on the contextual information value of competing data provided by different multi-modal sensors. We further propose the use of influence diagrams to guide data-driven decision making in selecting the appropriate action or

course of actions which maximize a given utility function by designing a sensor embedded software agent that uses an influence diagram to make decisions on whether to engage or not higher level sensors for accurately detecting human presence in the region. The overarching goal of the sensor system is to increase the probability of target detection and reduce the rate of false alarms. The proposed software agent is validated experimentally on a laboratory testbed for multiple border control scenarios.

8711-16, Session 5

Advanced video analytics for criminal justice applications *(Keynote Presentation)*

Mark Greene, National Institute of Justice (United States)

No Abstract Available.

8711-17, Session 6

Plasma-field barrier sentry

Ernesto Gonzaga, Plasma Technologies Inc. (United States)

Background: The primary function of a security system is to counter personnel attempting to breach security. This involves denying “access to” , or “possession of” facilities or high valued establishments. Most conventional security systems are reactive in design, requiring humans to constantly monitor and respond in post-active mode. In this paper a proactive system is introduced.

Result: The availability of related technologies that were blended together for the purpose of improving security systems was pursued. This resulted to design and development of innovative security systems introduced in the market. To compete in this business we are exploring new concept of access denial system. We believe the Plasma-field Barrier Sentry is unique for it utilizes the plasma channel emissions of solid state Tesla coils.

Conclusion: This system will provide several benefits including but not limited to; delay/defend/respond capabilities’; reduction in manpower and many associated cost, autonomous systems; reduces risks by replacing man with machine; capable of various configurations; will function electronically with no mechanical components; reduces material costs. By continually advancing research findings, and, as new ideas evolve, we envision this new security technology to become flexible, miniaturized and portable. As we strive to understand more and master controlling plasma energy, we are being led into related research areas and contemplating different electromagnetic apparatuses that will unlock and utilize the great resources that plasma holds available.

8711-18, Session 6

Adaptive sequential methods for detecting network intrusions

Xinjia Chen, Ernest L. Walker, Southern Univ. and A&M College (United States)

In this paper, we propose new sequential methods for detecting port-scan attackers which routinely perform random ``portscans” of IP addresses to find vulnerable servers to compromise. In addition to rigorously control the probability of falsely implicating benign remote hosts as malicious, our method performs significantly faster than other current solutions. Moreover, our method guarantees that the maximum amount of observational time is bounded. In contrast to the previous most effective method, Threshold Random Walk Algorithm, which is explicit and analytical in nature, our proposed algorithm involve parameters to be determined by numerical methods. We have developed computational techniques such as iterative minimax optimization for quick determination of the parameters of the new detection algorithm. A framework of multi-valued decision for detecting portscanners is also proposed.

8711-20, Session 6

Automated night/day standoff detection, tracking, and identification of personnel for installation protection

Brian E. Lemoff, Robert B. Martin, Mikhail Sluch, Kristopher M. Kafka, William B. McCormick, Robert V. Ice, West Virginia High Technology Consortium Foundation (United States)

The capability to positively and covertly identify people at a safe distance, 24-hours per day, could provide a valuable advantage in protecting installations, both domestically and in an asymmetric warfare environment. This capability would enable installation security officers to identify known bad actors from a safe distance, even if they are approaching under cover of darkness. We will describe an active-SWIR imaging system being developed to automatically detect, track, and identify people at long range using computer face recognition. The system illuminates the target with an eye-safe and invisible SWIR laser beam, to provide consistent high-resolution imagery night and day. SWIR facial imagery produced by the system is matched against a watch-list of mug shots using computer face recognition algorithms. The current system relies on an operator to point the camera and to review and interpret the face recognition results. Automation software is being developed that will allow the system to be cued to a location by an external system, automatically detect a person, track the person as they move, zoom in on the face, select good facial images, and process the face recognition results, producing alarms and sharing data with other systems when people are detected and identified. Progress on the automation of this system will be presented along with experimental night-time face recognition results at distance.

8711-21, Session 6

Robust and compact infrared video motion stabilization for long-range surveillance

Kenji Tashiro, William D. Reynolds Jr., Teledyne Scientific Co. (United States)

Long-range surveillance systems are typically used in rural areas for detecting and tracking illegal border crossings, trafficking and drug activity. These systems commonly deploy mast or tower-based surveillance systems equipped with thermal infrared cameras, which have the advantage of providing early warnings and increasing the range of observation. However, these systems are subject to high frequency vibration due to slight wind or wind gusts, which is difficult to correct mechanically. In order to identify the border activity, it is critical for the vision system to robustly detect the objects in the scene, classify the objects and track the detected targets. The performance of these post-processing algorithms is known to suffer if the video is not properly stabilized.

Surveillance systems in rural areas, particularly in thermal band, pose several unique challenges to video stabilization algorithms. First, the scene rarely contains man-made objects. Water surface, trees and forests present very low contrast and ambiguous textures such that stabilization algorithms struggle to consistently and repeatedly extract distinctive corners and features. Second, even if the system captures certain human activities or structural objects in the scene, the video typically lacks sharpness in the background due to the motion blur at the long range. In this research paper, we propose a biologically-inspired, robust and compact video motion stabilization algorithm, which is ideal for rural areas. Our novel algorithm is compared quantitatively with other competing algorithms in terms of robustness and performance. Finally, we demonstrate the real-time performance and evaluate the resource usage on FPGA platforms.

8711-22, Session 7

Scaling issues in the selection of an approach for sensor network configuration design

Thomas A. Wettergren, Russell Costa, Naval Undersea Warfare Ctr. (United States)

Sensor networks have become a viable technology for a deployable surveillance solution in many military applications. In recent years, it has become recognized that the proper configuration of the network (positioning of nodes) can greatly reduce the number of nodes that are required to achieve a given level of system performance. This reduction in nodes can lead to cost savings, increases in coverage area, or reduced payload stress on the deployment platform. A variety of approaches have been developed to perform this configuration planning – ranging from sequential point placement to sensor density optimization. These techniques further utilize a variety of numerical optimization techniques – from nonlinear programming, to hierarchical planning, to meta-heuristic techniques. The selection of approach and numerical optimization technique is as much a matter of personal experience as it is the mathematics of the problem. Clearly some techniques perform better than others based on certain scales of the problem at hand: for varying numbers of sensors, level of network connectivity, uniformity of sensor placement, etc. In this paper we review the most promising of the design optimization approaches for sensor network configuration planning. We illustrate the scales of problem for which each approach is best utilized, demonstrating the scale effects on relative performance through numerical simulations. We begin with a taxonomy of sensor network scale considerations, and conclude with guidance for practitioners on the selection of approach.

8711-23, Session 7

Robotic disaster recovery efforts with ad-hoc deployable cloud computing

Jeremy Straub, Atif Mohammad, The Univ. of North Dakota (United States); Ronald Marsh, Univ of North Dakota (United States)

The increasingly complex urban landscape dramatically increases the complexity of responding to natural or man-made disaster. When disaster strikes, only limited a priori knowledge is available to guide decision making; this requires human and robotic responders, alike, to make decisions on-the-fly in a complex and potentially changing environment. Thus, the autonomous operation of search and rescue (SaR) robots is an ill posed problem, which is complexified by the dynamic disaster response environment. Robotic responders reduce or eliminate the risk to human response participants; however, a multitude of autonomous capabilities are required to facilitate autonomous response. These robots require different processing capabilities and use multiple algorithms during the response effort. Placing these capabilities onboard the robot is a less-than-optimal solution that precludes algorithm specific performance optimization and results in sub-optimal system performance. Cloud computing principles provide a possible solution to this problem. An ad-hoc, scalable and deployable cloud-computing network can be deployed to a disaster location to provide services to autonomous responder craft. While these craft must have some basic capability for independent response onboard (in case of communications interruption, etc.), most processing involved in situation analysis and decision-making can be offloaded to the cloud providers.

An architecture for an ad-hoc, deployable cloud environment suitable for use in a disaster response scenario is presented. Under this model, each service provider is task-optimized and maintains a database of situation-relevant information. The proposed framework is service-oriented architecture 3.0 compliant.

8711-47, Session 7

Novel mechanism of sensitive information protection on personal mobile devices

Alexander Milovanov, Leonid Bukshpun, Ranjit D. Pradhan, Physical Optics Corp. (United States)

A new intelligent technology has been developed to provide information security, data protection, and integrity on personal mobile devices, such as smartphones or mobile computers. The technology is based on novel integration of a biometric signature as one factor of a two-factor user authentication and uses biometric information for data protection in transit and at rest. Biometric key-based data protection approach enhances security and provides reliable user authentication and remote dynamic policy management. These enable secure integration of mobile technologies with business systems. This novel technology can be incorporated into wired or wireless networks that require protection of sensitive information residing on personal mobile devices when a connection to the network is not always available.

8711-26, Session 8

Estimation of target size using two passive infrared sensors

Thyagaraju Damarla, U.S. Army Research Lab. (United States); James M. Sabatier, Univ. of Mississippi (United States)

Passive infrared (PIR) sensors are widely used as a part of unattended ground sensor suite for situational awareness. Currently, the PIR sensor is mainly used as a wakeup sensor for the imaging sensor in order to conserve power. Since the PIR sensor mainly responds to the thermal radiation by the target, animals in the vicinity of the sensor can cause many false alarms. The number of false alarms can be cut drastically, if the target size can be estimated and the decision is made based on the target size. For example, if the target is 5 ft 9 in tall and 1.5 ft wide, it is most likely a human being as opposed to an animal. In this paper, we present a technique to estimate the target size using two PIR sensors with Fresnel lens arrays. One of the PIR sensors is mounted such that its Fresnel zones are horizontal to the ground, and the second PIR sensor is mounted such that its Fresnel zones are at a slant angle to the horizontal plane. The former is used to estimate the width/length, while the latter is used to estimate the height of the target. The relative signal strength between the two sensors is used to estimate the distance of the target from the sensor. The time it takes to cross the Fresnel zones is used to estimate the speed of the target. The algorithm is tested using the data collected in the woods, where several animals are observed roaming.

8711-27, Session 8

Searching social networks for subgraph pattern occurrences

Kirk Ogaard, Heather Roy, Sue E. Kase, U.S. Army Research Lab. (United States); Rakesh Nagi, Kedar Sambhoos, Moises Sudit, Univ. at Buffalo (United States)

Software tools for Social Network Analysis (SNA) are being developed which support various types of analysis of social networks extracted from social media websites (e.g. Twitter). Once extracted and stored in a database such social networks are amenable to analysis by SNA software. This data analysis often involves searching for occurrences of various subgraph patterns to determine the types of subgraphs present within the social network. The authors have developed the Graph Matching Toolkit (GMT). GMT is SNA software which provides an intuitive Graphical User Interface (GUI) for a heuristic graph matching algorithm called the Truncated Search Tree (TruST) algorithm. GMT is thus visualization software for graph matching algorithms for large social networks. GMT enables a user to draw a subgraph pattern by using a

mouse to select labels for nodes and links from drop-down menus. GMT then executes the TruST algorithm to find the top five occurrences of the subgraph pattern within the social network stored in the database. GMT was tested using a simulated counter-insurgency dataset consisting of email messages, reports, interviews, and sightings portraying day-to-day challenges within a populated area of operations in Iraq. The results indicated GMT (when executing the TruST graph matching algorithm) is a time-efficient approach to searching large social networks. Such a user interface as GMT could enable intelligence analysts to quickly analyze and summarize the large amounts of intelligence data necessary to produce actionable intelligence reports.

8711-28, Session 8

Unattended ground sensors, countermeasure, and counter-countermeasure: abilities, techniques, and effectiveness

Alexander A. Pakhomov, Security & Defense Research LLC (United States)

Contemporary advanced unattended ground sensors (UGS) usually use seismic, IR, magnetic, acoustic and other detection channels. Typically software for all those detection channels is optimized for using in common, statistically average ambient conditions. Sometimes the software is able to adapt to slow changing background noise. Most of that software can be successfully used for detection of the "occasional" intruder who does not know about UGS present and does not try to deceive it. But today "bad guys" are very smart, well-educated and trained. They can use various countermeasure techniques and devices that drastically reduce effectiveness of the UGS.

The most common general countermeasure techniques that can be used against UGSs are the following:

- Target masking, reducing of the target "visibility" and "recognizability"
- Noise jamming
- Deception & false target generation and imitation

This paper describes specific techniques that can be used against seismic, IR and acoustic detectors. We present and discuss basic principal and particular solutions for providing protection of the various detection channels from countermeasure. In other words this paper presents counter-countermeasure solutions for UGS. We show also effectiveness of possible countermeasure and counter-countermeasure activities and approach to the effectiveness evaluation of both of them. Presented data allows to achieve the higher level of security reliability.

8711-29, Session 8

Electric and magnetic-field sensor system for small unmanned aerial vehicles

John Matthews, Leonid Bukshpun, Ranjit D. Pradhan, Physical Optics Corp. (United States)

Autonomous navigation around power lines in a complex urban environment is a critical challenge facing small unmanned aerial vehicles (SUAVs). We report on the development of an electric and magnetic field sensor system designed to provide SUAVs with the capability to sense and avoid power transmission and distribution lines by monitoring their electric and magnetic field signatures. A system-level analysis of the sensor system is presented, including system requirements, and expected performance for representative SUAV platforms. We also discuss the nature of the power line signatures to be detected, and optimal strategies for detecting these signals amid SUAV platform noise and environmental interference. Based on an analysis of measured power line signals and vehicle noise, we have found that under certain circumstances power line harmonics can be detected at greater range than the fundamental. We explain this phenomenon by combining a model of power line signal nonlinearity with the quasi-static electric and magnetic signatures of multi-phase power lines. A description of the hardware components of the sensor system, including the electric and magnetic field sensors and the interrogation electronics module, and preliminary test results obtained with a prototype system, are presented.

8711-30, Session 8

Cost and effectiveness analyse on unmanned aerial vehicle (UAV) use at border security

Bahadir Yilmaz, Turkish War College (Turkey)

Border security is one of the tasks which is vital for any country. In general, border security is against drugs / people and arms smugglers, unauthorized migrations and terrorism. Classical border security is provided by land and sea vehicles by using manpower. However forest, desert, glacier, or mountainous terrains make it difficult to ensure the safety of the homeland security by using the classical methods.

Unmanned air vehicles (UAV), satellites and high-resolution sensors are the modern border security methods. UAV used in Afghanistan, Iraqi, Kosova and Libya for Intelligence Reconnaissance and Surveillance , attack, combat air patrol (CAP) and electronic warfare missions. UAV which are used successfully in different countries and terrotories can be use also in border security missions effectively.

This article examines the advantages and disadvantages of UAV use in homeland border security and figures out cost-effectiveness of UAV. Medium altitude long endurance (MALE) UAV's costs are more than it is expected in border security.As a result to use a cost effective system the best systems should be tactical UAV.

8711-31, Session 9

Directional antenna array for communications, control and data link protection

Pavlo A. Molchanov, Ampac Inc. (United States); Vincent M. Contarino, R Cubed Inc. (United States)

Why do UAV's transmit communication and sensor information through an omni-directional antenna to everyone? This wastes valuable battery energy transmitting classified information in all directions even though the direction to the receiving ground station or satellite is known.

Why do UAV's use an omni-directional receiver antenna for command, control, communication and GPS when the omni-directional antenna is vulnerable to jam or spoof by terrorist signals coming from any direction and the direction to the transmitting ground station or satellite is known?

A directional antenna array (DAA) can transmit or receive signals in an exact direction providing counter terrorism protection for data link, control, communication and GPS. The proposed approach is based on using a DAA, where each antenna is connected to its own separate receiver.

First level of protection:

- Convex shape of the directional antenna array provides protection in that a jam signal from any one or even several directions cannot damage or saturate all of the receivers at the same time.

Second level of protection:

- The multi-channel processor calculates the direction of arrival for each signal, compares this with true ground station or satellite positions from onboard memory and exclude it if the direction does not corresponds.

Directional antennas have higher gain and in contrast to phase antenna arrays have wide bandwidth. A few models of miniature directional GPS antenna arrays with 7 helical directional antennas, 2" diameter, 1" tall and 1" diameter, 0.7" tall will be exhibited at the conference.

8711-32, Session 9

On a robust soft-input soft-output demodulator for OFDM systems: when unreliable channel state information is present

Chulong Chen, Michael D. Zoltowski, Purdue Univ. (United States)

In this paper an improved soft-input soft-output (SISO) QAM demodulator with robust performance on unreliable channel information are proposed for OFDM systems. The frequency-selective fading channel encountered in OFDM systems are modeled as complex Gaussian random variables with some mean and variance. And the AWGN variance is modeled as a Gamma random variable. The uncertainty of the channels are expressed in the respective variances of the channel coefficients. The likelihood function on the received symbols are derived by marginalizing over the fading channel coefficients and AWGN channel variance. It's application in a bit-interleaved coded modulation system (BICM) is demonstrated. And schemes with reduced complexity are also discussed. Simulation results show an improved performance when the estimated channel state information (CSI) are less reliable.

8711-33, Session 9

Modeling emergent border-crossing behaviors during pandemics

Eunice E. Santos, The Univ. of Texas at El Paso (United States); Eugene S. Santos Jr., Thayer School of Engineering at Dartmouth (United States); John Korah, The Univ. of Texas at El Paso (United States); Jeremy E. Thompson, Qi Gu, Keumjoo Kim, Deqing Li, Jacob A. Russell, Thayer School of Engineering at Dartmouth (United States); Suresh Subramanian, The Univ. of Texas at El Paso (United States); Yuxi Zhang, Yan Zhao, Thayer School of Engineering at Dartmouth (United States)

Modeling real-world scenarios is a challenge for traditional social science researchers, as it is often hard to capture the intricacies and dynamisms of real-world situations without making simplistic assumptions. This imposes severe limitations on the capabilities of such models and frameworks. Complex population dynamics during natural disasters such as pandemics is an area where computational social science can provide useful insights and explanations. In this paper, we employ a novel intent-driven modeling paradigm for such real-world scenarios by causally mapping beliefs, goals, and actions of individuals and groups to overall behavior using a probabilistic representation called Bayesian Knowledge Bases (BKBs). To validate our framework we examine emergent behavior occurring near a national border during pandemics, specifically the 2009 H1N1 pandemic in Mexico. The novelty of the work in this paper lies in representing the dynamism at multiple scales by including both coarse-grained (events at the national level) and fine-grained (events at two separate border locations) information. This is especially useful for analysts in disaster management and first responder organizations who need to be able to understand both macro-level behavior and changes in the immediate vicinity, to help with planning, prevention, and mitigation. We demonstrate the capabilities of our framework in uncovering previously hidden connections and explanations by comparing independent models of the border locations with their fused model to identify emergent behaviors not found in either independent location models nor in a simple linear combination of those models.

8711-34, Session 9

StunRay technology: nonlethal weapons for law enforcement, homeland security, and anti-piracy

Carlton W. Carroll, EOVERM Consulting LLC (United States) and Genesis Illumination, Inc. (United States)

Genesis Illunination has developed and fielded a handheld StunRay unit capable of causing disorientation and debilitating effects at ranges up to 100 meters. A long range system is being developed to provide the same effects at ranges of up to three quarters of a mile. The applications include the use on ships for anti-piracy and security around docks, ports, drilling rigs and anchorages. This presentation will cover the basic technology involved in the stun effect and data on physical effects on humans. The status of the long range system development will be covered, including performance specifications, physical characteristics and potential integrated applications.

8711-35, Session 9

Development of an Intercom: an undergraduate case study

J. Alejandro Betancur Ramírez, Francisco Cardona, Univ. EAFIT (Colombia)

This paper make a short description of a communication device at low cost. Wireless intercom devices presented here enable communication between any two of these products through specialized synchronization options. This communication system consists of two functionally linked radiofrequency intercoms in the 2.4GHz free band. Each of these devices consist of a free-hands cellular system containing a microphone and a loudspeaker which is connected individually to each communication device through a plug of four (4) contacts and three point five (3.5) mm in diameter, also has a single USB connector for battery charging (not data bus), which is lithium polymer, and finally has three (3) buttons from where are controlled the functions of: volume level, audio filters, on, off, among other functions.

8711-36, Session 10

Technologies to enhance next-generation sensing for near shore and harbor security *(Keynote Presentation)*

Pierre J. Corriveau, Naval Undersea Warfare Ctr. (United States)

No Abstract Available.

8711-45, Session 10

Pre-deployed distributed systems *(Keynote Presentation)*

Andrew Coon, Defense Advanced Research Projects Agency (United States)

No Abstract Available.

8711-37, Session 11

Electron dynamics for uncooled MWIR SiC detector for digital imaging

John W. Zeller, Tariq Manzur, Naval Undersea Warfare Ctr. (United States); Aravinda Kar, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

No Abstract Available.

8711-38, Session 11

Near-marine boundary layer atmospheric and turbulence testing and modeling

Olaleye A. Aina, Epitaxial Technologies, LLC (United States); Tariq Manzur, Naval Undersea Warfare Ctr. (United States)

No Abstract Available.

8711-39, Session 11

ZnO nanowire UV detector technology for marine boundary layer

Abdiel Rivera, Mehdi F. Anwar, Univ. of Connecticut (United States); John W. Zeller, Tariq Manzur, Naval Undersea Warfare Ctr. (United States); Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States)

No Abstract Available.

8711-40, Session 11

Atmospheric modeling near-marine boundary layer for high-energy beam propagation

Eric P. Magee, MZA Associates Corp. (United States); John W. Zeller, Tariq Manzur, Naval Undersea Warfare Ctr. (United States)

No Abstract Available.

8711-41, Session 11

Electron dynamics for uncooled MWIR SiC detector for digital imaging

Aravinda Kar, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); John W. Zeller, Tariq Manzur, Naval Undersea Warfare Ctr. (United States)

No Abstract Available.

8711-42, Session 11

Laser sensing of mid-wave infrared radiation with wavelength selective dopant in silicon carbide

Geunsik Lim, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Tariq Manzur, Naval Undersea Warfare Ctr. (United States); Aravinda Kar, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

No Abstract Available.

Conference 8712: Biometric and Surveillance Technology for Human and Activity Identification X

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8712-1, Session 1

Advanced biometric technologies for homeland security applications *(Keynote Presentation)*

Arun Vemury, U.S. Dept. of Homeland Security (United States)

No Abstract Available.

8712-2, Session 1

A novel hand-type detection technique with fingerprint sensor

Narishige Abe, Takashi Shinzaki, Fujitsu Labs., Ltd. (Japan)

The use of fingerprint authentication technologies is widespread in many applications. In particular, for large-scale authentication systems such as the US-Visit (USA) and AADHAAR project (India), a 10-fingerprints scanner which can simultaneously capture four fingerprints is used.

As the popularity of the large-scale system increases, we have to consider the situation in which there are no operators to train users regarding the use of the system. In this situation, when the system instructs users to apply a specific hand-type, it is important to detect whether the applied hand is a left or right hand for appropriate confirmation to be given in some cases.

First, the system enrolls or verifies his/her fingers incorrectly, when a user put incorrect hand's fingers which are not indicated by it. Especially, in enrollment phase, this becomes to be very critical issue. Secondly, in a large-scale authentication system, it is easy to use hand-type information for narrowing down the number of data for identification. In this system, incorrect hand detection causes low authentication performance due to the incorrect narrowing down result. Furthermore, hand-type detection technique is utilized for assistance of an operator at the border control for check the put hand-type.

In this paper, we investigated the features which are effective for detecting hand-type from general optical scanner images. We then developed a trial system based on the obtained knowledge. As a result, in general optical scanner images, we obtained an accuracy of over 95%, but in real fingerprint images, the accuracy was about 80%.

8712-3, Session 1

Security analysis for fingerprint fuzzy vaults

Jesse L. Hartloff, Maxwell Bileschi, Sergey Tulyakov, Jimmy Dobler, Atri Rudra, Venu Govindaraju, Univ. at Buffalo (United States)

In this work we place some of the traditional biometrics work on fingerprint verification via the fuzzy vault scheme within a cryptographic framework. We show that the breaking of a fuzzy vault leads to decoding of Reed-Solomon codes from random errors, which has been proposed as a hard problem in the cryptography community. We provide a security parameter for the fuzzy vault in terms of the decoding problem, which gives context for the breaking of the fuzzy vault, whereas most of the existing literature measures the strength of the fuzzy vault in terms of its resistance to pre-defined attacks or by the entropy of the vault. We keep track of our security parameter, and provide it alongside ROC statistics. We also aim to be more aware of the nature of the fingerprints when placing them in the fuzzy vault, noting that the distribution of minutiae is far from uniformly random. The results we show provide additional support that the fuzzy vault can be a viable scheme for secure fingerprint verification.

8712-4, Session 1

Performance characterization of structured light-based fingerprint scanner

Laurence G. Hassebrook, Minghao Wang, Raymond C Daley, Univ. of Kentucky (United States)

Our group believes that the evolution of fingerprint capture technology is in transition to include 3-D non-contact fingerprint capture. More specifically we believe that systems based on structured light illumination provide the highest level of depth measurement accuracy. However, for these new technologies to be fully accepted by the biometric community they must be compliant with federal standards of performance. At present these standards do not exist for this new technology. We propose and define a set of test procedures to be used to verify compliance with the Federal Bureau of Investigation's image quality specification for Personal Identity Verification single fingerprint capture devices. The proposed test procedures include: geometric accuracy, spatial and depth resolution performance, gray level uniformity and flattened fingerprint image quality. Several 2-D contact analogies, performance tradeoffs and optimization dilemmas are evaluated and proposed solutions are presented.

8712-5, Session 2

RDT&E for criminal justice applications: operational challenges, technical solutions, and managing expectations in the future *(Keynote Presentation)*

Mark Greene, National Institute of Justice, Office of Science and Technology (United States)

The National Institute of Justice (NIJ) maintains a primary emphasis on the needs and requirements of Federal, state, local and tribal criminal justice systems in how it prioritizes a balance between basic and applied research to support improved outcomes for practitioners. The Office of Science and Technology (OST) at NIJ supports this goal by focusing on challenging the research community to provide innovative solutions, building a rigorous scientific knowledge base to guide future RDT&E directions, transitioning emerging technologies to RDT&E professionals, and translating research efforts into practical results for operational use cases. Several R&D projects in the areas of biometrics, sensors, and surveillance will be presented to provide an overview the current state of research in person identification such as matching forensic sketches to mugshot databases. However, a number of real-world examples will be discussed to highlight operational challenges and the current limitations in technology available to help solve person identification problems in law enforcement scenarios, particularly with respect to violent crime. The possible root causes of the technical gaps with each scenario, potential approaches to address the problems with each scenario, and the similarities among the scenarios and potential overlap of solutions will be discussed. Matching the needs from practitioners with the ideas from the research community assists OST with setting realistic expectations regarding the particular efforts that would be required including costs and timelines to address the outstanding problems in person identification in criminal justice.

8712-6, Session 2

Privacy information management for video surveillance

Ying Luo, Sen-ching S. Cheung, Univ. of Kentucky (United

States)

The widespread deployment of surveillance cameras has raised serious privacy concerns. Many privacy-enhancing schemes have been proposed to automatically redact images of trusted individuals in the surveillance video. To identify these individuals for protection, the most reliable approach is to use biometric signals such as iris patterns as they are immutable and highly discriminative. In this paper, we propose a privacy data management system to be used in a privacy-aware video surveillance system. The privacy status of a subject is anonymously determined based on her iris pattern. For a trusted subject, the surveillance video is redacted and the original imagery is considered to be the privacy information. Our proposed system allows a subject to access her privacy information via the same biometric signal for privacy status determination. Two secure protocols, one for privacy information encryption and the other for privacy information retrieval are proposed. Error control coding is used to cope with the variability in iris patterns and efficient implementation is achieved using surrogate data records.

Experimental results on a public iris biometric database demonstrate the validity of our framework.

8712-7, Session 2

Eyebrow segmentation using active shape models

Karen P. Hollingsworth, Samuel Clark, Joseph Thompson, Patrick J. Flynn, Kevin W. Bowyer, Univ. of Notre Dame (United States)

Prior research has shown that manually-segmented eyebrows can be used for recognition purposes. However, eyebrow recognition is not as useful without an automated segmentation algorithm. We propose a method to automatically outline the eyebrows in a face using active shape models. We train several models using the images from the Face Recognition Grand Challenge and find that including more landmark points around the eyebrows and including the eyes in the model are beneficial. Our eyebrow active shape model gives a 38.6% improvement over eyebrow segmentation obtained using an open-source face active shape model. When comparing the automatically segmented regions with manual segmentation, we achieve 87% true overlap score with a 12% false overlap score.

8712-8, Session 3

Machines better than humans for general face recognition? *(Keynote Presentation)*

Jonathon Philips, National Institute of Standards and Technology (United States)

No Abstract Available.

8712-9, Session 3

Encoding and selecting features for boosted multispectral face recognition: Matching SWIR versus color

Sirisha Boothapati, Natalia A. Schmid, West Virginia Univ. (United States)

In this paper, we propose a methodology for cross matching color face images and Short Wave Infrared (SWIR) face images reliably and accurately. We first adopt a recently designed Boosted and Improved Local Gabor Pattern (ILGP) encoding and matching technique to encode face images in both visible and SWIR spectral bands. We then apply newly developed feature selection methods to prune irrelevant information in encoded data and to improve performance of the Boosted ILGP. The two newly developed feature selection methods are: (1) Genuine segment score-based thresholding and (2) AdaBoost inspired methods. We further compare the performance of the original Boosted ILGP face recognition method with the performance of the modified method that involves one of the proposed feature selection approaches.

Under a general parameter set up, significant performance improvement is observed.

8712-10, Session 3

Using crypts as iris minutiae

Feng Shen, Patrick J. Flynn, Univ. of Notre Dame (United States)

One important factor that prevents iris biometrics from being further deployed in law enforcement is the way iris features are represented and matched. The pattern of iris texture is claimed to be unique for each person and each eye. Current iris recognition techniques are typically based on the analysis of iris textures by their phase responses to local band-pass filters. Because these features are not easily recognized by human vision system, it is difficult for forensic examiners to confirm the result of automated identification.

In this paper we propose an identity verification system that concentrates on iris crypts as the type of visible feature to represent the characteristics of irises in a similar way to fingerprint minutiae. Crypts are a sequence of openings located near the collarette on the anterior layer of the eye. They appear as local dark regions surrounded by relatively strong edges under NIR spectrum. The identity of the questioned iris image is confirmed if there are sufficient number of common crypt pairs between this image and the iris image enrolled in the dataset.

The crypt features are extracted by a sequence of morphological operators and noise removal steps based on edges, intensities and pixel variations. The matching of crypts is based on their appearances and locations. It is a three-level approach that includes global feature comparison, template matching and manual inspection. The number of matching crypt pairs found between two irises can be used for identity verification and the convenience of manual inspection makes iris crypts a potential candidate for forensic applications.

8712-11, Session 3

Automatic detection of non-cosmetic soft contact lenses in ocular images

Gizem Erdogan, Arun A. Ross, West Virginia Univ. (United States)

Recent research in iris recognition has established the impact of non-cosmetic soft contact lenses on the recognition performance of iris matchers. Researchers in Notre Dame demonstrated an increase in False Reject Rate (FRR) when an iris without a contact lens was compared against the same iris with a transparent soft contact lens. Detecting the presence of a contact lens in ocular images can, therefore, be beneficial to iris recognition systems. This study proposes a method to automatically detect the presence of non-cosmetic soft contact lenses in ocular images of the eye acquired in the Near Infrared (NIR) spectrum. While cosmetic lenses are more easily discernible, the problem of detecting non-cosmetic lenses is substantially difficult and poses a significant challenge to iris researchers. The lens boundary is detected by traversing a small annular region located in the vicinity of the outer boundary of the segmented iris and locating candidate points corresponding to the lens perimeter. Candidate points are identified by examining intensity profiles in the radial direction within the annular region. The proposed detection method is evaluated on two databases: ICE 2005 and MBGC Iris. In the ICE 2005 database, a correct lens detection rate of 72% is achieved. In the MBGC Iris database, a correct lens detection rate of 70% is obtained. To the best of our knowledge, this is one of the earliest work attempting to detect the presence of non-cosmetic soft contact lenses in NIR ocular images. The results of this research suggest the possibility of detecting soft contact lenses in ocular images but highlight the need for further research in this area.

8712-12, Session 4

Challenges and opportunities in active authentication *(Keynote Presentation)*

Richard Guidorizzi, DARPA/DoD (United States)

No Abstract Available.

8712-13, Session 4

Securing iris recognition systems against masquerade attacks

Javier Galbally-Herrero, Marta Gomez-Barrero, Univ. Autónoma de Madrid (Spain); Arun A. Ross, West Virginia Univ. (United States); Julian Fierrez, Javier Ortega-Garcia, Univ. Autónoma de Madrid (Spain)

Among the various biometric traits that have been studied in the recent past, iris is commonly believed to be reliable and accurate. The templates used by most iris-based systems are the so called IrisCodes, which are binary representations of the iris pattern. Since an IrisCode is an extremely compact representation of the iris, it has been a common belief in the biometric community that binary templates do not divulge enough information to reconstruct the original iris image from them.

However, this belief has been recently questioned in the literature by researchers who have explored the reversibility of IrisCodes. In particular, a probabilistic reconstruction method based on genetic algorithms was presented in a previous study by the authors, and used to evaluate the vulnerabilities of a commercial iris recognition system (VeriEye, by Neurotechnology) against several masquerade attacks.

In the present work we address the security issues disclosed in that previous work by proposing a novel two-stage effective countermeasure to detect the synthetic iris patterns reconstructed from a real IrisCode. The protection scheme uses different characteristics of real iris images to differentiate them from the synthetic ones. Thus, the main objective of the work is to develop a reliable solution to an actual vulnerability flaw present in commercial biometric applications in order to enhance the level of security offered to the final users. Experiments are carried out on the publicly available Biosecure DB and demonstrate the efficacy of the proposed security enhancing approach.

8712-14, Session 4

Gaze estimation for off-angle iris recognition based on the biometric eye model

Mahmut Karakaya, Del Barstow, Hector J. Santos-Villalobos, Joseph Thompson, David S. Bolme, Christopher B. Boehnen, Oak Ridge National Lab. (United States)

Iris recognition is among the highest accuracy biometrics. However, its accuracy relies on controlled high quality capture data and is negatively affected by several factors such as angle, occlusion, and dilation. Non-ideal iris recognition is a new research focus in biometrics. In this paper, we present a gaze estimation method designed for use in an off-angle iris recognition framework based on the ORNL biometric eye model. Gaze estimation is an important prerequisite step to correct an off-angle iris images. To achieve the accurate frontal reconstruction of an off-angle iris image, we first need to estimate the eye gaze direction from elliptical features of an iris image. Typically additional information such as well-controlled light sources, head mounted equipment, and multiple cameras are not available. Our approach utilizes only the iris and pupil boundary segmentation allowing it to be applicable to all iris capture hardware. We compare the boundaries with a look-up-table generated by using our biologically inspired biometric eye model and find the closest feature point in the look-up-table to estimate the gaze. Based on the results from real images, the proposed method shows effectiveness in gaze estimation accuracy for our biometric eye model with an average error of approximately 3.5 degrees over a 50 degree range.

8712-18, Session PThu1

Infrared enhanced imaging for security/ surveillance

Martin U. Pralle, Homayoon Haddad, Stephen Noble, SiOnyx Inc. (United States)

SiOnyx has developed visible/infrared CMOS image sensors leveraging a proprietary ultrafast laser semiconductor process technology. This technology demonstrates 10 fold improvements in infrared sensitivity over incumbent imaging technology while maintaining complete compatibility with standard CMOS image sensor process flows. Furthermore, these sensitivity enhancements (from 400 to 1200 nm) are achieved on a focal plane with state of the art noise performance of 2 electrons/pixel. By capturing light in the visible regime as well as infrared light from the night glow, this sensor technology provides imaging in daytime through twilight and into nighttime conditions. SiOnyx has developed a family of IP based security surveillance cameras using these groundbreaking new sensors. The benefits of these cameras over incumbent systems will be discussed as well as the benefits of enhanced infrared sensitivity for biometric image capture.

Demonstrated performance characteristics:

Camera: IP based zoom block camera

Pixel size : 5.6 & 10 um

Array size: SVGA, 720P and SXGA

Frame rate: 60 Hz

Read noise: 2 ele/pixel

Spectral sensitivity: 400 to 1200 nm (with 10x QE at 1064nm)

Daytime imaging: color (Bayer pattern)

Nighttime imaging: down below ¼ moon conditions

1064nm laser imaging: below 10 uJ in room light conditions

8712-20, Session PThu1

Detection of latent fingerprints by ultraviolet spectral imaging

Wei Huang, Guiqiang Wang, Xiaojing Xu, Institute of Forensic Science (China)

Spectral imaging technology research is becoming more extensive in the field of examination of material evidence. Ultraviolet spectral imaging technology is an important part of the full spectrum of imaging technology. Due to the limitations of previous devices, most research has focused on technology of the near-infrared light and visible light. The study of ultraviolet spectral imaging technology is much fewer. This paper summarizes the application of the results of ultraviolet imaging technology in the field of forensic science, explores the common object of latent fingerprints of ultraviolet spectra characteristic for the research objectives, which shows the potential traces of criminal using the ultraviolet spectrum imaging method.

This paper finished the experiment contents of the ultraviolet spectrum imaging method and image acquisition system ultraviolet spectral imaging technology. The experiment of ultraviolet spectral imaging method obtains the image set of the ultraviolet spectrum, and formats a pseudo-color images to show the potential traces successfully by processing the set of spectral images; ultraviolet spectral imaging technology explores the technology method of obtaining the image set of ultraviolet spectrometer and image acquisition system, and extensive access to the ultraviolet spectrum information of latent fingerprints on common objects, and study the characteristics of the ultraviolet spectrum.

In this paper, the experimental ultraviolet spectral imaging method for

the ultraviolet spectral imaging technology provides a reference path to practical experience for future experiments. Ultraviolet spectroscopic imaging experiments explores a wide variety of ultraviolet reflectance spectra of the object material curve and its ultraviolet spectrum of imaging modalities, can not only gives a reference for choosing ultraviolet wavelength to show the object surface potential traces of substances, but also gives important data for the ultraviolet spectrum of imaging technology development.

8712-22, Session PThu1

The relationship between 2D static features and 2D dynamic features used in gait recognition

Hamad Alawar, Hassan Ugail, Mumtaz Kamala, David R. Connah, Univ. of Bradford (United Kingdom)

In most gait recognition techniques, both static and dynamic features are used to define a subject’s gait signature. In this study, the existence of a relationship between static and dynamic features was investigated. The correlation coefficient was used to analyse the relationship between the features extracted from the “University of Bradford Multi-Modal Gait Database”. This study includes two dimensional dynamic and static features from 19 subjects. The dynamic features were compromised of Phase-Weighted Magnitudes driven by a Fourier Transform of the temporal rotational data of a subject’s joints (knee, thigh, shoulder, and elbow). The results concluded that there are eleven pairs of features that are considered significantly correlated with ($p<0.05$). This result indicates the existence of a statistical relationship between static and dynamics features, which challenges the results of several similar studies. These results bare great potential for further research into the area, and would potentially contribute to the creation of a gait signature using latent data.

8712-23, Session PThu1

Investigating gait recognition in the short-wave infrared (SWIR) spectrum: dataset and challenges

Brian DeCann, Arun A. Ross, Jeremy M. Dawson, West Virginia Univ. (United States)

In the biometrics community, challenge datasets are often released to determine the robustness of state-of-the-art algorithms to conditions that can confound recognition accuracy. In the context of automated human gait recognition, evaluation has predominantly been conducted on video data acquired in the active visible spectral band, although recent literature has explored recognition in the passive thermal band. The advent of sophisticated sensors has piqued interest in performing gait recognition in other spectral bands such as short wave infrared (SWIR), due to their use in military-based tactical applications and the possibility of operating in nighttime environments. Further, in many operational scenarios, the environmental variables are not controlled, thereby posing several challenges to traditional recognition schemes. In this work, we discuss the possibility of performing gait recognition in the SWIR spectrum by first assembling a dataset, referred to as the WVU Outdoor SWIR Gait (WOSG) Dataset, and then evaluate the performance of three gait recognition algorithms on the dataset. The dataset consists of 155 subjects and represents gait information acquired under multiple walking paths in an uncontrolled, outdoor environment. Detailed experimental analysis suggests the benefits of distributing this new challenging dataset to the broader research community. In particular, the following observations were made: (a) the importance of SWIR imagery in acquiring data covertly for surveillance applications; (b) the difficulty in extracting human silhouettes in low-contrast SWIR imagery; (c) the impact of silhouette quality on overall recognition accuracy; (d) the possibility of matching gait sequences pertaining to different walking trajectories; and (e) the need for developing sophisticated gait recognition algorithms to handle data acquired in unconstrained environments.

8712-24, Session PThu1

Palm Vein for Efficient Person Recognition Based on 2D Gabor Filter

Jixing Wang, Yuqing He, Jiadan Zhu, Xinru Gao, Beijing Institute of Technology (China); Yongsheng Cui, Zhejiang Univ. (China)

Palm vein recognition uses the vascular patterns of an individual’s palm as personal identification data. A palm vein recognition system typically performs the following steps: Image Acquisition, Preprocessing, Feature Extraction and Recognition. This paper presents an effective palm vein extraction of the region of interest (ROI) and feature extraction approach for improving the efficiency of palm vein identification. In preprocessing, we locate the finger-web to extract approximate immovable ROI of palm vein image. we also adopt Gaussian filter to smooth the image and filter some noise. In feature extraction, multiple 2D Gabor filters with 4 orientations (0 °, 45 °, 90 ° and 135°) are employed to extract the phase information on the ROI of palm vein image. The real part of the Gabor coefficient of every pixel is used to encode as the distinctive feature of palm vein image. Since there are four 4 directions Gabor filter to extract features in a image, the final feature is 4-rank binary string. In Palm vein recognition we choose Hamming distance (HD) classifier to identify the palm vein features. We conduct experiments on a self-made palm vein database including 800 images of 80 hands. We evaluate our method with different parameters of Gabor filter. Furthermore, we compare our method with another 2 methods (2D-FLD, Triangulation and Knuckle Shape) to demonstrate the superiority of our method. Experimental results show that the method in this paper achieved a higher correct recognition rate (98.73%) and a faster speed.

8712-25, Session PThu1

Effects of mascara on iris recognition

Jay Doyle, Patrick J. Flynn, Kevin W. Bowyer, Univ. of Notre Dame (United States)

Iris biometrics systems rely on analysis of a visual presentation of the human iris, which must be extracted from the periocular region. Topical cosmetics can greatly alter the appearance of the periocular region, and can occlude portions of the iris texture. In this paper, the presence of topical cosmetics is shown to negatively impact the authentic distribution of iris match scores, causing an increase in the false non-match rate at a fixed false match rate.

8712-26, Session PThu1

A red-eye detector for iris segmentation using shape context

Changpeng Ti, Univ. of Kentucky (United States); Xinyu Huang, Alade Tokuta, North Carolina Central Univ. (United States); Ruigang Yang, Univ. of Kentucky (United States)

In iris recognition systems, it is essential to accurately locate the pupil and iris. Among segmentation algorithms for systems utilizing near-infrared light, some make the assumption that the pupil is darker than the rest of the image. For this class of algorithms, the red eye effect, which makes the pupil region brighter than the iris, could damage their performance. Other segmentation algorithms use edge information to fit circles, yet noisy images make them inaccurate. Therefore, it would be desirable to use different segmentation algorithms for images with the red eye effect and without. In this paper, we introduce a novel method which distinguishes iris images exhibiting the red eye effect from those with a dark pupil. Our detector starts with a 2D darkness map of the iris image, and generates a customized shape context descriptor from the estimated pupil region. The descriptor is then compared with the reference descriptor, generated from a number of training images with dark pupils. The distance to the reference descriptor is used to define how close the

estimated pupil region is from a dark pupil. Tests with images captured with our own acquisition system shows the proposed pupil detector is highly effective.

8712-27, Session PThu1

Ear recognition: a complete system

Ayman A. Abaza, Mary Ann F. Harrison, West Virginia High Technology Consortium Foundation (United States)

Ear Recognition has recently received significant attention in the literature. This paper presents an efficient complete ear-based biometric system that can process five frames/sec; Hence it can be used for surveillance applications. The ear detection is achieved using Haar features arranged in a cascaded Adaboost classifier. We propose the use of the Block-based Local Binary Pattern (LBP) to generate features for ear recognition. We present detailed experiments to evaluate:

- Performance optimization by tuning various LBP parameters such as the uniform pattern, number of neighbor pixels, radius of neighbor pixels, division of the input image into blocks, and feature selection techniques to assign weights for the blocks.

- The LBP performance compared to bench mark techniques such as the principal component analysis (PCA), and scale-invariant feature transform (SIFT). Detailed experiments show that the proposed ear recognition system achieves identification rate (rank1 = 94.34%) compared to Scale-invariant feature transform (67.92%).

- The error accumulates from automation of various components of the ear system. The identification rate (rank-1) for the mentioned experiment: (i) 94.34% using manually segmented and aligned ear regions, (ii) 93.33% using automated alignment but manually segmentation, and (iii) 83.50% using automated detection and alignment. The general drop in performance returns to segmentation accuracy, in other words the system detects an ear but does not accurately segment the ear region.

- The system performance in case of occlusion. Experimental results show that the proposed system can achieve about (78%) rank-1 identification rate, even in presence of 60% occlusion.

8712-28, Session PThu1

An efficient visualization method for analyzing biometric data

Mark D. Rahmes, Michael D. McGonagle, John H. Yates, Ronda R. Henning, Jay K. Hackett, Harris Corp. (United States)

We introduce a novel application for biometric data analysis. This technology can be used as part of a unique and systematic approach designed to augment existing processing chains. Our system provides image quality control and analysis capabilities. We show how analysis and efficient visualization are used as part of an automated process. The goal of this system is to provide a unified platform for the analysis of biometric images that reduce manual effort and increase the likelihood of a match being brought to an examiners attention from either a manual or "Lights Out" application. We discuss the functionality of FeatureSCOPETM which provides an efficient tool for feature analysis and quality control of biometric extracted features. Biometric databases must be checked for accuracy for a large volume of data attributes. Our solution accelerates review of features by a factor of up to 100 times faster. Review of qualitative results and cost reduction is shown by using efficient parallel visual review capability for quality control. Our process automatically sorts and filters features for examination, and packs these into a condensed view. An analyst can then rapidly page through screens of features and flag and annotate as necessary.

8712-29, Session PThu1

Secure voice based authentication for mobile devices: vaulted voice verification

R. C. Johnson, Univ. of Colorado at Colorado Springs (United States); Walter J. Scheirer, Harvard Univ. (United States); Terrance E. Boult, Univ. of Colorado at Colorado Springs (United States)

As the use of biometrics becomes more wide-spread, the privacy concerns that stem from the use of biometrics are becoming more apparent. As the usage of mobile devices grows, so does the desire to implement biometric identification into such devices. A large majority of mobile devices being used are mobile phones. While work is being done to implement different types of biometrics into mobile phones, such as photo based biometrics, voice is a more natural choice. The idea of voice as a biometric identifier has been around a long time. One of the major concerns with using voice as an identifier is the instability of voice. We have developed a protocol that addresses those instabilities and preserves privacy. This paper describes a novel protocol that allows a user to authenticate using voice on a mobile/remote device without compromising their privacy. We first discuss the Vaulted Verification protocol, which has recently been introduced in research literature, and then describe its limitations. We then introduce a novel adaptation and extension of the Vaulted Verification protocol to voice, dubbed Vaulted Voice Verification (V 3). Following that we show a performance evaluation and then conclude with a discussion of security and future work.

8712-15, Session PThu2

How reliable are your visual attributes?

Walter J. Scheirer, Univ. of Colorado at Colorado Springs (United States); Neeraj Kumar, University of Washington (United States); Vijay Iyer, Securics, Inc. (United States); Peter Belhumeur, Columbia University (United States); Terrance Boult, Securics, Inc. (United States)

Describable visual attributes are a powerful way to label parts of an image, and taken together, build a detailed representation of a scene's appearance. Attributes enable highly accurate approaches to a variety of tasks, including object recognition, face recognition and image retrieval. Recent published results have shown that attributes outperform more traditional recognition algorithms over the latest unconstrained face data sets, justifying their potential for real-world applications. An important consideration not previously addressed in the literature is the reliability of attribute classifiers as the relative quality of an image degrades. In this paper, we introduce a general framework for conducting reliability studies that assesses attribute classifier accuracy as a function of image degradation. This framework allows us to bound, in a probabilistic manner, the input imagery that is deemed acceptable for consideration by the attribute system, leading to fewer inaccurate results. To demonstrate the utility of our framework, we present an extensive case study incorporating 64 unique facial attributes.

8712-16, Session PThu2

Local gradient Gabor pattern (LGGP) with applications in face recognition, cross-spectral matching, and soft biometrics

Cunjian Chen, Arun A. Ross, West Virginia Univ. (United States)

Researchers in face recognition have been using Gabor filters for image representation due to their robustness to complex variations in texture and illumination. Numerous methods have been proposed to model the output of filter responses by employing either local or global descriptors. In this work, we propose a novel but simple approach for encoding

Gradient information on Gabor-transformed images to represent the facial features, which can be flexibly used to predict identity, gender and ethnicity. Extensive results obtained from the standard face benchmark FERET (Visible versus Visible), as well as the heterogeneous face dataset HFB (Near-infrared versus Visible), suggest that the performance due to the proposed descriptor is comparable against state-of-the-art approaches in face recognition applications. Furthermore, the same feature set in the framework of a Collaborative Representation Classification (CRC) scheme based on Sparse Representation Classification (SRC) is demonstrated to be effective in deducing soft biometric traits such as gender and ethnicity from face images in the AR, Morph and CAS-PEAL databases.

8712-17, Session PThu2

Color constancy in 3D-2D face recognition

Manuel Meyer, Christian Riess, Elli Angelopoulou, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Georgios Evangelopoulos, Ioannis Kakadiaris, Univ. of Houston (United States)

Face recognition is one of the most popular biometric modalities. However, up to now, color is rarely actively used in face recognition. In contrast, it is known that when a person recognizes a face, color cues can become as important as shape, especially when combined with the ability of people to identify the color of objects independent of illuminant color variations. In this paper, we examine the feasibility and effect of explicitly embedding illuminant color information in face recognition systems. We empirically examine the theoretical maximum gain of including known illuminant color to a 3D-2D face recognition system. We also investigate the impact of using computational color constancy methods for estimating the illuminant color, which is then incorporated into the face recognition framework. Our experiments show that under close-to-ideal illumination estimates, one can improve face recognition rates by 16%. When the illuminant color is algorithmically estimated, the improvement is approximately 5%. These results suggest that color constancy has a positive impact on face recognition, but the accuracy of the illuminant color estimate has a considerable effect on its benefits.

8712-19, Session PThu2

The impact of specular highlights on 3D-2D face recognition

Vincent Christlein, Christian Riess, Elli Angelopoulou, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Georgios Evangelopulos, Ioannis Kakadiaris, Univ. of Houston (United States)

In this work, we analyze the impact of such highlights on a 3D-2D face recognition system.

8712-21, Session PThu2

ASIE: application specific image enhancement for face recognition

Emil Bilgazyev, Uday Kurkure, Shishir Shah, Ioannis Kakadiaris, Univ. of Houston (United States)

We propose a novel method to enhance low quality images. In this paper, we focus on face recognition.

Wednesday - Thursday 1 –2 May 2013

Part of Proceedings of SPIE Vol. 8713 Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications X

8713-1, Session 1

What's on the horizon for ISR? *(Keynote Presentation)*

Jay Harrison, Mav6, LLC (United States)

No abstract available.

8713-2, Session 1

Sensor and payload considerations for future unmanned vehicles

Harry Koper, John Lehman, Navmar Applied Sciences Corp. (United States)

Current military operations in uncontested airspace have permitted the use of various types of turret mounted video sensors to collect persistent types of imagery of high valued targets day and night. In the future, with the high probability of operating in contested airspace against lethal air to air and ground to air threats, can current tactics, vehicles and sensors provide the quantity and quality of imagery required? This paper will entertain how sensor and payload performance when fused with emerging technology and complimentary tactics will provide a capability that permits operation in a high threat environment. Future reconnaissance systems will have to be capable of collecting the required amount and acuity level of imagery under entirely different operational conditions that exist in the current theater of operations. Topics presented will include the following: trade-offs between the use of framing versus push broom sensors, imagery recorder requirements, data link performance, data rate and data storage requirements. Vehicle, sensor payload performance and operational considerations will be addressed. Future payload design considerations will be presented along with concepts of operations on the use of futuristic payloads. A major consideration presented will address current paradigms and tactics might have to be modified to meet the needs and requirements of various users in the future. Projected sensor designs, payload performance and operational tactics envisioned for the future will be presented.

8713-3, Session 1

Gadget: a new model for tactical manned reconnaissance

Bekir Arapsun, Adem Bora, Turkish Air Force (Turkey)

Fighter aircrafts are generally designed for attack, defense or reconnaissance (recce) missions. Since unmanned systems like UAV's and satellites are used for recce, the manned tactical recce assets will not be in produce anymore. In this situation, recce missions will be performed by any strike aircraft, as manned systems. Since UAVs designed for recce missions can only fly at lower speed and satellites can take photo at desired point lately, both of them are incapable of especially post attack recce needs. At this point, the importance of tactical manned recce, which has capability of high speed, all weather condition and low altitude is easily understood. Yet, a recce missions performed by a strike fighter reveals a concept dilemma between ISR and Non Traditional ISR (NTISR). For instance, if this aircraft takes information for recce with the help of its radar, SAR, targeting pods, this consept is called NTISR. But, if it executes mission with recce pods, this is called ISR. So, the question:"what kind of a recce architecture can solve this problem?" is defined as the main objective of the study.

In this study, Turkish Air Force (TurAF) recce architecture is analyzed and Gadget model is built as a new one. It provides modern strike aircraft to be included in architecture as a main recce systems, which is divided into two parts as "soft recce" and "smart recce" to execute "recce-based-attack". Furthermore, NTISR is defined as "Auxiliary Systems For Recce" and ISR-NTISR dilemma is solved with the help of 7-year-experience as reconnaissance pilot.

8713-5, Session 1

Validating a UAV artificial intelligence control system using an autonomous test case generator

Jeremy Straub, The Univ. of North Dakota (United States)

The validation of safety-critical applications, such as autonomous UAV operations in an unknown environment which may include human actors, is an ill posed problem. To create user and regulator confidence in the autonomous control technology, a multitude of prospective scenarios must be considered, many of which cannot be preconceived. Numerous combinations of approach vectors, failure states and other factors must be explored. In addition to the extreme expense of human-based design of these tests, humans may introduce (in many cases unintended) bias towards or away from various test conditions or types of testing. This paper expands upon previous work, related to autonomous testing of robotic control algorithms in a two dimensional plane, to evaluate the suitability of similar techniques for validating artificial intelligence control in three dimensions, where a minimum level of airspeed must be maintained. The challenges of simulating this environment for testing artificial intelligence techniques (without confounding the results with sensor and other issue-factors) are discussed. The testing environment and conditions are presented. A near-worst-case scenario of a craft that attempts to position itself to be struck by the AI system under test (it will not collide with the AI craft, but will try to cause the AI craft to collide with it) is utilized to validate the performance of a limited-scope flight control AI. The results of human-conducted testing are compared to this automated testing, in terms of error detection, speed and testing cost. The cost benefits and other efficiencies of the automated testing approach are detailed.

8713-45, Session 1

Solution space exploration of volumetric surveillance using a general taxonomy

Naeem Ahmad, Muhammad Imran, Khursheed Khursheed, Najeem Lawal, Mattias O'Nils, Mid Sweden Univ. (Sweden)

Visual surveillance systems provide real time monitoring of the events or the environment. The availability of low cost sensors and processors has increased the number of possible applications of these kinds of systems. However, designing an optimized visual surveillance system for a given application is a challenging task, which often becomes a unique design task for each system. Moreover, the choice of components for a given surveillance application out of a wide spectrum of available products is not an easy job. In this paper, we propose a general surveillance taxonomy as a base to structure the analysis and development of surveillance systems. We demonstrate the proposed method for designing a vision surveillance system for monitoring the movement of eagles in wind parks aiming to avoid their collision with wind mills. The analysis of the problem is performed based on taxonomy and behavioral and implementation models are identified to formulate the solution space to solve the problem.

8713-6, Session 2

Advanced metal mirror processing for tactical ISR systems

John Schaefer, Raytheon EO Innovations (United States)

Raytheon EO Innovations has been producing low scatter, low figure, and affordable aluminum 6061 based mirrors in production since 2005 for long stand-off ISR systems using our patented VQ™ finishing process. These common aperture multi-spectral systems typically require λ/30 mirror figure and sub-20Å RMS finishes for optimal visible imaging performance. Reflective, common aperture architecture enables multi-spectral performance and exceptional bore sight stability for long range targeting. This paper will discusses process results, scatter performance, fabrication capabilities, and will introduce a new lightweight substrate material, MeRLOT™ that is enabling common aperture, broad-band performance to be scaled down and put in the hands of the warfighter for precision targeting and surveillance operations.

8713-7, Session 2

Cost effective multispectral three-mirror anastigmat imaging system for high-performance surveillance applications using electroformed free-form mirrors

Massimiliano Rossi, Robert Banham, Media Lario Technologies (Italy); Davide Blandino, Optec S.p.A. (Italy); Giuseppe Borghi, Ivan Ferrario, Media Lario Technologies (Italy); Roberto Formaro, Agenzia Spaziale Italiana (Italy); Wolf C. Glage, Raytheon ELCAN Optical Technologies (Canada); Nadia Missaglia, Stefano Moretti, Media Lario Technologies (Italy); Iain A. Neil, ScotOptix (Switzerland); Antonio Ritucci, Media Lario Technologies (Italy); Antonio Sposito, Agenzia Spaziale Italiana (Italy); Viktor P. Syvokin, Raytheon ELCAN Optical Technologies (Canada); Giuseppe Valsecchi, Paolo Zago, Fabio E. Zocchi, Media Lario Technologies (Italy)

Limitations in the shape of mirrors due to manufacturing and cost constraints make it difficult to achieve satisfactory compactness, fast F-number, and good aberration correction in conventional multispectral imaging systems. A three-mirror anastigmat (TMA) imaging system overcoming these limitations has been designed and manufactured by using thin free-form mirrors produced by electroforming replicas of negative masters. With this approach, manufacturing complexity and cost are directed towards fabrication of the masters, the contribution of which to the imaging system cost decreases with the number of replicas, achieving substantial series production cost/cycle time saving. At the same time, electroforming replication allows the manufacturing of thin mirrors with a thickness of the order of 1 mm, helping to keep the overall mass below 3 kg.

The TMA that has been developed and tested employs F/1.4 optics with a focal length of 136 mm and a field of view of 4.3°x3.1°, and nominally provides a contrast better than 75% in the visible wavelength band at 25 cycles/mm. The optical design is free from vignetting, provides a cold stop position, and has low distortion. By means of a beam-splitter, the imaging system provides two optical output channels, one in the visible and one in the LWIR waveband.

Thermal and structural design and analysis have been done to comply with typical airborne conditions. Stray light analysis has been also performed, leading to a preliminary baffle design.

The design of the instrument and the as-built measured performance are presented in this paper.

8713-8, Session 2

Gimbal system configurations and line-of-sight control techniques for small UAV applications

Rick Miller, Greg Mooty, Ascendant Engineering Solutions LLC (United States); James M. Hilkert, Alpha-Theta Technologies (United States)

The proliferation of small Unmanned Air Vehicles (UAVs) in the past decade has been driven, in part, by the diverse applications that various industries have found for these platforms. Originally, these applications were predominately military in nature but now include law enforcement / security, environmental monitoring / remote sensing, agricultural surveying, movie making and others. Many of these require sensors / payloads such as cameras, laser pointer / markers / designators and even weapon systems that must be pointed and/or stabilized and therefore require a precision miniature gimbal or other means to control their line-of-sight (LOS). Until now, these markets have been served by traditional / larger gimbals; however, the latest class of small UAVs demand much smaller gimbals while maintaining high-performance. The limited size and weight of these gimbaled devices result in design challenges unique to the small-gimbal design field. In the past five years, Ascendant Engineering Solutions has engaged in designing, analyzing and building several small-gimbal systems to meet these challenges and has undertaken a number of trade studies to investigate techniques to achieve optimal performance within the inherent limitations mentioned above. These have included investigating various gimbal configurations, feedback sensors such as gyros, IMUs and encoders, drive train configurations, control system techniques, packaging and interconnect, as well as technology such as fast-steering-mirrors and anti-blur algorithms. This paper summarizes the results of these trade studies, attempts to identify inherent trends and limitations in the various design approaches and techniques, and discusses some practical issues such as test and verification.

8713-46, Session 2

A lightweight and wide-swath UAV camera for high-resolution surveillance missions

Bavo Delauré, Tanja Van Achteren, Bart Michiels, VITO NV (Belgium)

Designed to execute mapping and surveillance missions for crisis monitoring on a solar powered UAV 18 km high up in the stratosphere, the MEDUSA high resolution camera is able to acquire frame images with a ground sampling distance of 30 cm and swath of 3 km. Since mass is a dominant driver for the UAV performance the MEDUSA payload was severely mass optimised to fit within the physical boundaries of 2.6 kg, 12 cm diameter and 1 m length. An inertial navigation system and data transmission equipment is included. Due to the innovative dual sensor on single chip concept the MEDUSA payload hosts two independent frame camera's of each 10000x1200 pixels (one panchromatic and one colour sensitive). The MEDUSA stratospheric camera has completed its system level test campaign in autumn 2012 and is ready for its maiden flight.

Using the main building blocks of this stratospheric camera a modified version is being developed which is adapted to more conventional UAV's flying at lower altitude. The current design is targeting a ground resolution of 10 cm and swath of 1 km with each single image. First test flights have been conducted with an engineering model version of the camera generating representative image data. Also the functionality is being expanded by adding hyperspectral sensitivity to high spatial resolution image acquisition within the same compact camera system. The presentation will address the MEDUSA stratospheric camera and the derived camera developments.

8713-9, Session 3

LaserCom in UAS missions: benefits and operational aspects

Wolfgang Griethe, Frank F. Heine, Tesat-Spacecom GmbH & Co. KG (Germany); Lester L. Begg, Detao Du, General Atomics Aeronautical Systems, Inc. (United States)

Optical communication has made significant progress in recent years. With the successful in-orbit verification of Tesat's Laser Communication Terminal (LCT), the coherent homodyne BPSK scheme advanced to a standard for optical free-space communication which now prevails more and more. The LCT from Tesat is located not only on satellites like TerraSAR-X and NFIRE in Low Earth Orbit (LEO), with spacecrafts like Alphasat and EDRS the terminal will also exist in Geosynchronous Orbit (GEO) in the near future. In other words, the LCT from Tesat has reached its practical application.

With existence of such space assets the time has come for other utilizations beyond of establishing optical inter-satellite links. Aeronautical applications, as for instance HALE / MALE UAS, have to be addressed because the need to transfer large amounts of data in near real-time is evident for UAS missions. In view of the global connectivity of sensors, decision makers and shooters, LaserCom can yield extended possibilities.

The paper describes driving factors and advantages of LaserCom in HALE / MALE UAS missions. It shows in which way the laser link can contribute also to the safety of the platform, as for instance by plausibility check of SatNav signals or by increasing the interference immunity of the radio Command and Control (C2) link. Moreover, numerous practice-related issues are discussed, which are associated with the introduction of this technology in HALE / MALE platforms. That concerns the space segment, the airborne segment as well as the ground segment. Typical examples for these issues are

- the design of the airborne LCT as counterpart to the spaceborne LCT
- the strategy for Pointing, Acquisition and Tracking (PAT)
- the dimensioning of the Forward Downlinks and the Return Uplink and
- the Concept of Operations (CONOPS).

The paper highlights LaserCom as enabler for the integration of air and space-based wideband Intelligence, Surveillance & Reconnaissance (ISR) systems into military command and control systems in a way that was not possible until now.

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8713-10, Session 3

An autonomous surveillance system for blind sources localization and separation

Sean F. Wu, Raghavendra Kulkarni, Wayne State Univ. (United States); Srikanth Duraiswamy, Wayne State University (United States)

This paper aims at developing a technology that enables one to conduct an autonomous and silent surveillance to monitor sound sources stationary or moving in 3D space and a blind separation of target acoustic signals. The underlying principle of this technology is a hybrid approach that uses: 1) passive sonic detection and ranging method that consists of iterative triangulation and redundant checking to locate the Cartesian coordinates of arbitrary sound sources in 3D space, 2) advanced signal processing including the wavelet transform to sanitizing the measured data, and 3) impulse response functions and convolution integrals to extract target acoustic signals. A prototype based on this technology is developed and its hardware includes six B&K ¼-in condenser microphones, Type 4935, two 4-channel data acquisition units, Type NI-9234, with a maximum sampling rate of 51.2kS/s per channel, one NI-cDAQ 9174 chassis, a thermometer to measure the air temperature, a camera to view the relative positions of located sources, and a laptop to control data acquisition and post processing. Test results for locating arbitrary sound sources emitting continuous, random, impulsive, and transient signals, and blind sources separation in various non-ideal environments are presented. This system is invisible to any anti-surveillance device because it uses the acoustic signal emitted by a target source. It can be mounted on a robot or an unmanned vehicle to perform a variety of covert operations, including intelligence gathering in an open or a confined field, and rescue mission to search people trapped inside ruins or buried under wreckage.

8713-11, Session 4

AV Sentry®: a high-dynamic range, ultra-low noise ROIC for the visible through the infrared bandwidths

John C. Liobe, ADVIS, Inc. (United States); Zhe Gao, Zeljko Ignjatovic, Mark F. Bocko, Univ. of Rochester (United States)

Imaging systems for intelligence, surveillance and reconnaissance applications have highly demanding and often, conflicting requirements. To obtain useful information from a scene, high dynamic range, high signal to noise, and high-resolution images are needed. However such performance must be achieved with a limited power budget and often times, severe size and weight constraints. Transmission of the flood of raw data from an imaging system is often impractical in remote viewing applications so in-camera integration of video analytics is another highly desirable feature for ISR systems, which makes further demands on the system power budget. Ideally, an ISR sensor could operate in a "monitoring" mode, perhaps with reduced resolution and image bit-depth, to collect only enough information to ascertain whether a specific target-of-interest is present. This event could trigger a closer look where resolution and image quality could be increased and additional information extracted. Such a scheme requires a sensor capable of on-the-fly reconfigurability. In addition, ISR applications span the electromagnetic spectrum from infrared to x-rays and span a large range of flux levels. Typically, ReadOut Integrated Circuits (ROICs) are designed to meet the specifications of one region of this spectrum: visible, infrared (IR), or X-ray. The ADVIS AV Sentry® ROIC technology utilizes proprietary digital signal processing techniques within each pixel to simultaneously achieve the low readout-noise levels essential for the inspection of the visible segment, the high dynamic range to prevent saturation for the IR band, and fast frame and sample rates for the study of X-rays. This scheme leverages the performance benefits of both an oversampling and an algorithmic analog-to-digital converter (ADC) at each pixel location employing a common architecture. A prototype, visible-spectrum sensor with a 320 x 180 pixel array has been developed in a generic 0.35-µm CMOS process and results will be presented.

8713-14, Session 4

A long-wave infrared hyperspectral sensor for Shadow class UAVs

Paul G. Lucey, Univ. of Hawai'i (United States); Jason T. Akagi, John L. Hinrichs, Spectrum Photonics, Inc. (United States); Sarah T. Crites, Univ. of Hawai'i (United States)

We have developed an airborne LWIR hyperspectral imaging system intended for use in Shadow class UAVs. The sensor features a 20 kg mass in a 20x15x45 cm package that consumes 20W power. The sensor also features 10 minutes from power on to data collection readiness. The sensor is an uncooled static Sagnac spectral interferometer with a cooled HgCdTe focal plane in a standard camera package. The sensor is operated in pushbroom mode, and with the current cameras, has a 320 element swath width and a spectral resolution of 20 wavenumbers yielding 23 bands from 8-10.5 microns. The current optics and camera provides 20 cm ground resolution operating from 3500 ft at 100 kt airspeed. We have tested the sensor in commercial air survey aircraft and obtained spectral imagery and detection of solid chemicals and chemical vapors. Long range optics designed but not yet built would provide similar ground sample distances from 10,000 ft.

8713-15, Session 4

Novel compact airborne platform for Hyper-Cam infrared hyperspectral imager for intelligence, surveillance, and reconnaissance

Caroline S. Turcotte, Eldon Puckrin, Defence Research and Development Canada, Valcartier (Canada); Marc-André Gagnon, Jean-Alexis Boulet, Francoys Aube, Vincent Farley, Martin Chamberland, Telops (Canada)

Persistent surveillance and collection of airborne intelligence, surveillance and reconnaissance information is critical in today's warfare against terrorism. High resolution imagery in visible and infrared bands provides valuable detection capabilities based on target shapes and temperatures. However, the spectral resolution provided by a hyperspectral imager adds a spectral dimension to the measurements, leading to additional tools for detection and identification of targets, based on their spectral signature.

The Telops Hyper-Cam sensor is an interferometer-based imaging system that enables the spatial and spectral analysis of targets using a single sensor. It is based on the Fourier-transform technology yielding high spectral resolution and enabling high accuracy radiometric calibration. It provides datacubes of up to 320×256 pixels at spectral resolutions as fine as 0.25 cm-1. The LWIR version covers the 8.0 to 11.8 µm spectral range. The Hyper-Cam has been recently integrated and floan on a novel airborne gyro-stabilized platform in a fixed-wing aircraft.

The new platform, more compact and more advanced than its predecessor, is described in this paper. The first results of target detection and identification are also presented.

8713-17, Session 5

Low-light NV-CMOS(TM) image sensors for day/night imaging

Thomas L. Vogelsong, John Tower, Thomas Senko, Peter A. Levine, Judy Zhu, David C. Zhang, Gooitzen S. van der Wal, SRI International Sarnoff (United States)

Traditionally, daylight and night vision imaging systems have required image intensifiers plus daytime cameras. But SRI's new NV-CMOS image sensor technology is designed to capture images over the full range of illumination from bright sunlight to overcast starlight. SRI's low-light NV-CMOS image sensors provide the low light sensitivity previously only achievable with an analog image intensifier tube with the cost, power, ruggedness, flexibility and convenience of a digital CMOS imager chip. NV-CMOS provides multi-megapixels at video frame rates with low noise (<2 e-), high sensitivity across the visible and near infrared (NIR) bands (peak QE >90%), high resolution (MTF at Nyquist > 50%), and extended dynamic range (>90 dB). The latest test data from the NV-CMOS imager technology will be presented.

Unlike conventional image intensifiers, the NV-CMOS image sensor outputs a digital signal, ideal for recording or sharing video as well as fusion with thermal imagery. The result is a substantial reduction in weight, power and size, ideal for SWaP-constrained missions such as UAV's and mobile operations. SRI's motion adaptive noise reduction processing further increases the sensitivity and reduces image smear. Enhancement of moving targets in imagery captured under extreme low light conditions imposes difficult challenges. SRI has demonstrated that image registration provides a robust solution for enhancing global scene content under very low SNR conditions, improving sensitivity by up to 10x. In this paper, we present a method for enhancing global scene SNR as well as detecting and enhancing locally moving objects in the scene.

8713-18, Session 5

The capability of time- and frequency-domain algorithms for bistatic SAR processing

Viet T. Vu, Thomas K. Sjögren, Mats I. Pettersson, Blekinge Institute of Technology (Sweden)

Bistatic SAR processing is based on algorithms which can be divided in two groups: time- and frequency-domain. The time-domain algorithms refer to the backprojection algorithms such as BiGBP, BiFBP, and BiFFBP [1],[2]. The processing of these algorithms is performed only in time-domain whereas other algorithms such as BiRDA [3], BiCSA [4] and BiRMA [5] process the SAR data in frequency domain. In the monostatic case, the frequency-domain algorithms generally have the advantage of processing time over time-domain algorithms. However, the frequency-domain algorithms show the limitations while time-domain algorithms do not.

The choice of an algorithm is seen as a practical issue in bistatic SAR processing. Bases for this choice can be operating frequency range, motion error, ratio of aperture length to minimum range and required number of operations and thus determine the capability of algorithms.

The aim of this study is to investigate the capability of time and frequency-domain algorithms for bistatic SAR processing. Two algorithms, BiFBP and BiRDA, are selected for the investigations. The algorithms are examined with two different sets of parameters. One is of LORA [6], a NB system, and the other CARABAS-II [7], a UWB system. The simulation results indicate that both BiFBP and BiRDA work well with the simulated LORA data. However, BiRDA faces to different challenges when it is used for the simulated CARABAS-II data while BiFBP does not. The processing time of BiRDA is analytically and experimentally shown to be shorter than the one of BiFBP. Thanks to the flexibility of BiFBP, there are also different ways to shorten its processing time.

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8713-19, Session 5

Another possibility to focus moving targets by normalized relative speed in UWB SAR

Viet T. Vu, Thomas K. Sjögren, Mats I. Pettersson, Blekinge Tekniska Högskola (Sweden)

One of the most crucial applications of SAR is GMTI as it is of interest to both military and civilian end users. Among the available GMTI methods, the moving target detection by focusing technique [1] is considered as a promising technique aiming at UWB SAR systems such as CARABAS-II [2], LORA [3] and P-3 [4]. The technique has been experimented with different sets of data collected by CARABAS-II [1]. However, an extension of the technique to complicated cases like bistatic SAR may not be possible.

The limitation of the technique originates from the assumptions in the derivation of the focusing approach. Hence, in the derivation [1], the flight track of a platform is assumed to be parallel to the x-axis of the Cartesian coordinate system. Also, the derivation is strongly related to the minimum range of a target. However, such assumptions may not be fulfilled in more complicated cases, e.g. bistatic SAR. For bistatic SAR, the flight tracks of the transmitting and receiving platforms may not be parallel. The minimum ranges may not be simultaneously obtained for both the platforms.

The objective of this paper is to investigate the limitation of the currently used focusing approach and to propose a new one which allows extending the technique to complicated cases like bistatic SAR. The proposal in this paper is validated and examined with both the simulated data and the real data. It is also extended to the bistatic case and shown to overcome the limitation of the original approach. CARABAS-II is selected as a reference system in this research work.

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8713-20, Session 6

Real-time focal-plane wavefront sensing for compact imaging phased-array telescopes: numerical and experimental demonstration

Bertrand Denolle, Frédéric Cassaing, Joseph Montri, ONERA (France); Jean-Philippe Amans, Observatoire de Paris à Meudon (France)

Phase retrieval and phase diversity are wavefront sensing techniques fed by focal-plane data. In phase retrieval, the incoming wavefront is estimated from a single (near-) focal image of an unresolved source. In phase diversity, from at least two images of the same (complex) object recorded in presence of a known optical aberration (eg. defocus), both the unknown incoming wavefront and the observed object can be derived. These two techniques have many advantages: the hardware is limited to (or can be merged in) the usual imaging sensor, the number of estimated modes can be continuously tuned and both are one of the very few methods enabling the measurement of differential pistons/tip/tilts on segmented or divided apertures. The counterpart is that complexity is reported to digital processing, which is either iterative and long, or fast but limited to a first-order phase expansion.

Based on an innovative physical approach and mathematical inversion, resulting from 20 years of work on stellar interferometers or imaging spaceborne telescopes, new simple, analytical and exact algorithms have been recently derived for phase retrieval and diversity. Conjugated with recent detector and processor advances, these algorithms can be implemented in adaptive/active optics loops, or even provide a purely-digital on-the-fly alternative.

In this paper, for the first time, we present evaluations of these algorithms: by simulation in a wide range of application cases (object structure, aperture shape, SNR, aberration type and amplitude,…), by comparison with a traditional iterative Maximum a Posteriori algorithm, by experiments with the cophasing of a segmented mirror.

8713-21, Session 6

Computational imaging for aberrated optics (CIAO): experimental results

Robert Saperstein, Eliseo Ranalli, Patrick C. Mock, Anis Husain, Ziva Corp. (United States)

This paper presents simulations and experimental results obtained with a novel image processing algorithm called Computational Imaging for Aberrated Optics (CIAO), which is a multi-image deconvolution algorithm. CIAO enhances the performance of imaging systems by accommodating wavefront error (WFE). This accommodation effectively increases the WFE budget of the imaging system, which allows the designer to improve system performance or reduce system cost. For example, simulations show that CIAO can double the field of view or relax design tolerances to reduce cost by 10X. CIAO has been successfully tested in a wide field of view, foveated imaging system, which has significant aberrations. These experimental results show that CIAO can recover high quality images from highly blurred images at the edge of the field of view. Specifically, CIAO allows the pupil to open 50% beyond the diffraction limited aperture, which allows more light capture and higher cut-off resolution. Alternatively, CIAO can accommodate a commensurate increase in wavefront error with field, allowing higher resolution over an expanded field of view for a given entrance pupil.

8713-22, Session 6

ATCOM: accelerated image processing for terrestrial long-range imaging through atmospheric effects

Petersen F. Curt, Aaron L. Paolini, EM Photonics, Inc. (United States)

Long-range imaging is a critical tool for law enforcement and border security. Enforcers are better protected if they can identify persons of interest or what they may be carrying at safe range. Border security can cover wider areas with fewer long-range sensors deployed. Unfortunately resolution is generally degraded by atmospheric effects when the coherence length approaches the aperture of the imaging system. Larger apertures can reduce the effects, but at the cost of increased SWaP. For better portability, we have developed a real-time digital processing approach.

Originally developed by astronomers, the bispectrum speckle averaging technique is a multi-frame algorithm that can enhance imagery degraded by atmospheric turbulence. The technique deblurs videos by averaging in the bispectral domain to produce diffraction-limited imagery which would otherwise be limited by the atmosphere. Using multi core- and GPU-based techniques, we have accelerated this algorithm to real-time and demonstrated its fieldability using a laptop, cassegrain telescope and digital IR camera. As a result, the potential for enhancement is no longer limited to post-processing in the laboratory, but rather real-time surveillance.

We present the results of our research and implementation, demonstrating the potential for a small portable system capable of identifying signs, faces and objects at long-range.

8713-23, Session 6

A comparison of the mean square error performance of speckle and MFBD image reconstruction techniques under anisoplanatic, long horizontal-path imaging

Glen E. Archer, Jeremy P. Bos, Michael C. Roggemann, Michigan Technological Univ. (United States)

The simulation model assumed uniform atmospheric turbulence distributions along a 1 kilometer path using low, Cn^2 = 2.25x10 -14 m^(-2/3), moderate, Cn^2 = 3.25x10 -14 m^(-2/3)and severe, Cn^2 = 5.25x10 -14 m^(-2/3) turbulence cases. Both bispectrum and Knox-Thompson methods are compared using 5 estimates of the object phase averaged per spatial frequency. For the MFBD reconstruction, the original object and aberration parameters are jointly estimated using multiple input frames. The number of frames and number of Zernike terms were varied for the MFBD technique and the number of input frames was varied for the bispectrum case. 15 input frames were found to be optimal for all three techniques. For MFBD, optimal results were achieved using 30 Zernike coefficients to characterize the aberrations.

The comparison shows that speckle-imaging techniques reduce the mean square error 46%, 42% and 47% on average for low, moderate, and severe cases, respectively using 15 input frames under daytime conditions and moderate frame rates. Similarly, the MFBD method provides, 40%, 25%, and 36% improvements in MSE on average under the same conditions. The comparison is repeated under low light conditions (less than 100 photons per pixel) where improvements of 39%, 29% and 27% are available using speckle imaging methods and 25 input frames and 38%, 34% and 33% respectively for the MFBD method and 150 input frames.

Work is continuing in order to present details on execution time but preliminary results indicate that MFBD is significantly slower than both bispectrum and Knox-Thompson.

8713-24, Session 6

A simple yet effective real-time solution to reduce total information loss in highly-compressed video

Amber D. Fischer, 21st Century Systems, Inc. (United States)

Sensors are only becoming more powerful with increased fields of view at higher resolutions, thus enabling ‘more pixels on target’. However, in accessing this information, the bottleneck is the bandwidth… especially to mobile devices in remote locations where direct network connectivity and WIFI are not an option.

In UAV operations for example, the bandwidth available to access onboard video in real-time can vary significantly and unpredictably for many reasons. Adaptive lossy compression algorithms, such as H.264 and MJPEG2000, provide capability to automatically adjust the compression rate based on the available bandwidth, allowing streaming of video from the UAV to remain uninterrupted. However, this results in a variation in quality from frame to frame of the transmitted video data, potentially omitting or obscuring operationally relevant information.

In this paper, we demonstrate a simple yet effective software-only based solution that provides opportunity to recover information that would otherwise be lost in highly compressed video. Our results demonstrate that you can obtain equal or even smaller size compressed video as compared to the original uniformly compressed video with an obvious quality gain in a subset region of the video. For bandwidth limited environments, our approach can provide opportunity to communicate operationally relevant information in streamed video that would have otherwise been lost.

8713-25, Session 6

A comparative analysis of dynamic range compression techniques in IR images for maritime applications

Alessandro Rossi, Univ. di Pisa (Italy); Nicola Acito, Accademia Navale di Livorno (Italy); Marco Diani, Univ. di Pisa (Italy); Cristian Luison, Altran Italy S.p.A. (Italy); Monica Olivieri, Gianni Barani, SELEX Galileo S.p.A. (Italy)

Modern thermal cameras acquire IR images with a high dynamic range which can be considered as a direct consequence of the joint effects of (i) the high thermal resolution of modern IR devices and (ii) the great temperature changes of monitored scenarios in specific surveillance applications.

Initially developed for visible light images and recently extended for display of IR images, high dynamic range compression (HDRC) techniques aim at furnishing plain images to human operators for a first intuitive comprehension of the sensed scenario without altering the features of IR images.

In this context, the maritime scenario represents a challenging case to test and develop HDRC strategies since images collected for surveillance at sea are typically characterized by high thermal gradients among the background scene and classes of objects at different temperatures.

In the development of a new IRST system, SelexGalileo assembled a demonstrator equipped with modern thermal cameras and planned a measurement campaign on a maritime scenario so as to collect IR sequences in different operating conditions. This has led to build up a case record of situations suitable to test HDRC techniques.

In this work, a survey of HDRC approaches is introduced pointing out advantages and drawbacks with focus on strategies specifically designed to display IR images. A detailed analysis of the performance is discussed in order to address the task of visualization with reference to typical issues of IR maritime images, such as robustness to the horizon effect and displaying of very warm objects and flat areas.

8713-26, Session 7

Material characterization using passive multispectral polarimetric imagery

Melissa Sawyer, Milo W. Hyde IV, Air Force Institute of Technology (United States)

A new method for characterization of unknown targets using passive multispectral polarimetric imagery is presented. Previous work makes use of a pBRDF derived equation for the degree of linear polarization and with the aid of multiple incidence angles estimates refractive index and reflection angle. This work uses known incidence and reflection angles along with dispersion equations and polarimetric data at multiple wavelengths to recover the index of refraction. Experimental results are presented showing the new method's ability to characterize a range of materials.

8713-27, Session 7

An estimation of geometric transformation parameters of the multispectral image based on multiple reference area tracking

Valery V. Strotov, Boris A. Alpatov, Ryazan State Radio Engineering Univ. (Russian Federation)

A new estimation algorithm of the multispectral images geometric transformation parameters is suggested. Multispectral frames appear to be a set of prior aligned grayscale images taken from various video sources in different spectral ranges.

The main idea of the algorithm is to estimate the frame transformation parameters using information about positions of small (32x32 pixels or less) rectangle regions on separated images of this frame. The key features of this algorithm are the procedures of region extraction and replacement. The designed criterion for the optimal reference region extraction is based on minimal position estimation error. The replacing criterion is based on an evaluation of mismatch of the region position to the transformation model. Usage of the described procedures allows decreasing the number of reference regions downto 5-10 in dependency of signal-to-noise ratio. The image transformation parameters can be defined by analyzing the variation of the region positions in neighboring frames.

The experimental research was performed on a set of multispectral frame sequences. The algorithm showed a good performance, noise tolerance and accuracy of image transformation parameter estimation.

The proposed algorithm has been successfully applied in real-time airborne vision system based on Virtex-II FPGAs.

8713-28, Session 7

OREOS: a new EO-IR modeling and simulation tool for US Coast Guard search and rescue applications

Sarah E. Lane, C. Spencer Nichols, Alan M. Thomas, J. Michael Cathcart, Georgia Tech Research Institute (United States)

Georgia Tech has developed a new modeling and simulation tool under the Optimization of Radar and Electro-Optical Sensors (OREOS) program; OREOS is a tool that predicts both RADAR and EO-IR lateral range curves (LRCs) and sweep widths for Coast Guard Search and Rescue (SAR) applications. In a search scenario when the location of the lost or overdue craft is unknown, the Coast Guard will conduct searches based upon standard procedure, personnel expertise, experimental findings, and models. One metric for search planning is the sweep width, or integrated area under a LRC. Because a searching craft is equipped with RADAR and Electro-Optical Infrared (EO-IR) sensor suites, the Coast Guard is interested in accurate predictions of sweep width for the particular search scenario. Here, we will discuss the physical models that make up the EO-IR portion of the OREOS code. First, GTSIG (Georgia Tech SIGnature) generates thermal signatures of search targets based upon the thermal and optical properties of the target and the environment; a renderer then calculates target contrast. Sensor information and these contrasts are input into NVESD models to generate probability of detection (PD) vs. slant range. These PD vs. range values are then converted into LRCs taking into account a continuous look search from a moving platform; sweep widths are then calculated. The OREOS tool differs from previous methods in that physical models are used to predict the LRCs and sweep widths at every step in the process, whereas before heuristic methods were employed to generate final predictions.

8713-29, Session 7

Situational awareness investigation using tracking and enhancement of imagery with highly dynamic lighting conditions

Andrey V. Kanaev, Christopher W. Miller, U.S. Naval Research Lab. (United States); Collin J. Seanor, Jeremy Murray-Krezan, Air Force Research Lab. (United States)

Situational awareness consisting of object detection and identification from low-resolution low-frame rate video collected under highly dynamic lightning conditions is an important but arduous task, necessary for many environments. One way to approach the problem is to enhance image resolution using multi-frame super-resolution (SR) techniques. We investigate applicability of classical SR algorithms that rely heavily on motion estimation between the video frames and nonlocal SR algorithms with implicit motion estimation. Complex motion between the frames is addressed using optical flow (OF) techniques which are based on the assumption of illumination, or image intensity, constancy. The difficulty of applying OF algorithms to highly dynamic lighting conditions is the fact that these conditions often violate the constancy assumption. We examine performance of illumination-change tolerant OF algorithms, which use a gradient based fidelity term, a nonlinearized constancy assumption, and feature tracking. Additionally, low video frame rates may translate into large displacements between images, which represents a significant hurdle to both OF algorithms and SR algorithms with implicit motion estimation. The study of how the values of displacements between images affect OF and SR performance is conducted

8713-30, Session 7

Parallax visualization plug-in toolset for pursuer WAMI data

Christopher A. Mayhew, Craig M. Mayhew, Mark B. Forgues, Vision III Imaging, Inc. (United States)

Effective use of intelligence, surveillance, and reconnaissance (ISR) data gathered by unmanned aerial vehicle (UAV) missions is vital to US Military combat operations. Recently, Parallax Visualization (PV) technologies have been introduced, which: (1) use existing UAV sensor data, (2) provide critical alignment software tools, and (3) produce autostereoscopic ISR work products. These work products can be distributed across military networks and viewed on standard unaided displays.

Parallax Visualization techniques produce a near-three-dimensional visual response to standard two-dimensional UAV WAMI data. Parallax Visualization applies to the WAMI data by the virtue of its overlapping nature. This visualization is accomplished by using software tools to critically align a common point in two views while alternately displaying both views in a square-wave manner. Humans produce an autostereoscopic (automatic depth perception) response to critically aligned parallax information presented using Parallax Visualization on a standard unaided display at frequencies between 3 and 6 hertz.

This simple technique allows for the exploitation of spatial and temporal differences in image sequences to enhance depth, size, and spatial relationships of terrain features and objects in areas of interest. Any two images in a data set that contain different points of view can be visualized in a manner that will render object shapes and ambiguous surface features obvious.

Previous evaluations have established that Parallax Visualization of the ISR full motion video (FMV) data presents three-dimensional information in an obvious and immediate manner. The authors are working with the Air Force Research Lab (AFRL) Sensor Exploitation Applications Branch to develop a WAMI Parallax Visualization Plug-in Toolset for the Pursuer GUI.

8713-31, Session 8

Meta-image navigation augmenters for unmanned aircraft systems (MINA for UAS)

Koray Celik, Arun K. Somani, Iowa State Univ. (United States); Bernard A. Schnaufer, Patrick Y. Hwang, Gary A. McGraw, Jeremy Nadke, Rockwell Collins, Inc. (United States)

GPS is a critical sensor for Unmanned Aircraft Systems (UASs) due to its accuracy, global coverage and small hardware footprint, but is subject to denial due to signal blockage or RF interference. When GPS is unavailable, position, velocity and attitude (PVA) performance from other inertial and air data sensors is not sufficient, especially for small UASs. Recently, image-based navigation algorithms have been developed to address GPS outages for UASs, since most of these platforms already include a camera as standard equipage. Performing absolute navigation with real-time aerial images requires georeferenced data, either images or landmarks, as a reference. Georeferenced imagery is readily available today, but requires a large amount of storage, whereas collections of discrete landmarks are compact but must be generated by pre-processing. An alternative, compact source of georeferenced data having large coverage area is open source vector maps from which meta-objects can be extracted for matching against real-time acquired imagery. We have developed a novel, automated approach called MINA (Meta Image Navigation Augmenters), which is a synergy of machine-vision and machine-learning algorithms for map aided navigation. As opposed to existing image map matching algorithms, MINA utilizes publicly available open source geo-referenced vector map data, such as OpenStreetMap, in conjunction with real-time optical imagery from an on-board, monocular camera to augment the UAV navigation computer when GPS is not available. The MINA approach has been experimentally validated with both actual flight data and flight simulation data and results are presented in the paper.

8713-32, Session 8

Density estimation in aerial images of large crowds for automatic people counting

Christian Herrmann, Juergen Metzler, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Counting people is a common topic in the area of visual surveillance and crowd analysis. While many image based solutions are designed to count only a few persons at the same time like pedestrians entering a shop or watching an advertisement, there is hardly any solution for counting large crowds of several hundred persons or more. We addressed this problem previously by designing a semi-automatic system being able to count crowds consisting of hundreds or thousands of people based on aerial images of demonstrations or similar events. This system requires major user interaction to segment the image. Our principle aim is to reduce this manual interaction.

To achieve this, we propose a new and automatic system. Besides counting the people in large crowds, the system yields the positions of people allowing a plausibility check by a human operator. In order to automatize the people counting system, we move from manual foreground segmentation to automatic crowd density estimation. The determination of crowd density is based on several features like edge intensity or spatial frequency. They indicate the density and discriminate between a crowd and other image regions like buildings, bushes or trees.

We compare the performance of our automatic system to the previous semi-automatic system and to manual counting in images. By counting a test set of aerial images showing large crowds containing up to 12,000 people, the performance gain of our new system will be measured. By improving our previous system we will increase the benefit of an image based solution for counting people in large crowds.

8713-33, Session 9

Electronic image stabilization algorithms based on flight characteristics of the small UAV

Sijie Liu, Hongying Zhao, Lu Wang, Ying Mai, Peking Univ. (China)

Small-UAVs have characteristics such as low flight height, fast flight speed, light weight and so on. They have a wide application prospects on military and civil applications. However, the video sequences are commonly unstable and with complex motions. These bring many difficulties to electronic image stabilization.

In this paper, based on analyses of flight characteristics of small-UAVs, the author proposes effective electronic image stabilization algorithms.

Generally, the small UAV flies along with a preset route, its flight status can be classified into two kinds: rectilinear flight and turning flight. According to this, we find that:1)When the small UAV flies along with a straight line, while the wind and the flow are large, it will deviate from the preset route much, a large drift occurs. If compensating the images to the intended line, much information of images will be lost. 2) When small-UAVs are under the circumstances of large tilt angle, the motions of images are complicate. Simple motion models are not suitable.

To solve these problems, firstly,we prejudge the motion mode of the small-UAV by flying attitude, control command and other information. Secondly,we adopt adaptive kalman filtering to obtain the steady intentional motion and keep the most information. Thirdly,the homography model is used to the global motion estimation. The curve fitting and idea of uniform motion state are used to estimate the intentional motion. Then we reconstruct the global motion.

Lastly, carried out by actual airborne videos, the results indicate that our methods are effective.

8713-34, Session 9

A method of intentional movement estimation of oblique Small-UAV videos stabilized based on homography model

Shiyi Guo, Peking Univ. (China) and China Univ. of Mining and Technology (China); Ying Mai, Hongying Zhao, Peking Univ. (China); Pengqi Gao, National Astronomical Observatories, Chinese Academy of Sciences (China)

The airborne video streams of small-UAVs are commonly plagued with distractive jittery and shaking motions, disorienting rotations, noisy and distorted images and other unwanted movements. These problems collectively make it very difficult for observers to obtain useful information from the video. Due to the small payload of small-UAVs, it is a priority to improve the image quality by means of electronic image stabilization.

But when small-UAV makes a turn, affected by the flight characteristics of it, videos is easy to become oblique. This brings lots of difficulties to electronic image stabilization technology. As the common used simplified model cannot satisfy the tilt state, the homography model is applied to estimate the motions between oblique images. Nevertheless, the

intentional movement estimation is still a problem.

Therefore, in this paper, we focus on solve the problem of the video stabilized when small-UAVs banking and turning. We attend to the small-UAVs fly along with an arc of a fixed turning radius. For this reason, after a series of experimental analysis on the flight characteristics and the path how small-UAVs turned, we present a new method to estimate the intentional motion in which the center of the image trajectory was used to fit the video moving track. Meanwhile, the image sequences dynamic mosaic was done to make up for the limited field of view. At last, the proposed algorithm was carried out and validated by actual airborne videos. The results show that the proposed method is effective to stabilize the oblique video of small-UAVs.

8713-35, Session 10

Cognitive video quality analysis

Darrell L. Young, Raytheon Intelligence & Information Systems (United States); Charles Li, Raytheon Intelligence Information and Services (United States)

A cognitive architecture is described which uses a Deep Learning approach to classify video sequences according to their quality. The cognitive approach is compared to a previous technique which used logistic regression to estimate perceived quality.

8713-36, Session 10

Real-time video image quality estimation supports enhanced tracker performance

John M. Irvine, Richard J. Wood, Draper Lab. (United States)

Numerous methods exist for quantifying the information potential of imagery exploited by a human observer. The National Imagery Interpretability Ratings Scale (NIIRS) is a useful standard for intelligence, surveillance, and reconnaissance (ISR) applications. Extensions of this approach to motion imagery provide an understanding of the factors affecting interpretability of video data. More recent investigations have shown, however, that human observers and automated processing methods are sensitive to different aspects of image quality. This paper extends earlier research to present a model for quantifying the quality of motion imagery in the context of automated exploitation. In particular, we present a method for predicting the tracker performance and demonstrate the results on a range of video clips. Automated methods for assessing video quality can provide valuable feedback for collection management and guide the exploitation and analysis of the imagery.

8713-37, Session 10

Motion adaptive signal integration-high dynamic range (MASI-HDR) video processing for dynamic platforms

Michael R. Piacentino, David C. Zhang, SRI International Sarnoff (United States); David C Berends, Eduardo Gudis, SRI International (United States)

Two of the biggest challenges in designing effective vision systems on moving platforms are properly representing very high dynamic range scene content using low dynamic range components (cameras and displays), and significantly reducing the motion blur caused by high platform speeds and angular velocities.

SRI's MASI HDR (Motion Adaptive Signal Integration: High Dynamic Range) is a novel technique for generating blur-reduced video using multiple camera captures per each frame of displayed video. MASI HDR also increases the effective dynamic range of 8- to 12-bit COTS cameras by four bits (24dB) or more, allowing simultaneous dark and light areas in scenes to be accurately captured with little or no loss of information due to saturation. By running the video camera at frame rates typically four times faster than the image display rate while varying exposure times from very short (thus "freezing" scene motion) to "as long as possible", significant blur reduction is achieved while increasing the effective dynamic range of the sensor. The resulting enhanced 12-bit video may then be processed with SRI's Laplacian Pyramid-based Contrast Normalization—a powerful form of local area contrast enhancement—to allow its representation on COTS 8-bit computer displays with virtually no loss of information.

MASI HDR processing thus enables high performance video to be captured from any rapidly moving platform in real-world conditions (e.g. bright sunlight with deep dark shadows) and displayed in low latency real time. MASI HDR provides thus high performance video for even the most demanding applications on air, ground and water.

8713-38, Session 11

3D target tracking using a pan and tilt stereovision system

Moulay A. Akhloufi, Ayann Regent, Ctr. of Robotics and Vision (Canada); Rivonala Ssosse, Ctr of Robotics and Vision (Canada)

Tracking targets in video surveillance with the possibility of moving the camera to keep the target within the field of view is an important task for security personnel working in sensitive sites.

This work presents a real-time 3D tracking system based on stereovision. The camera system is positioned on a Pan and Tilt platform in order to continuously track a detected target. Particle filters are used for tracking and a pattern recognition approach is performed in order to keep the focus on the target of interest. The 3D position of the target relative to the stereovision frame is computed using stereovision techniques. This computed position gives the possibility of following the target position in a site map in real-time.

Tests conducted in outdoor scenarios show the efficiency of the proposed approach.

8713-39, Session 11

Reliable ISR algorithms for a very low power approximate computer

Ross S. Eaton, Jonah C. McBride, Charles River Analytics, Inc. (United States); Joseph Bates, Singular Computing LLC (United States)

Computing with approximate arithmetic can provide 100x improvements in size, weight, and power (SWaP) than the best traditional embedded computing approaches (and 10,000x better SWaP than desktop CPUs). DARPA and ONR are funding fabrication of a small, low power, single chip machine, developed by Singular Computing, with many thousands of cores. Industry and academia are exploring applications in vision, speech, signals, learning, and other domains.

Producing reliable results efficiently on massively parallel approximate machines sometimes requires adapting the core kernels of algorithms, often to eschew the optimizations developed for typical serial computers in favor of more brute-force approaches. We describe two such algorithms for ISR. First, we describe a mover detection algorithm suitable for use onboard a UAV. Second, we describe a feature-aided tracking algorithm that uses appearance modeling to match detections over time. Tests have shown these algorithms producing better quality results than state-of-the-art traditional approaches and running on the novel Singular Computing architecture roughly 89 times faster than on a standard CPU while using about 72 times less power, yielding a ~6400x improvement in speed/power overall.

8713-40, Session 11

Real-time low-power neuromorphic hardware for autonomous object recognition

Deepak Khosla, Yang Chen, David J. Huber, Darrel J. Van Buer, Kyungnam Kim, Shinko Y. Cheng, HRL Labs., LLC (United States)

Unmanned autonomous platforms are increasingly being used for surveillance and reconnaissance in various military and commercial applications. The ever-increasing resolution and fidelity of the video sensors on these platforms requires unprecedented communication bandwidth for the mostly mundane data, which puts higher workload on the analysts. Therefore, there is an increasing need to perform on-board data processing and transmit only potentially valuable information to the ground stations to reduce both the data bandwidth requirements and analyst workload.

In this paper, we present an experimental system for real-time video object recognition that can be embedded in autonomous platforms to provide on-board information extraction. Our system is based on models of human visual processing from neuroscience research and is implemented in state-of-the-art COTS hardware using only CPUs and FPGAs to achieve low size, weight and power, while maintaining real-time processing. We use motion-and-form based visual attention methods for detection and multi-scale convolutional neural networks for classification. The algorithms have been mapped to COTS FPGA hardware, exploiting neuromorphic principles of modularity, hierarchical processing, and parallelism to achieve streaming implementations. Evaluation of our system has shown that we can achieve real-time speeds of thirty frames per second with up to five-megapixel resolution videos. In a systematic evaluation conducted by DARPA on the Neovision2 program, our system showed three to four orders of magnitude in power reduction compared to state of the art computer vision implementations while achieving the same level of performance.

8713-41, Session 11

An integrated multitarget tracking system for interacting target scenarios

Hongwei Mao, Arizona State Univ. (United States); Glen P. Abousleman, General Dynamics C4 Systems (United States); Jennie Si, Arizona State Univ. (United States)

In real-world target tracking scenarios, interactions among multiple moving targets can severely compromise the performance of the tracking system. Closely spaced targets are difficult to distinguish, and targets may be partially or totally invisible for uncontrolled durations when occluded by other objects. These situations are very likely to degrade the performance or cause the tracker to fail because the system may use invalid target observations to update the tracks. To address these issues, we propose an integrated multi-target tracking system. A background-subtraction-based method is used to detect moving objects in video frames captured by a moving camera with arbitrary motion. The data association method evaluates the overlap rates between newly detected objects (target observations) and already-tracked targets, and makes decisions pertaining to whether a target is interacting with other targets and whether it has a valid observation. Thus, the system is capable of recognizing target interactions and will reject invalid target observations. According to the association results, distinct strategies are adopted to update and manage the tracks of interacting versus well-isolated targets. The proposed system has been tested with a set of real-world airborne video sequences and demonstrates excellent track continuity in the presence of multiple target interactions. Moreover, the system operates in real time on an ordinary desktop computer.

8713-42, Session 11

Object detection and tracking under planar constraints

Qiang He, Mississippi Valley State Univ. (United States); Henry Chu, The Univ. of Louisiana at Lafayette (United States); Aldo Camargo, The Univ. of North Dakota (United States)

Object detection and tracking is a very fundamental task in image understanding, which has been widely applied in surveillance systems, military reconnaissance, and homeland security. Here we develop an algorithm for object detection and tracking under planar constraints. Planar surfaces are important characteristics in man-made environment, such as architectural buildings, mechanical equipments, etc. Planar surfaces encapsulate two-dimensional information of objects and have been successfully applied to camera calibration, interactive modeling, and feature matching. Here we incorporate the planar constraints to detect and track objects in an image sequence. The objects with planar surfaces are related by a planar homography, which could be computed from feature correspondences. In two-view image pair, the homography between planar surfaces is limited by the fundamental matrix in epipolar geometry. As a consequence, the degrees of freedom for the planar homography under epipolar constraint are reduced from eight to three. In N-view images, the planar homography could be estimated using RANSAC method based on feature correspondences. We will deal with the two different cases separately. After the planar homogrpathy is calculated, the man-made objects could be detected and tracked through the correspondences between planar surfaces. Our algorithm is tested on the image pairs and a series of images from simulated structures and/or taken from UAVs (Unmanned Aircraft Vehicles).

8713-44, Session PThur

Efficient parallel implementation of real-time airborne target tracking system on heterogeneous multicore SoC

Xiang Gao, Arizona State Univ. (United States); Hongwei Mao, Arizona State Univ. (United States) and Arizona State Univ. (United States); Eric Munson, Arizona State Univ. (United States); Glen P. Abousleman, General Dynamics C4 Systems (United States); Jennie Si, Arizona State Univ. (United States)

In real-world target tracking on airborne imagery, the system is designed to be able to detect and track multiple targets from a moving camera through occlusion and discriminate them when they are close to each other. The algorithm in both detection and tracking must be sophisticated enough to handle complicated scenarios. However, it also makes the system miniaturization on a low power embedded system a very challenging task. In our previous work, we presented a robust motion-based detection and tracking system achieved real-time performance on a desktop computer. In this paper, we present a parallel scheme by reconstructing the traditional sequential motion estimation and tracking process. In order to achieve real-time performance on a heterogeneous-core ARM+DSP platform, the DSP core is served as motion estimation preprocessing unit for target detection. After the motion estimation step on DSP, the descriptors of potential targets are passed to general-purpose ARM for further tracking analysis. At the same time, the DSP will start preprocessing the next frame. The leveraging of DSP's parallel computation capability makes it possible do tracking on an embedded system. Experimental results demonstrate that this parallel implementation greatly reduces the average processing time of each frame up to 60%.

8713-47, Session PThur

A wireless sensor network design and implementation for vehicle detection, classification, and tracking

Anwar Al-Assaf, King Abdullah II Design and Development Bureau (Jordan)

Vehicle intrusion is considered a significant threat for critical zones specially the militarized zones and therefore vehicles monitoring has a great importance. In this project we designed and implemented a small wireless sensor network for vehicle intrusion monitoring consists of a five inexpensive sensor nodes distributed over a small area and connected with a gateway using star topology. The system is able to detect a passage of an intrusive vehicle, classify it either wheeled or tracked, and track the direction of its movement. Our approach is based on Vehicle's ground vibrations for detection, vehicle's acoustic signature for classification and the Energy- based target localization for tracking. Detection and classification are implemented by using different algorithms and techniques including Analog to Digital Conversion, Fast Fourier Transformation and Neural Network .All of these algorithms and techniques are implemented locally in the sensor node using Microchip dsPIC digital signal controller. Results are sent from the sensor node to the gateway using ZigBee technology and then from the gateway to a web server using GPRS technology

8714-1, Session 1

Detection of concealed metal objects and human targets in defilade using a wideband millimeter-wave noise radar

Kyle A. Gallagher, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

This paper describes the application of a millimeter-wave (mm-wave) radar system transmitting a composite signal consisting of a wideband noise waveform combined with an embedded single tone for concealed object detection. The radar was designed to detect human targets at long range (greater than 100 feet) and through light foliage cover. This paper will briefly describe the hardware architecture of the system and focus on how the mm-wave system is applied in various applications. The system has been used to detect the presence of concealed metal objects and to discriminate between objects in different orientations. This system's ability to discriminate between concealed metal objects at different standoff distances from the radar is also presented. In addition, the radar's ability to detect humans through foliage is also presented. This is done using different types of foliage at different standoff distances. The standoff distance between the foliage and the human target is also varied. For these applications, combinations of different antennas were used to explore the tradeoff between antenna size and system performance.

8714-2, Session 1

FPGA implementation of a software-defined radar processor

Hernan A. Suarez, Yan (Rockee) Zhang, The Univ. of Oklahoma (United States)

Real-time implementation of the pulse compression in reconfigurable hardware device is a critical element of the next generation of airborne and spaceborne radars, which reply on solid-state transmitters, antenna diversities and adaptive waveform diversities for the challenging missions such as spaceborne precipitation measurement, sense-and-avoid (SAA), and imaging. This work proposes a unified digital transceiver and processor architecture that can utilize multiple waveforms, such as chirp, phase coding, noise and chaotic waveforms, adjust these waveforms adaptively based on missions and observation scenarios, and perform real-time pulse compression processing independent of waveforms activated. The hardware pulse compression can be reconfigured at different levels of complexity depending on the requirements of the missions. For example, fast operation is needed for point target tracking in SAA radars, so an efficient implementation is important. For distributed target remote sensing, however, extreme low sidelobes are needed and very high sensitivity is required, then the windowing-combined with adaptive pulse compression iterations are applied. For covert and LPI operations, capability of handling random and continuous wave waveforms is incorporated. The radar-application-specific-processor (RASP) architecture has been initially implemented in the most advanced Xilinx FPGA platforms, the basic building blocks inside the FPGA mix the commercial IP cores and in-house developments to achieve the optimized efficiency on resource utilization. The prototype implementation is tested together with a Ku band spaceborne radar RF transceiver testbed. It is verified that the system can smoothly handle waveform diversities and different pulse compression requirements, achieve good real-time performance and balance among cost/power consumption/speed compared with competing options.

Submitted to Special Session on Noise and Noise-Like Radar

8714-3, Session 1

A compressive radar system with chaotic-based FM signals using the Bernoulli map

Hector A. Ochoa, Charan Teja Enugula, The Univ. of Texas at Tyler (United States)

Matched filters are used in radar systems to identify echo signals embedded in noise. They allow us to extract range and Doppler information about the target from the reflected signal. In high frequency radars, matched filters make the system expensive and complex. For that reason, the radar research community is looking at techniques like compressive sensing or compressive sampling to eliminate the use of matched filters and high frequency analog-to-digital converters[1]-[7]. In this work, compressive sensing is proposed to increase the resolution and eliminate the use of matched filters in chaotic radars[8][9]. This research considers two basic scenarios, one for stationary and one for non-stationary targets. For the stationary targets, the radar scene was a one dimensional vector, in which each element of the vector represents a target position. For the non-stationary targets, the radar scene was a two dimensional matrix, in which one direction of the matrix represents the target's range, and the other direction represents the target's velocity. Using optimization techniques it was possible to recover both radar scenes from an under sampled echo signal[10][11]. The reconstructed scenes were compared against a traditional matched filter system. In both cases, the matched filter was capable of recovering the radar scene. However, there was a considerable amount of artifacts introduced by the matched filter that made target identification a daunting task. On the other hand, using compressive sensing it was possible to recover both radar scenes perfectly, even when the echo signal was under sampled.

8714-4, Session 1

Influence of signal parameters in noise radar sensor technologies used for sensing through dispersive media

Ana V. Alejos, New Mexico State Univ. (United States) and Univ. de Vigo (Spain); Muhammad Dawood, Zir Zeeshan, New Mexico State Univ. (United States)

The frequency dispersive behavior of natural media such as soil, vegetation, water, and atmosphere, can lead noise radar techniques and sensors to unexpected inaccuracies in their performance due to the likely appearance of the precursor electromagnetic signals. The formation of these precursor fields is related to the chosen frequency spectrum window, the desired frequency signal bandwidth, and the selected shape of the transmitted signal.

For frequency-dependent media, the propagated signal then, becomes a critical part of the system and the final performance depends on its proper configuration because this latter can decide the formation or absence of the precursor field which appears as an additional component superimposed to the propagated signal.

In case of a precursor arising out, the distortion undergone by the signal transmitted through or reflected on a dispersive medium basically consists of amplitude level modification and spreading of the pulse width duration. These alterations introduce uncertainty in the received signal making the information retrieval difficult and inaccurate.

However, the formation of the precursor fields can improve the propagation by offering significantly better signal-to-noise ratio to achieve an enhanced sensing capability.

Theoretically for a LIDAR system and experimentally for a random noise signal in the THz band, we have estimated that precursors can occur in a different way according to the input pulse setting.

We examine the theoretical evolution of various waveform shapes through water, soil and vegetation. Measurements carried out in the THZ band provide an experimental verification of the precursor formation through water for random noise signals.

8714-5, Session 2

Demonstration of detection and ranging using solvable chaos

Jonathan N. Blakely, U.S. Army Research, Development and Engineering Command (United States); Ned J. Corron, U.S. Army Aviation and Missile Command (United States); Mark T. Stahl, NASA Marshall Space Flight Ctr. (United States)

Acoustic experiments demonstrate a novel approach to ranging and detection that exploits the properties of a solvable chaotic oscillator. This nonlinear oscillator includes an ordinary differential equation and a discrete switching condition. The chaotic waveform generated by this hybrid system is used as the transmitted waveform. The oscillator admits an exact analytic solution that can be written as the linear convolution of binary symbols and a single basis function. This linear representation enables coherent reception using a simple analog matched filter and without need for digital sampling or signal processing. An audio frequency implementation of the transmitter and receiver is described. Successful acoustic ranging measurements are presented to demonstrate the viability of the approach.

8714-6, Session 2

Initial experimental results using the noise correlation radar

Mark A. Govoni, U.S. Army Research, Development and Engineering Command (United States); John Clark, Jerry Silvious, U.S. Army Research Lab. (United States); Charles Overman, Univ. of Florida/Electronic Communications Lab (United States)

Experimental results from initial field testing with the Noise Correlation Radar (NCR) are presented as proof of concept. The results are used to validate the theoretical claims made regarding the novel pulse LFM noise-modulated waveform. Compliments of a unique matched filter solution, the so-called advanced pulse compression noise (APCN) waveform promises low probability of intercept (LPI) and robustness to in-band RF interference.

We establish the actual target location error (TLE) of the radar system using real target data and known-geolocation information. In addition, we extrapolate to what extent the APCN waveform disassociates itself with the pulse LFM spectral characteristics. Lastly, we quantify the signal-to-interference+noise (SINR) ratio when in-band interference is present during the system processing interval and compare those to a conventional radar system not practicing noise modulation.

8714-7, Session 2

Comparative analysis of transfer function measurements on various lossy media using an ultrawideband S-Band noise radar

Sonny Smith, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

An S-Band noise radar for through-wall ranging and tracking of targets has been developed at the Pennsylvania State University. Ranging to target is achieved by the cross-correlation between the reflected return signal and the time-delayed replica of the transmit signal; both are bandlimited ultra wideband (UWB) noise signals. Furthermore, successive scene subtraction allows for target tracking using the range profiles created by the cross-correlation technique. In this paper, we continue our investigation in the viability of characterizing the "impulse response" of varied, lossy media (e.g. a 4-inch thick brick wall, an 8-inch thick brick wall and an 8-inch thick cinder-block wall) via transfer function-like measurements using the S-Band radar system. As purported by Yuk Wing Lee and others, there exists a mathematical basis for determining the impulse response of a linear system with inputs that are wideband, white noise or noise-like. The principle hinges on cross-correlating the inputs; and hence, since the correlation method is used in noise radars, we believe that such radars are well-suited for characterization applications. Moreover, we will present a sensitivity analysis for the S-Band noise radar as operated under disparate testing configurations (i.e. different walls, targets, etc.) with different antennas (e.g. dual polarized horns, helical antennas with different ground planes, etc.). In addition, we will also share key concepts of noise radars and impulse testing as well as some of the design and development of the helical (end-fire) antennas over diverse ground planes used by the system.

8714-8, Session 2

GNSS-based passive radar sensing using hybrid-aperture system

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Passive radar using non-cooperative transmitters is becoming a critical solution to future RF surveillance that can be used on small-medium (Tier I and II) UAVs. The concept of using both synthetic aperture (SA) and real aperture (RA) array in the GNSS-based passive radar observations has been mentioned before but a seamless combination of two apertures in real-time observation has not been demonstrated. A hybrid aperture system consisting of an electronic scanning array at GPS frequency band and synthetic array processing is being developed by University of Oklahoma. The radar adapts both downward looking and side-looking modes. For downward looking mode, the electronic scanning array antenna scans through the cross-range direction and perform synthetic aperture processing for signal received along flight path at the same time. The key challenge of GNSS-based processing is signal synchronization, which is achieved at both the hardware level (containing two synchronized software receiver and a WAAS receiver providing Time and Space Position Information (TSPI) in real time for the reference) and software level (precise code/phase-tracking, UTC time decoding and local template generation technique). The current real aperture array contains 32 active elements and scan in azimuth direction with about 3 degree beam resolution, and the software-defined GPS receivers are modified to perform radar image formation and target detection. In addition to the covertness of ISR operation and reduced SWaP, the significant advantages of the hybrid aperture system include reduced computational complexity of onboard processor, good phase coherency, integration with GNSS navigation system and potential multiple functionalities.

8714-9, Session 3

Detection and depth estimation of shallow buried non-metallic dummy landmines without explosives using Independent Component Analysis (ICA) of multipolarization data in microwave X band region

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A lot of research has been conducted with single polarization data obtained from different sensors with limited success. With the advent of satellites which can provide data in various polarizations, it has

increasingly become relevant to investigate methods which can be used to manipulate data in different polarizations for the purpose of landmine detection. The conditions existing in the western borders of India match that of sandy deserts where surface roughness conditions are smooth making them extremely suitable for application of radar remote sensing for detection of minefields using data obtained in different polarisations. Independent component analysis (ICA) is an emerging signal processing technique which has been used to extract statistically independent signals from mixed signals. In this paper, application of Independent component analysis (ICA) for detection of dummy landmines (without explosives) using multipolarisation data has been investigated. The data for the purpose was generated through lab experiments in HH and VV polarizations in microwave X band frequency (10 GHz, 3 cm) using dummy landmines (without explosives). The backscatter data collected is cluttered due to several factors such as surface roughness and multilayer interactions etc. It was found that Otsu's thresholding when applied to ICA components obtained using FastICA algorithm provided good detections. The backscatter values obtained for the pixels segmented as landmine were further input in an EM (electromagnetic) model and optimized using a genetic algorithm based cost function for estimation of the depth. The model does not have any requirement of any a priori data and still highly accurate results.

8714-10, Session 3

Design of spectrally versatile forward-looking ground-penetrating radar for detection of concealed targets

Brian R. Phelan, The Pennsylvania State Univ. (United States); Marc A. Ressler, Gregory J. Mazzaro, Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

The design of high-resolution radars which can operate in theater involves a careful consideration of the radar's radiated spectrum. While a wide bandwidth yields better target detectability and classification, it can also interfere with other devices and/or violate federal and international communication laws. The Army Research Laboratory (ARL) Partnerships in Research Transition (PIRT) program is investigating the design and development of a Stepped-Frequency Radar (SFR) which allows for manipulation of the radiated spectrum, while still maintaining an effective ultra-wide bandwidth. The SFR is a forward-looking, ultra-wideBand (UWB) imaging radar capable of detecting concealed targets. This paper presents the research and analysis undertaken during the design of the SFR which will eventually be implemented in an existing ARL system, the Synchronous Impulse REconstruction (SIRE) radar. The SFR is capable of excising prohibited frequency bands, while maintaining the down-range resolution capability of the original SIRE radar. The SFR, like the SIRE radar, is a vehicle mounted, forward-looking, Ground Penetrating Radar (GPR) capable of using Synthetic Aperture Radar (SAR) technology to produce suitable cross-range resolution for detection of sub-surface targets. Many contradicting design considerations are analyzed in this report. The selection of system bandwidth, antenna types, number of antennas, frequency synthesizers, digitizers, receive amplifiers, wideband splitters, and many other components are critical to the design of the SFR. Leveraging commercial components and SIRE sub-systems were design factors which will allow for an expedited time to the initial implementation of the radar while reducing overall costs. This SFR design will result in an ARL asset to support obscured target detection such as improvised explosive devices (IEDs) and landmines.

8714-11, Session 3

Development of a longer range standoff millimetre wave radar concealed threat detector

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A millimetre wave (75 - 110 GHz) polarimetric radar system (MiRTLE) has been developed for the detection of threat objects, such as guns, knives, or explosive devices, which had been concealed under clothing upon the human body. The system though using geometric optics is able to successfully operate at stand-off ranges up to 25 metres. The system uses an ultra-wideband Swept Frequency Continuous Wave Radar high resolution (~ 1 cm) radar system and is capable of detecting and measuring the range of a target. By interpretation of the response the presence of a wide spectrum of threat items concealed on the human body may be identified. Threat detection is autonomously rendered by application of a neural network to the scattered time domain polarimetric radar returns and the system may be taught to alarm or reject certain classes of objects; this allows for highly specific or broad spectrum threat detection. The radar system is portable and operator steerable allowing standoff monitoring of moving human targets. Through using rapid (1ms) sweep times and rapid signal acquisition and processing, decisions can be obtained at video frame rates (20 fps) and can be integrated directly to a video feed available to the operator showing the field of view of the system. Performance parameters for detection of guns and simulated explosive devices will be presented for ranges up to 25 metres.

8714-12, Session 3

Emulation of forward-looking radar technology for threat detection in rough terrain environments: a scattering and imaging study

DaHan Liao, Traian V. Dogaru, U.S. Army Research Lab. (United States)

To predict the performance of forward-looking radar technology deployed in complex environments, large-scale, full-wave analysis of multi-static target-imaging in a rough ground environment is described. The emulation methodology employs a parallelized three-dimensional "near-field" algorithm in characterizing the electromagnetic scattering from the ground-surface and buried and on-surface targets. The transmitting antennas are represented by equivalent current sheets placed at the real antenna aperture locations. Subsequent focusing of the scattered fields at the receiver locations into an image is obtained by exploiting the time-reversal technique, with the aid of asymptotics. The overall simulator is expected to be a useful tool for studying the effects of ground properties—both physical and electrical—on the signatures of various targets.

8714-13, Session 3

Multitone harmonic radar

Gregory J. Mazzaro, Anthony F. Martone, U.S. Army Research Lab. (United States)

The U.S. Army Research Laboratory is evaluating radar technologies for detecting in-road threats. One technology that is well-suited for the detection of threats containing RF electronics is nonlinear radar, which exploits the electronic response from a target whose reflected frequencies are different from those transmitted. Reception of frequencies that are not part of the transmitted probe distinguishes the received signal from a linear return produced by clutter and indicates the presence of electronics. For the warfighter, the presence of electronics in a location that typically does not contain electronics implies the presence of a threat.

Presented in this paper is a type of nonlinear radar that transmits multiple frequencies and listens for a harmonic of these frequencies as well as other frequencies near that harmonic. Upon reception of the nonlinear frequency content, the multitone radar registers a detection. By measuring the amplitudes of multiple frequencies and matching these

amplitudes against pre-recorded device responses, the radar classifies the target as a particular electronic device.

Multitone harmonic radar has several advantages over existing nonlinear radars. It enables a narrower-bandwidth antenna design while providing target information comparable to wider-bandwidth designs, it enables increased sensitivity and signal-to-interference ratio using multiple stages of filtering, and it allows a single-transmit-antenna design for generating and receiving mixing products that are usually stimulated from a target using multiple transmit antennas.

A laboratory test-bed has been constructed to demonstrate the multitone radar concept. Measurements of nonlinear responses from RF devices probed by multiple tones are reported.

8714-14, Session 3

Testing a transmission line model for buried targets using ground penetrating radar

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In our previous work we showed the results obtained for an inversion algorithm that calculates the intrinsic impedance of the subsurface media from the received signal of a short-pulse Ground Penetrating Radar. We simulated different environments with lossless and lossy media, modeling the transmitted signal as a Ricker Wavelet. In this article, we extend the study to the analysis of experimental near field data. For this purpose, we collected data in a controlled environment and analyzed the data using the inversion algorithm. This analysis is not trivial and requires multiple adjustments, since the use of a field system introduces several unknowns, such as variations in the waveform used by the radar device, the amplitude of the transmitted wave and the instantaneous position of the radar antenna with respect to the ground. Furthermore, compensation for the geometric spreading losses and conductivity spreading losses is required to accurately characterize the subsurface media. We develop an approach to deduce characteristics of the transmitted wave based on the shape of the received signal from buried targets of known shape with a specific dielectric constant and to compensate for geometric losses. We demonstrate that using this methodology we are able to accurately estimate the permittivity and depth of the buried targets used on the experimental setup.

8714-57, Session 4

Cognitive processing for nonlinear radar

Anthony F. Martone, Kenneth Ranney, Abigail Hedden, David McNamara, Gregory Mazzaro, U.S. Army Research Lab. (United States)

An increasingly cluttered electromagnetic (EM) environment is a growing problem for radar and radio frequency (RF) systems. This problem is becoming critical as the available frequency spectrum shrinks due to growing wireless communication device usage and changing regulations. A possible solution to this problem is cognitive RF processing, where the cognitive RF system learns from the environment and intelligently modifies the tranmission waveform. In this paper a proposed cognitive RF processing framework is discussed for nonlinear radar. Nonlinear radar produces frequencies in a nonlinear target (e.g. electronics or metal object) that are different from those transmitted by the radar thereby separating natural clutter from the nonlinear target response. Examples of nonlinear system applications include automobile accident avoidance; junction range finder; detection of concealed weapons, electronics, and other man-made objects; electronic device detection for FCC Part-15 compliance; and insect tracking. The proposed processing framework, i.e. the nonlinear cognitive radar (NCR) framework, utilizes a target detection methodology applied to nonlinear radar. This methodology has the advantage, as compared with other nonlinear radar systems that do not implement a cognitive scheme, of being able to adapt to the RF environment. By leveraging adaptive algorithms, it can intelligently select the best waveform parameters.

8714-67, Session 4

Noisy stepped frequency (NSF) waveform in three-dimensional RF tomography

Russell Vela, Air Force Research Lab. (United States)

No Abstract Available.

8714-70, Session 4

Scattering and imaging of nonlinearly loaded antenna structures in half-space environments

DaHan Liao, U.S. Army Research Lab. (United States)

The electromagnetic scattering responses of nonlinearly loaded antenna structures excited by single-tone or multi-tone incident fields are considered in the frequency domain by employing a combination of the method-of-moments and a harmonic balance technique. Subsequently, standoff detection and localization of the scatterers in the presence of a half space is demonstrated with a subspace imaging procedure by exploiting the harmonic scattering responses.

8714-19, Session 5

Effect of Pulse Fidelity on Detection of Landmines

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Detection of landmines based on complex resonance frequencies has been studied in the past and no distinctive results have been reported. Especially for low metal content landmines buried at depths greater than 9 cm, resonant frequencies become fairly distributed in the background and no specific frequency of interest can be used. However, in a typical impulse radar, spectral energy density of the transmitted pulse can be very broad and its peak can be located anywhere. Usually, a compromise is made between penetration depth and feature resolution for spectral energy peak allocation. Pulse amplitude, duration, symmetry, its spectral energy distribution, ringing level all affect depth and resolution metrics in a complicated way. Considering receiver dynamic range, we study two distinct pulses having different spectral energy density peaks and their detection ability for landmines with little or no metallic content. We devise several analytical bounds on pulse durations and their corresponding energy spectrum. We also carry out experiments to show that pulse shape/fidelity is critical to obtain desired contrast in post-processing of data.

8714-20, Session 5

Buried target radar imaging with an ultra-wideband, vehicle-mounted antenna array

Kenneth I. Ranney, DaHan Liao, Traian V. Dogaru, Lam H. Nguyen, U.S. Army Research Lab. (United States)

The problem of detecting buried objects has engaged radar system developers for quite some time. Many systems—both experimental and commercial—have been developed, including vehicle-mounted systems that look beneath road surfaces. Most of these downward-looking systems exploit multiple transmit and receive channels to enhance

resolution in the final radar imagery used for target detection. In such a system, the configuration and operation of the various transmit and receive elements play a critical role in the quality of the output imagery.

In what follows, we leverage high-fidelity electromagnetic model data to examine a multi-static downward-looking radar system. We evaluate the signatures produced by various targets of interest and describe, both qualitatively and quantitatively, the variations in target signatures produced by different system configurations. Finally, we analyze the underlying physics of the problem to explain certain characteristics in the observed target signatures.

8714-21, Session 5

Three-dimensional radar imaging of buildings based on computer models

Traian V. Dogaru, DaHan Liao, Calvin Le, U.S. Army Research Lab. (United States)

Through the wall radar imaging of building interiors is a topic that received considerable attention by defense and law enforcement agencies over last few years. Typically, low-frequency (under 4 GHz) radar systems using ultra-wideband (UWB) waveforms are employed in this application. The building layout and interior are imaged via synthetic aperture radar (SAR) techniques, operating from either ground-based or airborne platforms. Previous studies have shown the difficulty of interpreting two-dimensional radar images of buildings, especially when multiple stories are involved.

In this paper, we demonstrate a three-dimensional (3-D) radar system for building imaging based on computer simulations of the radar signature. We create the models of a single-story and a two-story building containing multiple rooms, furniture, appliances and humans down to a fine level of detail. We also consider two possible SAR configurations: an airborne radar system operating in the spotlight mode and a ground-based radar system operating in the strip-map mode. The paper describes all the steps involved in this analysis: creating the computational meshes, calculating the radar signals scattered by the target, forming the radar images and processing the images for visualization and interpretation. Particular attention is given to the scattering phenomenology and its dependence on the system geometry. The images are created via the time-reversal technique and further processed using a constant false-alarm rate (CFAR) detector. We discuss methods of 3-D image visualization and interpretation of the results and point the way to possible improvements.

8714-22, Session 5

Through-the-wall radar human detection via spectral characteristics

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This paper investigates the detection of stationary human targets for through-the-wall radar in complex scenarios. Utilizing Finite Difference Time Domain (FDTD) techniques, we examine the radar cross section (RCS) of human and indoor clutter objects of complex indoor environments. FDTD allows for the spectral characteristics to be acquired over a wide range of frequencies, polarization, and aspect angle. We observe that the spectral characteristics of humans show some unique features with peaks and troughs occurring generally in the vicinity of the same frequencies for different humans. The proposed method makes use of the acquired spectral data from models to form ratios of radar returns from multiple frequencies for discrimination of human targets. We aim to apply the method and data to multiple wall and room configurations. We hypothesize that the use of spectral information will yield an adaptive approach to target identification of stationary humans within complex indoor environments.

8714-23, Session 5

Textural feature based target detection in through-the-wall radar imagery

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In urban sensing and through wall imaging, biometric radars can face challenges when dealing with exterior attenuative walls prohibiting high frequency operations. In this case, detection of animate targets would solely depend on high fidelity imaging and effective classification techniques. The problem of stationary target detection in through-the-wall radar imaging and urban sensing using image segmentation techniques has recently been considered in the literature [1-2]. Specifically, histogram thresholding methods, such as the Otsu's method [3] and maximum entropy segmentation [4], have been considered to aid in removing the clutter, resulting in 'clean' radar images with target regions only. In this paper, we show that histogram thresholding schemes are effective in enhancing the images by suppressing clutter regions, which are distinct from target regions. However, target detection using these methods becomes challenging, if not impossible, in the presence of multipath ghosts and clutter that closely mimics the target in size and intensity. Because of the small variations between the target regions and such clutter and multipath ghosts, we investigate the use of texture based features for classifying target and clutter regions. More specifically, we extract textural features, such as contrast, correlation, energy, and homogeneity, from gray level co-occurrence matrices [5]. A co-occurrence matrix is defined as the spatial-dependence probability-distribution matrix of pairs of pixels separated by a given offset in a particular direction.We employ Mahalanobis distance to calculate the similarity and distinction between the textural features corresponding to the target and clutter classes. The performance of the proposed scheme is evaluated using real data collected with the multi-channel TWSAR, which is the vehicle-borne through-the-wall radar imaging system by Defence Research and Development Canada. The dataset corresponds to through-the-wall measurements of multiple humans of different heights, standing or sitting at different downranges in an empty room. For the specific data analyzed, it is shown that the proposed feature based method yields much improved results compared to histogram thresholding based segmentation methods.

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8714-24, Session 6

SIRE: a MIMO radar for landmine/IED detection

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Multiple-input multiple-output (MIMO) radar systems have been shown to have significant performance improvements over their single-input

multiple-output (SIMO) counterparts. For transmit and receive elements that are collocated, the waveform diversity afforded by this radar is exploited for performance improvements. These improvements include but are not limited to improved target detection, improved parameter identifiability and better resolvability. In this paper, we present the Synchronous Impulse Reconstruction Radar (SIRE) Ultra-wideband (UWB) radar designed by the Army Research Lab (ARL) for landmine and improvised explosive device (IED) detection as a 2 by 16 MIMO radar (with collocated antennas). Its improvement over its SIMO counterpart in terms of beampattern/cross range resolution are discussed and demonstrated using simulated data herein. The limitations of this radar for Radio Frequency Interference (RFI) suppression are also discussed in this paper. A relaxation method (RELAX) combined with averaging of multiple realizations of the measured data is presented for RFI suppression; results show no noticeable target signature distortion after suppression. In this paper, the back-projection (delay and sum) data independent method is used for generating SAR images. A side-lobe minimization technique called recursive side-lobe minimization (RSM) is also discussed for reducing side-lobes in this data independent approach. We introduce a data-dependent sparsity based spectral estimation technique called Sparse Learning via Iterative Minimization (SLIM) as well as a data-dependent CLEAN approach for generating SAR images for the SIRE radar. These data-adaptive techniques show improvement in side-lobe reduction and resolution for simulated data for the SIRE radar.

8714-26, Session 6

Robust adaptive beamforming for MIMO monopulse radar

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Researchers have recently proposed a widely separated multiple input multiple output (MIMO) radar using (amplitude) monopulse angle estimation techniques for target tracking. The widely separated antennas provide improved tracking performance by mitigating complex target radar cross section fades and angle scintillation (glint). It was demonstrated through numerical examples to provide better target tracking than a standard phased array tracking system. An adaptive array is necessary in this paradigm as the direct path from any transmitter could act as a jammer. In the original proposed system the standard Capon beamformer was proposed to generate the necessary adaptive beams required to perform monopulse estimation. The interference and noise covariance matrix was always assumed to be measurable and did not contain the signals of interest.

In this work, we examine robust adaptive beamforming techniques for amplitude and phase monopulse estimation for a MIMO tracking radar. Specifically, we examine the cases where the sample covariance matrix contains interference and noise only and when it also contains the signals of interest. In the former, we review the optimal monopulse weights and formulate them as a minimization problem that can be solved by Lagrange multipliers. In the latter case, it is critical to include robustness into the beamformer weights since monopulse estimation is formulated using the error in the angle of arrival estimate. When multipath is of significant concern as well as interference, we consider adaptive matrix approach (AMA) for amplitude monopulse beampattern synthesis. Performance for all the methods is demonstrated via numerical simulations.

8714-27, Session 6

New distributed radar technology based on UAV or UGV application

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A new concept of pocket size distributed radar based on the micro-UGV for the tracking of low altitude low profile targets at short and medium distances (stadium, camp, military facility protection) is proposed. The distributed radar consists of a minimum of three micro-UGV with illuminating devices distributed in a surveillance area transmits RF illuminating signals synchronized with the reference clock and information about its own position received from GPS. Cell phone size passive observing devices with display is receive the signals directly from the illuminating devices as well as the same signals reflected from the target and calculates target range and location by triangulation. High accuracy of target location is the result of combining the high accuracy of GPS location of the illuminating and observing devices with the high accuracy of range measurement provided by an atomic reference clock and triangulation. Illuminating devices transmit illuminating signals in desired directions by directional antenna arrays to increase radar range and energy efficiency.

In another concept of distributed radar a few UAV's with passive observing devices distributed in a surveillance area or along a border use regular radar signals transmitted from ground or ship based main radar for target illumination. The observing devices can detect low profile stealth targets because they a hundred times closer to the target than the main radar. The energy of the signal reflected from the target is inversely proportional to the square of the distance to the target and can therefore be detected by simple micro-size UAV receivers.

8714-28, Session 6

Tomographic imaging of ultra-wideband noise radar using time-domain data

Hee Jung Shin, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Muralidhar Rangaswamy, Air Force Research Lab. (United States)

Ultra-wideband (UWB) random noise radar has been widely considered as a promising technique for covert high-resolution localization and detection of the target due to several advantages such as excellent immunity from jamming and interference, low probability of detection and interception. However, the use of UWB random noise waveforms for tomographic imaging has not yet been investigated. This paper investigates the feasibility of using an arbitrary noise waveform in a UWB radar system for 2D tomographic imaging of a stationary object with a multistatic tomographic geometry. Multiple UWB transmitters and receivers are positioned along each side of the imaging area so that reflected signals are collected by all receivers including the receiver at the transmitter position. In the simulation, multiple i.i.d. random noise signals with full 500-MHz bandwidth are transmitted, and the back projection algorithm applied on all reflected signals to generate the final image. We perform several numerical simulations in time-domain, and the successful imaging of the target is achieved by visual inspection of the formed images.

8714-29, Session 7

Concealed target detection using augmented reality with SIRE radar

Philip J. Saponaro Jr., Chandra Kambhamettu, Univ. of Delaware (United States)

The Synchronous Impulse Reconstruction (SIRE) forward-looking radar, developed by the U.S. Army Research Laboratory (ARL), can detect concealed targets using ultra-wideband synthetic aperture technology. The SIRE radar has been mounted on a Ford Expedition and combined with other sensors, including a pan/tilt/ zoom camera, to test its capabilities of concealed target detection in a realistic environment. Augmented Reality (AR) can be used to coalesce the SIRE radar image with the live camera stream into one view, which provides the user with

information that is quicker to access and easier to understand than each separated.

In this paper we present an AR system which utilizes a global positioning system (GPS) and inertial measurement unit (IMU) to overlay a SIRE radar image onto a live video stream. We describe a method for transforming 3D world points in the UTM coordinate system onto the video stream by calibrating for the intrinsic parameters of the camera. This calibration is performed offline to save computation time and achieve real time performance. Since the intrinsic parameters are affected by the zoom of the camera, we calibrate at ten different zooms and interpolate these parameters. Finally, we show the results of a real time transformation of the SAR imagery onto the video stream. In the future, we will implement our algorithms on the GPU to increase computation speed.

8714-30, Session 7

Lightweight SAR GMTI radar technology development

John C. Kirk Jr., Goleta Star, LLC (United States)

A small liteweight Dual-Channel Radar (DCR) has been developed for SAR data collections. Using standard Displaced Phase Center Antenna (DPCA) radar digital signal processing, SAR GMTI images have been obtained. That is the moving targets embedded in a high-resolution SAR image can now be detected using the dual radar channels. The signal processing algorithms can be implemented in an on-board FPGA based Radar Signal Processor (RSP) for real-time implementation. This radar is suitable, not only for data collections to support algorithm development, but for real-time UAV applications as well. This DCR can provide lite-weight SAR GMTI capability for Small UAVs. The prototype radar weighs 5-lbs and has demonstrated the extraction of ground moving targets (GMTs) embedded in high-resolution SAR imagery data. Sum and difference channel data is used in the DPCA algorithm to extract the GMTs and display them on the Sum channel high resolution SAR image. Heretofore this type of capability has been reserved for much larger systems such as the JSTARS. Previously small liteweight SARs featured only a single-channel and only displayed SAR imagery. Now, with the advent of this new capability, SAR GMTI performance is now possible for small UAV class radars. In this paper we show typical single-channel SAR images from this radar, and also a 2-channel SAR MTI image where the GMT detections are displayed as dots on the sum channel image. This DCR is a first step in the development of a multi-channel MIMO radar capability in the sub 10-lb category, for small UAVs.

8714-31, Session 7

SAR and LIDAR fusion: experiments and applications

Matthew C. Edwards, Evan C. Zaugg, Joshua P. Bradley, Ryan D. Bowden, ARTEMIS, Inc. (United States)

In recent years ARTEMIS, Inc. has developed a series of compact, versatile Synthetic Aperture Radar (SAR) systems which have been operated on a variety of small manned and unmanned aircraft. The multi-frequency-band SlimSAR has demonstrated a variety of capabilities including maritime and littoral target detection, ground moving target indication, polarimetry, interferometry, change detection, and foliage penetration. ARTEMIS also continues to build upon the radar's capabilities through fusion with other sensors, such as electro-optical and infrared camera gimbals and light detection and ranging (LIDAR) devices. In this paper we focus on experiments and applications employing SAR and LIDAR fusion. LIDAR is similar to radar in that it transmits a signal which bounces off the target area and it records the signal that is returned to the sensor. The differences are that a LIDAR uses a laser as a transmitter and optical sensors as a receiver, and the wavelengths used exhibit a very different scattering phenomenology than the microwaves used in radar, making SAR and LIDAR good complementary technologies. LIDAR is used in many applications including agriculture, archeology, geo-science, and surveying. Some typical data products include digital elevation maps of a target area and features and shapes extracted from the data. A set of experiments conducted to demonstrate the fusion of SAR and LIDAR data include a LIDAR DEM used in accurately processing the SAR data of a high relief area (mountainous, urban). Also, feature extraction is used in improving geolocation accuracy of the SAR and LIDAR data.

8714-32, Session 7

High-efficiency switching power amplifiers for P, L, S, and X Band

Jarred W. Lawler, Justin S. Wells, Salvador W. Mendez, Timothy J. Wurth, NuWaves Engineering (United States)

Traditional RF Power Amplifier (PA) classes based on limited conduction angle topologies (i.e., Classes AB, B, and C) are unable to achieve better than 50% efficiency over a large bandwidth. Hence, this study concentrates on the more efficient breed of switching power amplifiers while realizing improvements in the size, weight, power, and cost (SWaP-C). In particular, the focus of this investigation is the Class F and Inverse Class F PAs incorporating new techniques to operate on multiple radar bands, specifically P, L, S, and X bands. This effort presents the techniques involved in achieving amplifier designs at P, L, S, and X band with greater than 80% efficiency and peak output power greater than 25 Watts.

The amplifier efficiency improvements were achievable by incorporation of innovative harmonic matching techniques based on Class F and Inverse Class F topologies. By ingeniously choosing the bias point and presenting defined impedances at the second and third harmonic frequencies, it becomes possible to significantly increase the amplifier efficiency. At P and L bands the peak power-added efficiency (PAE) achieved was 81% over a 23% and 16% bandwidth, respectively. A tradeoff exists between efficiency, power, and bandwidth. For this reason, designs were realized for both narrowband and broadband operation. The broadband designs achieved efficiencies greater than 50% at more than 30% bandwidth. The amplifier designs also include fast voltage switching circuits, making it possible to turn on and turn off the device in under 280 ns. Presented herein are state-of-the-art power amplifier technologies.

8714-33, Session 8

Calibration methods for phased array radars

Ilgin Seker, ASELSAN Inc. (Turkey)

For successful beam shaping and scanning in phased array radars, it is essential to be able to precisely set the gain and phase of each antenna element. However, considerable amplitude and phase differences among the elements can occur due to the different RF hardware connected to each element. Also, the phase and gain characteristics of most RF devices depend on frequency and temperature and usually drift in time. Thus, phased array antennas need to be calibrated periodically to equalize the phase and gain of each element.

In the literature, various phased array calibration methods are discussed. However, the details of these methods are usually not given. Here, we describe four of the most commonly used calibration methods in detail: near-field scanning probe, fixed peripheral probes, calibration transmission lines, and mutual coupling. The first method is preferred for factory calibration whereas the others can be used in the field for periodic calibration. The steps of each calibration method and relevant formulas are given. The advantages and disadvantages of each method for various phased array radar systems are also discussed. We conclude by presenting experimental results of calibrating a phased array test antenna.

8714-34, Session 8

Cognitive nonlinear radar test-bed

Abigail S. Hedden, David A. Wikner, Anthony F. Martone, David M. McNamara, U.S. Army Research Lab. (United States)

Providing situational awareness to the warfighter requires radar, communications, and other electronic systems that operate in the presence of co-site interference. In addition, the effective operation of current Army radar systems is threatened by the growing complexity of today's RF environment due partly to the ever increasing demand for electromagnetic spectrum from the wireless communications community. There is a growing need for cognitive RF systems that are capable of monitoring, adapting to, and learning from their environments in order to maintain their effectiveness and functionality. This work focuses on ongoing efforts at the Army Research Laboratory to develop a cognitive radar test-bed based on an existing nonlinear radar system. We are working toward implementing a test-bed that uses continuous real-time spectrum monitoring to inform and dynamically change radar transmit waveforms in order to maintain target detection with high confidence in a complex RF environment. This work presents the architecture of the test-bed system along with a discussion of its current capabilities and limitations. The test-bed is used to determine requirements for a future cognitive radar system.

8714-35, Session 8

Compact, autonomous, multi-mission synthetic aperture radar

Thomas J. Walls, Michael L. Wilson, U.S. Naval Research Lab. (United States); Chad Knight, David Madsen, Mark Jensen, Scott A. Anderson, Space Dynamics Lab. (United States); Mike Addario, SRC Inc. (United States)

The utilization of unmanned aerial systems (UAS) for intelligence, surveillance and reconnaissance (ISR) applications continues to increase and unmanned systems have become a critical asset in current and future battlespaces. With the development of medium-to-low altitude, rapidly deployable aircraft platforms, the ISR community has seen an increasing push to develop ISR sensors and systems with real-time mission support capabilities. This paper describes the design, development and presents demonstration flight test results of the RASAR (Real-time, Autonomous, Synthetic Aperture Radar) sensor system. RASAR is a modular, multi-band (L and X) synthetic aperture radar (SAR) imaging sensor designed for self-contained, autonomous, real-time operation with mission flexibility to support a wide range of ISR needs within the size, weight and power constraints of Group III UASs. SAR waveforms are generated through direct digital synthesis enabling arbitrary waveform notching to enable operations in cluttered RF environments and is capable of simultaneous dual-channel receive to enable polarization based target discrimination. The sensor command and control and real-time image formation processing are designed for integration of RASAR into larger, multi-intelligence system of systems. The multi-intelligence architecture and a demonstration of real-time autonomous cross-cueing of a separate optical sensor will be presented.

8714-36, Session 8

Real-time beyond the horizon vessel detection

Hugh J. Roarty, Michael Smith, Rutgers Coastal Ocean Observation Lab. (United States); Donald E. Barrick, CODAR Ocean Sensors (United States); Scott Glenn, Rutgers Coastal Ocean Observation Lab. (United States)

The marine transportation system (MTS) is a vital component of the United States Economy. Waterborne cargo accounts for more than $742 billion of the nation's economy and creates employment for 13 million citizens. A disruption in this system would have far reaching consequences to the security of the country.

The US National High Frequency radar network, which comprises 130 radar stations around the country, became operational in May 2009. It provides hourly measurements of surface currents to the US Coast Guard for search and rescue (SAR). This system has the capability of being a dual use system providing information for environmental monitoring as well as vessel position information for maritime security.

Real time vessel detection has been implemented at two of the radar stations outside New York Harbor. Several experiments were conducted to see the amount vessel traffic that the radar could capture. The radars were able to detect a majority of the vessels that are reporting via the Automatic Identification System (AIS) as well as 30 percent of mid to large size vessels that are not reporting via AIS. The radars were able to detect vessels out to 60 km from the coast.

The addition of a vessel detection capability to the National HF radar network will provide valuable information to maritime security sector. This dual use capability will fill a gap in the current surveillance of US coastal waters. It will also provide longer-range situational awareness necessary to detect and track smaller size vessels in the large vessel clutter.

8714-37, Session 8

Remote concealed threat detection by novel classification algorithms applied to multi-polarimetric UWB radar

Dean O'Reilly, Nicholas Bowring, David Andrews, Nacer D. Rezgui, Stuart Harmer, Manchester Metropolitan Univ. (United Kingdom)

A method of effectively detecting remote concealed threats, particularly knives and guns, has been developed, which uses multi-polarimetric ultra wide band active millimeter wave radar to remotely scan a person under investigation. It has been shown that the radar signatures from such scans can be used to detect whether a person is carrying a concealed threat. A PCA data reduction technique followed by a neural network is used to effectively classify the information extracted from the radar signals.

The technique combines the co, 45 degree, cross, and 135 degree transceived radar signals into a single data set for classification. Illuminating the target with a range of polarisations, together with choosing a radar beam size commensurate with the targets in question, produces good discrimination between threat and non threat items. Once collected, the data sets obtained are reduced via Principal Component Analysis, which significantly improves the correct classification rate at the NN stage and makes the technique more tolerant of variations in the target orientation and better able to detect a wider range of weapon types. Experimental results are presented that show that a detection rate of up to 80% for knives can be achieved, with a false alarm rate as low as 6%.

8714-48, Session PTue

A comparison of interferometric SAR antenna options

Armin Doerry, Douglas L. Bickel, Sandia National Labs. (United States)

We examine the relative merits of several different antenna configurations for radar interferometry, specifically SAR elevation interferometry. Specifically, we examine a conventional arrangement where a dedicated antenna is used to transmit and receive with another to receive only, a MIMO configuration where transmit and receive operations are ping-ponged, and a monopulse configuration. Our figure of merit is the RMS height noise in the DEM. We show that a monopulse configuration is equivalent to MIMO, and both offer an advantage over the conventional arrangement.

8714-49, Session PTue

Random-phase radar waveforms with shaped spectrum

Armin Doerry, Sandia National Labs. (United States); Brandeis Marquette, General Atomics Aeronautical Systems, Inc. (United States)

A random phase signal will also have random phase differences between two independent random phases. A phase increment across a time increment is in fact a phase-rate, or frequency. A phase-rate change is in fact a frequency-hop. By controlling the phase-rate, that is the characteristics of the phase increments, we can control the spectrum of the random-phase waveform. Spectrum precision and sharpness is enhanced by holding a frequency for some 'chip' length. For digitally generated phase samples, this means that the chip length needs to be many samples. This is a time-bandwidth issue. The definition of 'many' will depend on the sharpness desired, but often several tens' of samples will be adequate. To shape the ESD of a random-phase signal, we need to control the average energy at various phase-rates. This can be done with either or a combination of 1) Controlling the likelihood of specific phase increments, and/or 2) Controlling the duration of a specific phase increment chip length. For range-Doppler images, it is the 2-dimensional IPR that is of principal concern. This will tend to average out the random effects of any single pulse.

8714-50, Session PTue

Compound radar waveforms with multiple frames

Armin Doerry, Sandia National Labs. (United States); Brandeis Marquette, General Atomics Aeronautical Systems, Inc. (United States)

A pulse may be divided into contiguous sequential frames, sometimes called sub-pulses. In a typical pulse-Doppler radar, receiving echo energy must be deferred until after the entire pulse waveform is transmitted. This sets a nearest possible range at which the beginning of the echo pulse can be processed. However, even when early frames or portions of frames are occluded or eclipsed by the transmit pulse, the echo from later frames may still be received and processed. This allows latter frames to be received in their entirety from nearer ranges than earlier frames or the entire pulse. As long as the latter frames still exhibit the desired resolution bandwidth, no loss of resolution is suffered by processing against only the latter frames. In this manner, a compound multi-frame pulse can be processed against a larger range swath than a more conventional pulse modulation scheme. Essentially, the traditional constraints between near-range detection and pulsewidth have been considerably loosened. Relative frame durations can be optimized to allow SNR to exceed some minimum level.

8714-51, Session PTue

Effect of bistatic angle on bistatic ISAR image resolution

Sung-Taek Chun, U.S. Naval Research Lab. (United States); Keunha Lee, U.S. Naval Research Lab. (United States) and U.S. Naval Research Lab. (United States); Ronald D. Lipps, U.S. Naval Research Lab. (United States)

Bistatic inverse synthetic aperture radar (ISAR) has been shown to overcome some of the limitations of monostatic ISAR by placing the transmitter and receiver at different locations. Typically, the transmitter and receiver are not along the line of sight from the targets and a finite bistatic angle exists between the transmitter and receiver. Though there are many advantages of bistatic ISAR, it will be shown in this paper that the finite bistatic angle affects both the range and Doppler resolutions in such a way that the image resolution degrades as the bistatic angle increases. Even though the imaging resolution degrades, bistatic ISAR can increase the effective resolution of the target in many cases such as for poor target aspect. Using a bistatic ISAR signal processing formulation and the MUSIC super-resolution method, the effect of bistatic angle on the bistatic ISAR image resolution will be explored in detail.

8714-53, Session PTue

A mathematical observation on synthetic aperture radar

Yufeng Cao, Juan Lopez, Alejandro Martinez, Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

We present the foundation of conventional strip-mode synthetic aperture radar form a mathematical point of view. We also show how a simple antenna model can be used together with a scattering approximation to predict the received signal, in conventional strip-mode synthetic aperture radar (SAR) imaging, a plane or satellite flies along a straight track, which we will assume is in the direction of the horizontal axis. The antenna emits pulses of electromagnetic radiation in a directed beam perpendicular to the flight track. The waves scatter off the terrain, and the scattered waves are detected with the same antenna. The received signals are then used to produce an image of the terrain.

8714-54, Session PTue

Platform for research and education on ground penetrating radar

Michelle J. Salvador, Virginia Jimenez, Rafael G Lopez, Ricardo von Borries, The Univ. of Texas at El Paso (United States)

Current commercial Ground Penetrating Radar (GPR) systems are expensive and allow little interaction between the user and the system. In this work, we present a low cost and flexible GPR platform attractive for use in education and research. The hardware for this platform is based on the Universal Software Radio Peripheral (USRP) N210 and SBX RF daughterboard developed by Ettus Research. The USRP and daughterboard were chosen for their programmability, maximum RF bandwidth at 50 MHz, and ability to handle frequency ranges of 400-4400 MHz, ideal for GPR research. A software application developed using National Instrument's Labview enables users to select and modify fundamental parameters of the transmission and reception stages of this GPR system. Users are able to modify parameters such as sampling and carrier frequencies, waveform shape, amplitude, and bandwidth. Furthermore, the users are given the opportunity to choose how they wish to define the waveform with two different options; either import a waveform data file created from an outside source or choose from a list of predefined Gaussian derived waveforms as their template. Thus, this frees the user to explore and observe the results of different signal modifications for research and education purposes in GPR. The programmability of the USRP in conjunction with the developed software tools allows the creation of a user-friendly GPR platform.

8714-55, Session PTue

Lynx multi-mode SAR in support of NATO Unified Vision 2012 trial

Ralf Dunkel, Tobias Verge, Robert Linnehan, General Atomics Aeronautical Systems, Inc. (United States); Armin W. Doerry, Sandia National Labs. (United States)

In June 2012, General Atomics Aeronautical Systems, Inc. (GA-ASI) Reconnaissance Systems Group participated in the NATO Unified Vision

2012 (UV12) Joint ISR (JISR) Trial at Orland Main Air Station in Brekstad, Norway. GA-ASI supplied a modified King Air 200 as a Predator B/ MQ-9 Reaper RPA surrogate outfitted with a Lynx Block 30 Multi-mode Synthetic Aperture Radar/Ground Moving Target Indicator (SAR/GMTI), a FLIR Star SAFIRE 3800HD Electro-optical/Infrared (EO/IR) sensor, and a L-3 Tactical Common Data Link. This airborne platform was combined with GA-ASI's new System for Tactical Archival, Retrieval, and Exploitation (STARE) for full integration into the NATO ISR exploitation community.

UV12 was an event sponsored by the NATO Joint Capability Group on Intelligence, Surveillance, and Reconnaissance (ISR) to focus on the interoperability of national ISR assets and improving JISR concept of operations. The Predator B RPA surrogate flew alongside multiple NATO ISR assets in nine missions that showcased the platform's all weather ISR capabilities focusing on the Lynx SAR/GMTI and Maritime Wide Area Search (MWAS) modes.

The inclusion of the STARE technology allowed GA-ASI's radar and Full Motion Video (FMV) data to be seamlessly processed and passed to joint networks where the data was fused with other NATO ISR products, resulting in a full battlefield reconnaissance picture.

8714-56, Session PTue

An anisotropic SAR model incorporating aspect and spatial filters

Chad Knight, Space Dynamics Lab. (United States); Jacob Gunther, Todd Moon, Utah State Univ. (United States)

In theory integration over a wide-range of aspects provides enhanced scene interpretability and target detection. However, because the radar cross section of both targets and background clutter varies with aspect angle, integrating over wide aspect angles is inconsistent with standard SAR imaging algorithms, which implicitly assume that radar cross section is isotropic (i.e., constant with respect to aspect angle). This presentation focuses on the development of an anisotropic model that can be used for systems that integrate over wide aspects. The model is formulated using linear algebra in order to cast the image formation problem as an optimization problem. The problem we pose is convex, which ensures that the globally optimal solution can be computed efficiently.

Since SAR is inherently the convolution of a beam with a 3-D scene, the model equation is generally under-determined (unless a large amount of data is collected from different aspects). This means in most cases there are many solutions to the inverse problem. Constraints are incorporated into the optimization problem to find solutions consistent with prior information. This is accomplished by using spatial filters and aspect filters that are tuned to targets of interest. This accentuates the targets while suppressing the "clutter" or components of the scene that are of no interest.

This presentation will go through a detailed formulation of the model, the optimization problem, and constraint (filter) generation, discussing the inherent assumptions. Results on both real and synthetic data will be compared with traditional convolution back-projection SAR imagery.

8714-38, Session 9

Transforming optical image data into a SAR system's range based image space

Harald Anglberger, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Rainer Speck, German Aerospace Center (DLR) (Germany); Helmut Suess, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The fusion of image data of different sensor types is an important process for many remote sensing applications to maximize information retrieval from a given area of interest. The basic process to fuse image data is to select a common coordinate system and resample the data to this new image space. Usually, this is done by orthorectifying all those different image spaces, which means a transformation of the image's projection plane to a geographic coordinate system. Unfortunately, the resampling of the slant range based image space of a space borne synthetic aperture radar (SAR) to such a coordinate system strongly distorts its content and therefore reduces the amount of extractable information. The understanding of the complex signatures, which are already hard to interpret in the original data, even gets worse. To preserve maximum information extraction, this paper shows an approach to transform optical images into the radar image space. This can be accomplished by using an orthorectified optical image along with a digital elevation model and project it to the same slant range image plane as the one from the radar image acquisition. This whole process will be explained in detail along with practical examples. Specifically the fused image data can be used to improve the understanding of radar signatures in the imaged scene in general or can also assist the analyst in tasks like target recognition, the screening of time series for change detection or even in radar image acquisition planning.

8714-39, Session 9

Rejection of interference and near-field coupled LNA-noise on FPA-fed multibeam dish antennas using 3-D analog filters

Arjuna Madanayake, The Univ. of Akron (United States); Leonid Belostotski, The Univ. of Calgary (Canada); Chamith Wijenayake, The Univ. of Akron (United States); Yongsheng Xu, Len Bruton, Thushara Gunaratne, The Univ. of Calgary (Canada)

A fixed parabolic antenna can be combined with focal-plane array (FPA) beamforming to realize multiple independent broadband RF beams. Electronically scanned FPA-driven dishes provide both high directivity/ gain as well as rapid electronic steerability for emerging mm-wave radar, sensing and imaging systems. However, such FPAs for high-sensitivity applications suffer from degradation in sensitivity due to reasons such as clutter/noise from off-dish sources, and noise emerging out of inputs of low-noise amplifiers (LNAs) connected to each FPA elements. The LNA noise is re-radiated from elements in the FPA and coupled to neighboring elements leading to an overall degradation of the noise figure of the FPA receiver. Coupled noise from FPA LNAs therefore result in loss of system sensitivity leading to a beamformer dependent (i.e. directional) noise figure.

We propose multi-dimensional signal processing methods realized in the analog RF domain to reduce the effect of near-field coupled LNA noise. The proposed signal processing theory takes into account the three-dimensional (3-D) spatio-temporal frequency-spectrum of incident received signals, interference, clutter/jammers as well as coupled LNA noise, and exploits geometric properties of the spectrum to improve the signal-to-interference-plus-noise ratio (SINR) of the receiver system. We propose a 3-D spatio temporal filter bank having infinite impulse response (IIR) and corresponding 3-D cone/frustum shaped frequency response that achieves SINR improvement by setting a passband on the 3-D region of support of the desired received signals of interest in the spatio-temporal frequency domain. RF electromagnetic simulations, analog CMOS realizations, and estimated performance metrics of the filter is described.

8714-40, Session 9

A method to evaluate residual phase error for polar formatted synthetic aperture radar systems

Cameron Musgrove, Richard M. Naething, Sandia National Labs. (United States)

Synthetic aperture radar systems that use the polar format algorithm are subject to a focused scene size limit inherent to the polar format algorithm. The classic focused scene size limit is determined from the dominant residual range phase error term. Given the many sources of phase error in a practical synthetic aperture radar, a system designer is interested in how much phase error results from the assumptions made with the polar format algorithm. Autofocus algorithms have limits to the amount and type of phase error that can be corrected. Current methods correct only one or a few terms of the residual phase error. A system designer needs to be able to evaluate the contribution of the residual or uncorrected phase error terms to determine the new focused scene size limit. This paper describes a method to estimate the complete residual phase error, not just one or a few of the dominant residual terms. A benefit for the system designer is that additional correction terms can be added or deleted from the analysis as necessary to evaluate the resulting effect upon image quality.

8714-41, Session 9

Analysis of SAR autofocus performance

Richard M. Naething, Roger D. West, Sandia National Labs. (United States)

High quality focused SAR imaging dictates that the relative phase error over an aperture must be kept below a fraction of a wavelength. On most deployed SAR systems the internal measurement system's ability to measure position uncertainty is not sufficient to achieve this required precision. This necessitates an additional step of data-driven phase error mitigation. This additional post processing step is known as autofocus.

This step is typically performed using a parametric algorithm (such as map-drift) that relies on a model of the effects of motion error on imaging, or a non-parametric estimation technique such as PGA (phase gradient autofocus). Recently, several new autofocus techniques have been presented in the literature based on the optimization of various image quality metrics. These techniques assert that better performance than PGA is achievable at the expense of greater computational complexity.

The performance of PGA, particularly in variants that excise data to speed performance, can vary depending on algorithmic parameters. The optimal parameters may be scene content specific. This necessitates care when performing an assessment of autofocus quality to ensure optimal performance of PGA.

We present results comparing the performance of a variety of autofocus techniques, including image metric optimization based techniques and several variants of PGA. The degree of focusing is evaluated with an image focus metric, specific to SAR images, that is not biased toward any particular autofocus algorithm. This evaluation is performed on a variety of scene types using both injected (known) phase errors and with real uncompensated (unknown) motion errors.

8714-42, Session 9

Air target position estimation for track declaration using air-to-air radar

Liu Guoqing, Jordan Ramrus, General Atomics Aeronautical Systems, Inc. (United States)

General Atomics Aeronautical Systems, Inc. (GA-ASI) has recently designed and prototyped an air-to-air radar to provide Due Regard and Sense and Avoid capabilities for Remotely Piloted Aircraft (RPA). This radar employs a Search While Track (SWT) mode to perform target detection, acquisition, and tracking in a search volume. SWT utilizes a set of Kalman filters for implementing multi-target tracking (MTT), and the outputs of these Kalman filters are used to compute the track quality for track declaration. To formally declare a track on a target, it is required that the target position be predicted at a future time of interest and that the prediction uncertainty satisfies a certain criterion, which is derived from the safety requirement of the RPA.

Since the Kalman filters are usually designed to handle tracking of maneuvering targets, a large amount of updates may be needed to achieve the required track quality if there is any mismatch in the target maneuvering model. A Weighted Least Squared (WLS) approach is proposed in this study to improve the filtering accuracy, and thus to improve the target positioning accuracy. The proposed approach uses the outputs of the Kalman filters within a sliding window to refine estimates of current target position and velocity, as well as their uncertainties. These WLS estimates are then used to predict the target position and uncertainty. The effectiveness of the proposed approach is demonstrated by using Monte Carlo simulations. Impacts of contributing factors to the target positioning uncertainty are also quantified via simulations.

8714-43, Session 9

A global review of optronic synthetic aperture radar/ladar processing

Linda Marchese, Michel Doucet, Pascal Bourqui, INO (Canada); Bernd Harnisch, Martin Suess, European Space Research and Technology Ctr. (Netherlands); Mathieu Legros, Nochola Desnoyers, Simon Turbide, Sandra Turgeon, Luc Mercier, Maxime Savard, Anne Martel, Francois Chateauneuf, Alain Bergeron, INO (Canada)

Synthetic aperture (SA) techniques are currently employed in a variety of imaging modalities, such as radar (SAR) and ladar (SAL). The advantage of fine resolution provided by these systems far outweighs the disadvantage of having large amounts of raw data to process to obtain the final image. Digital processors have been the mainstay for synthetic aperture processing since the 1980's; however, the original method was optical that is, it employed lenses and other optical elements. This paper provides a global review of a compact light weight optronic processor that combines optical and digital techniques for ultra-fast generation of synthetic aperture images. The overall design of the optronic processor is detailed, including the optical design and data control and handling. As well, its real-time capabilities are demonstrated. Example ENVISAT/ASAR images generated optronically are also presented and compared with ENVISAT Level 1 products. As well, the extended capabilities of optronic processing, including wavefront correction and interferometry are discussed. Finally, a tabletop synthetic aperture ladar system is introduced and SAL images are presented that were generated using the exact optronic processor designed for SAR image generation.

8714-18, Session 10

High-resolution computation of electrical field propagation in land mine detection

Yury A. Gryazin, Idaho State Univ. (United States)

In recent years, the problem of increasing the resolution of existing numerical solvers has become an urgent task in many areas of science and engineering. Most of the existing efficient solvers for structured matrices were developed for lower-order approximation discretized partial differential equations. The need for improved accuracy of the underlying algorithms leads to modified discretized linear systems and as a result to the modification of the numerical solvers.

The goal of this paper is to describe a novel high-resolution 3D numerical method for the forward solution of high frequency electromagnetic wave propagation. This method will be used later by the author to computationally simulate data for the solution of the inverse problem of imaging mine-like targets. Thus the solution of the forward problem presented in this paper is a necessary prelude to the future solution of a related inverse problem.

In this paper, land mines are modeled as small abnormalities imbedded in an otherwise uniform media with an air-ground interface. These abnormalities are characterized by the electrical permittivity and the conductivity, whose values differ from those of the host media.

The main challenge in the calculation of the scattered electromagnetic signal in these settings is the requirement of solving a Helmholtz-like equation for high frequencies which is excessively time consuming using standard direct solution techniques. A novel high-resolution and rapid numerical procedure for the solution of this equation is described in this paper. The kernel of this algorithm is a combination of a sixth order compact finite-difference scheme and a preconditioned Krylov subspace method. The preconditioner in this method is based on a Fast Fourier Transform (FFT) algorithm. The extended problem of solving Helmholtz-like equations for many frequencies is also considered. Numerical results for realistic ranges of parameters in soil and mine-like targets, the investigation of the impact of the size of the truncation region on accuracy, and the sensitivity of detector readings to changes in the media are presented.

8714-44, Session 10

Comparison of filtering and smoothing algorithms for airborne radars

Bhashyam Balaji, Anthony Damini, Defence Research and Development Canada, Ottawa (Canada); Kai Wang, MDA Systems Ltd. (Canada); Martie Goulding, Kurt Hagen, MacDonald, Dettwiler and Associates Ltd. (Canada)

In an airborne radar with ground-moving target indication capabillity (specifically, with an ability to detect targets buried under clutter Doppler), the detection algorithm is based on space-time adaptive processing (STAP). The outputs of the STAP processor for use in kinematic tracking include the range, bearing, and Doppler. In this paper, we investigate the performance of some of the standard filtering and smoothing algorithms on simulated data as well as real airborne radar data. Specifically, we use the extended Kalman filter (EKF), unscented Kalman filtering (UKF) algorithms (and the converted measurement variants) as well as the Rauch-Tung-Streibel (RTS) algorithms that are based on the outputs of the filtering algorithms. Note that while there is a large and growing literature of tracking algorithms and their performance in radar applications, there are not many papers that investigate smoothing in this application.

We find that there is a slight difference in performance between the various filtering algorithms, especially pertaining to the robustness and reliability of state estimate. However, the smoother performance is significantly better than the filtering performance. The smoother performance is investigated as a function of the window length. It is interesting to see that even a relatively small window (of the order of 10) gives a markedly improved performance in terms track quality. In other words, a marked improvement in performance is seen for a small computational overhead in essentially real-time. A conclusion is that it is very fruitful to focus effort on investigating the smoothing and retrodiction algorithms in this application.

8714-45, Session 10

Instantaneous frequency and time-frequency signature estimation using compressive sensing

Branka Jokanovic, Univ. of Montenegro (Montenegro); Moeness Amin, Villanova Univ. (United States); Srdjan Stankovic, Univ. of Montenegro (Montenegro)

Signal reconstruction from undersampled or randomly sampled stationary signals using compressive sensing (CS) has proven effective in many applications, including radar. The Fourier-domain is typically the domain of choice for sparse signal representation. For nonstationary signals, such as microDoppler, the signals are wideband when viewed globally, but narrowband when considered instantaneously or through a short time-window.

This paper considers compressive sensing for time-frequency signal representation (TFSR) of nonstationary signals which are instantaneously narrowband. It is shown that the instantaneous frequency (IF), whether the signal is represented by a full data volume or with a large number of missing observations, cannot be accurately estimated using L1 minimization without invoking the signal local sparseness behavior through windowing techniques, that is, portioning the data into overlapping segments and carrying signal reconstruction over each segment separately.

In this paper, TFSR using L1 signal reconstruction is applied to the time-domain data rather than using the Ambiguity Function (AF), as previously proposed. The TFSR of the proposed approach depends on both the data window and the employed signal reconstruction algorithm. In this paper, we use both convex optimization and greedy algorithms and show that they provide different TFSRs and, subsequently, different IF estimates. We propose a follow-on step of the obtained TFSR which applies the S-method for improved IF estimation. The paper includes several examples of linear and nonlinear FM signals with mono- and multi-components. We compare the results, using microDoppler data, with existing techniques which use the AF and those that ignore the nonstationary nature of the data.

8714-46, Session 10

Riemannian mean and space-time adaptive processing using projection and inversion algorithms

Bhashyam Balaji, Defence Research and Development Canada, Ottawa (Canada); Frederic Barbaresco, Thales Air Systems SA (France)

Space-time adaptive processing (STAP) is a well-known technique to cancel interference due to clutter or jammer in airborne radar. STAP is based on the the ``clairvoyant” covariance matrix. This covariance matrix is then used for calculating the interference cancellation weights, typically based on covariance matrix inversion or projection/subspace methods.

However, the clairvoyant covariance matrix is never known in practice. It needs to be estimated from the received signal vector using the signal-free secondary data set. The sample covariance matrix is widely used because it can be shown to the maximum-likelihood estimate of the clairvoyant covariance matrix.

Recently, the relevance of some powerful concepts and methods of Riemannian and Kahler geometry to the radar signal processing has been proposed. Specifically, it has been to shown that the Riemannian geometry of symmetric cones are the natural mathematical object for studying covariance matrices. Also, the natural mathematical object for studying auto-regressive processes is Kahler geometry. Riemannian geometry is a vast, and extremely beautiful area of mathematics.

In a recent paper, significant gains were reported for the STAP application of information geometry based on computing the Riemannian mean of the snapshot covariance matrices. In this paper, we present an application of some further results to small sample-size STAP. We compare the performance of projection and inversion based STAP algorithms on a more challenging clutter scenario. It is found that the performance of the projection-based STAP algorithm is significantly better when the information-geometry inspired algorithm for estimating the covariance matrix is utilized.

8714-47, Session 10

3D wavelets-based denoising of high-frequency ultra-wideband synthetic aperture radar images

Anna Brook, Edison Cristofani, Marijke Vandewal, Royal Belgian Military Academy (Belgium); Carsten Matheis, Joachim Jonuscheit, Rene Beigang, Fraunhofer-Institut für Physikalische Messtechnik (Germany)

Recently, there has been an interest in employing high-frequency ultra-wideband imagery for industrial oriented applications in general and for non-destructive evaluation and testing of composite multi-layered materials in particular. The main motivations for using this technology are: it allows penetration of most non-metal and non-polarized materials, it provides the ability for three-dimensional (3-D) imagery and in-depth information, and these waves pose no health risk to the operator.

Commercially available frequency-modulated continuous-wave (FMCW) systems most commonly consider a classical set-up, focusing the beam using lenses. To overcome a negative effect of the beam waist, typically present in focused systems, the possibility to operate the FMCW system in a synthetic aperture (SA) mode is proposed. The main advantage is that a significantly wider aperture is providing constant cross-range resolution. The disadvantage is the random granular pattern noise, e.g. speckle, which is inherent to the data acquisition process and its appearance degrades the image quality. The contribution of the applied denoising technique is a higher image quality that will be further used in pattern recognition and image analysis.

The present study proposes a divergence-free coefficient (orthogonal isotropic bases) 3-D wavelets-based denoising method for FMCW (40 GHz bandwidth centered at 100 GHz) 3-D images, which are used to reveal surface and in-depth information8. This method relies on correlation between residual and retrieved signal by applying both qualitative and quantitative analysis for imagery data. The reported results are based on a real data set, containing manufactured calibration materials, which are commonly used in aeronautics and aerospace industries. Additionally, this study investigates and compares these results with other transformation and denoising techniques.

8714-15, Session 11

Micro-doppler and vibrometry at millimeter and sub-millimeter wavelengths

Duncan A. Robertson, Scott L. Cassidy, Univ. of St. Andrews (United Kingdom)

Micro-Doppler is an emerging technique for the measurement and analysis of target modulation characteristics. The topic emerged from analysis of X-band radar measurements of people and has led to a rapidly developing field. However, despite the advantage of higher Doppler sensitivity, there appears to be little work reported on micro-Doppler at millimeter or submillimeter wave frequencies.

We wish report on our current development of fully coherent solid state FMCW radar systems operating at 94 and 340 GHz which are suitable for micro-Doppler and vibrometry studies. Additionally, they can be applied to range-Doppler imaging and SAR/ISAR. The use of DDS chirp generation combined with upconversion and MMIC or Schottky diode frequency multiplication schemes yields low phase noise and rapid, contiguous chirps, necessary for Doppler studies and other coherent processing techniques.

We will present a comparison of the phase noise of the chirp signal compared with the measured phase variations from static point targets. Due to the low phase noise architecture, high SNR targets can yield a phase (i.e. displacement) sensitivity which is below 1 micron in distance. This high phase sensitivity demonstrates the advantage of performing micro-Doppler and vibrometry measurements at millimeter and submillimeter wave frequencies.

Our paper will include a description of the radar hardware, measured performance characteristics, and example micro-Doppler and vibrometry results.

8714-16, Session 11

Micro-range micro-doppler for dismount classification

David Tahmoush, U.S. Army Research Lab. (United States)

We demonstrate the effect high-range-resolution has on radar micro-Doppler dismount classification of individuals versus groups. We associate image detections with radar detections through micro-Doppler extracted from both radar and imagery. We explain how radar and IR together can produce an inexpensive alternative for wide-area persistent surveillance.

8714-17, Session 11

Initial measurements of the angular velocity of walking humans using an active millimeter-wave correlation interferometer

Kojo S. Zilevu, Jeffrey A. Nanzer, Johns Hopkins Univ. Applied Physics Lab. (United States); Kelly L. Kammerman, Syracuse Univ. (United States)

Measurement of the angular motion of moving objects is a desirable function in remote security sensing applications. Doppler radar sensors are able to measure the signature of moving humans based on micro-Doppler analysis; however, a person moving with little to no radial velocity produces negligible Doppler returns. Measurement of the angular movement of humans can be done with traditional radar techniques however the process involves either continuous tracking with narrow beamwidth or angle-of-arrival estimation algorithms. Recently, the authors presented a new method of measuring the angular velocity of moving objects using interferometry. The method measures the angular velocity of an object without tracking or complex processing. The frequency shift imparted on the signal response is proportional to the angular velocity of the object as it passes through the interferometer beam pattern.

The design of a 29.5 GHz experimental active interferometer for the measurement of the angular velocity of moving humans is presented in this paper, as well as initial measurements of walking humans. The experimental system consists of a transmitter and two separate receivers with two widely spaced antennas. The received signals in each of the two channels are downconverted and digitized, and post-processed in offline. Initial results of a walking human passing through the interferometer beam pattern are presented, which verify the expected operation of the receiver derived from the initial theory.

8715-1, Session 1

140-220 GHz imaging front-ends based on 250 nm InP/InGaAs/InP DHBT process

Vessen Vassilev, Herbert Zirath, Rumen Kozhuharov, Yogesh Karandikar, Vedran Furtula, Chalmers Univ. of Technology (Sweden)

Detectors based on Teledyne 250 nm InGaP/InGaAs HBT process are presented for the 140-220 GHz band – a passive where transistor's base-emitter junction is used as a diode, and an active, where the transistor is biased at all ports and the trans-conductance nonlinearity is used for detection. Measurements of transistors noise-power spectrum density at low frequencies are utilized to model and predict the NEP of the detectors.

The responsivity and the NEP are compared to measurements. Both measurements and modeling show that the diode detector offers lower NEP than the active. The reason for this, as it will be shown, is that the differential base-emitter resistance is lower at its optimum bias point in the case of diode detector. The same types of detectors are combined with LNA and integrated antenna. Characterization of these front ends will be presented at the conference. Based on the results, a prediction for the maximum temperature resolution of an imaging front end is given using this technology.

8715-2, Session 1

Enabling technologies for mmw and THz imaging systems

Bryan Bothwell, TriQuint Semiconductor, Inc. (United States)

TriQuint Semiconductor, a leading RF products manufacturer and foundry services provider, has the broadest portfolio of Gallium Arsenide (GaAs) and Gallium Nitride (GaN) process technologies. These are leveraged along with high volume/ high performance packaging capabilities to provide RF solutions across Mobile Device, Infrastructure, and Defense markets. Combined with a strong history in radar applications, this unique portfolio provides enabling technologies to address the performance and cost challenges facing the millimeter (mmw) and Terahertz (THz) imaging markets. This presentation will highlight the variety of solutions TriQuint brings to the mmw and THz imaging markets that may be considered non-traditional vs. current technologies. Initial focus will be on mmw where there have been significant advances in low cost GaAs based process/ packaging technology driven by the increased demand for Mobile Devices. The achievable noise figure is differentiated with respect to historical volume commercial process technologies in this case. The focus will then shift to the benefits of GaN and show the opportunities for both power and low noise solutions this technology offers from the mmw range up through 500GHz. As a world pioneer in GaN, TriQuint will address the Research and Development aspects of where GaN technology is being focused, as well as the manufacturing and reliability aspects that will be key for GaN commercialization across the frequency bands.

8715-3, Session 1

A SiGe BiCMOS W-band passive imaging receiver using lossless flicker-noise cancellation

Vipul Jain, Farbod Behbahani, SaberTek, Inc. (United States)

High-performance highly-integrated millimeter-wave ICs will enable next-generation passive imaging systems with smaller size, lower power dissipation, reduced cost, and enhanced image resolution. Existing compound-semiconductor technologies for imaging solutions are expensive and are not amenable to high integration. Several imaging receivers in silicon technologies have been demonstrated recently, but the reported NETD is far from acceptable due to a combination of high noise figure, insertion loss of Dicke switch, and flicker noise. In this paper, we report the first receiver chip in SiGe BiCMOS that meets the requirements of practical W-band passive imaging systems, and achieves an unprecedented performance that is even better than existing III-V imaging receivers. Unlike other silicon-based imagers, our chip does not need an SPDT switch at the receiver input, and hence does not suffer from its insertion loss. The performance of III-V imagers that do not incorporate a Dicke switch is typically limited by flicker-noise. To address this issue, a novel lossless flicker-noise cancellation technique was developed, which dramatically improves the imager NETD.

The design and measurements of the highly-integrated direct-detection-type imaging receiver chip are presented. The receiver IC integrates all necessary RF and analog functions including millimeter-wave amplification and power detection, baseband amplification, sample-and-hold, clock generation, imager calibration, bias, and digital control. Using the flicker-noise cancellation technique, the imaging receiver achieves a record NETD of 0.22K/0.15K/0.1K for 3ms/10ms/30ms integration-time, and a responsivity of 140 MV/W. The chip is fabricated in a 0.18-um SiGe BiCMOS technology with 240/280-GHz fT/fmax and occupies 2.5x2.5mm2. The power dissipation of the receiver is 40 mW.

8715-4, Session 1

Recent developments using TowerJazz SiGe BiCMOS platform for mmWave and THz applications

Arjun Kar-Roy, David Howard, Edward J. Preisler, Marco Racanelli, Jazz Semiconductor, Inc. (United States)

We report on the highest speed 250GHz/340GHz ft/fmax NPNs which have been demonstrated in the SBC18H4 process. This process is one of the process offerings in TowerJazz's high volume manufacturable commercial SBC18 and SBC13 silicon germanium (SiGe) BiCMOS technology platforms. NFmin of less than 2dB at 50GHz has been obtained with these NPNs. In addition to the high-speed NPNs, the SiGe BiCMOS process platforms integrate dual gate oxide MOSFETs in 0.18um and 0.13um process nodes, high density 5.6fF/um^2 stacked MIM capacitors, high value polysilicon resistors, high-Q metal resistors, lateral PNP transistors, triple well isolation using deep nwell, varactors, p-i-n diodes, Schottky diodes, compact high-Q inductors and deep trench isolation. In this paper, we will also report on the various circuit demonstrations obtained recently using the previous generation 240GHz/270GHz ft/fmax NPN SBC18H3 process for mmWave and THz applications. We will report results on a 4-element phased array chipset with both transmitter and receiver operating between 70 and 100GHz. The receiver channels have a conversion gain of 33dB and noise figure of <7dB and the transmit channels have a flat saturated output power of > 5dBm. Results from a 16-element array, operating at 110GHz frequency range and with independent amplitude and phase control will also be reported. In imaging, results from a 3x3 FPA W-band imaging array with NETD less than 0.5K and responsivity of 800MV/W will be presented. Extension to wafer scale phased array and mmWave imaging array, using available sub-field stitching process technology in SBC18 and SBC13 process platforms, will also be discussed. Other unique demonstrations such as improved LNA results and 200GHz varactor-less VCO with -7 dBm output power will be described.

8715-6, Session 1

Near-field measurements of submillimeter-wave reflectarrays

Aleksi A. Tamminen, Juha Ala-Laurinaho, Sampo Mäkelä, Aalto Univ. School of Science and Technology (Finland); David Gomes-Martins, VTT Technical Research Ctr. of Finland (Finland); Janne Häkli, VTT Technical Research Centre of Finland (Finland); Päivi Koivisto, Pekka Rantakari, Jussi Säily, Reijo Tuovinen, Arttu R. Luukanen, Markku Sipilä, VTT Technical Research Ctr. of Finland (Finland); Antti V. Räisänen, Aalto Univ. School of Science and Technology (Finland)

We present results of experimental characterization of a static 650-GHz reflectarray. The reflectarray is based on a 124-um circular microstrip patch antennas with a tuning stub as a phase shifter. The static reflectarray is considered as a predecessor for active reflectarray, and therefore reflectarray elements have two discrete phase-shift values: 0° and -180°. The reflectarray has 95 000 elements, and they have separation of 0.4 mm. The reflectarray is fabricated on a 150-mm silicon wafer plated with ground plane and 20-um polyimide substrate. The fabricated static reflectarrays are characterized in a near-field measurement range and their beam patterns at the focusing distance of 20 m are calculated with plane-to-plane transform. At this high frequency, fabrication tolerances are difficult to meet and, e.g., over-etching of the antenna and phase-shifting structure may offset the resonance frequency of the reflectarray element by more than its bandwidth. Also, near-field measurements require approximately 500 thousand data points in a day-long measurement. Together with presenting the measured performance of the static 650-GHz reflectarrays, we discuss the challenges related to such near-field measurements of offset-fed reflectarrays.

8715-24, Session 1

Backscattering of ground terrain and building materials at terahertz frequencies

David A. DiGiovanni, Andrew J. Gatesman, Robert H. Giles, Univ. of Massachusetts Lowell (United States); William E. Nixon, National Ground Intelligence Ctr. (United States)

As terrestrial remote sensing and communication systems continue to evolve in the 0.1 – 0.3 THz band, the need to understand the scattering behavior of common materials and ground terrain at these frequencies becomes important. Terrain features and surface roughness that would otherwise appear smooth at longer wavelengths begin to significantly impact the radar cross section of the surfaces at these higher frequencies. The HH and VV polarized backscattering coefficient of several types of ground terrain and building materials were measured in indoor compact radar ranges operating at 100 GHz and 240 GHz. Measurements of the various materials were collected at elevation angles ranging from 5 to 35 degrees. The goal of the effort was to begin to understand the polarimetric scattering behavior of materials in the 0.1 – 0.3 THz region. The statistical scattering behavior of the materials was also investigated.

8715-7, Session 2

Wide-bandwidth, wide-beamwidth, high-resolution, millimeter-wave imaging for concealed weapon detection

David M. Sheen, Justin L. Fernandes, Jonathan R. Tedeschi, Douglas L. McMakin, Mark Jones, Wayne M. Lechelt, Ronald H. Severtsen, Pacific Northwest National Lab. (United States)

Active millimeter-wave imaging is currently being used for personnel screening at airports and other high-security facilities. The cylindrical imaging techniques used in the deployed systems are based on licensed technology developed at the Pacific Northwest National Laboratory. The cylindrical and a related planar imaging technique form three-dimensional images by scanning a diverging beam swept frequency transceiver over a two-dimensional aperture and mathematically focusing or reconstructing the data into three-dimensional images of the person being screened. The resolution, clothing penetration, and image illumination quality obtained with these techniques can be significantly enhanced through the selection the aperture size, antenna beamwidth, center frequency, and bandwidth. The lateral resolution can be improved by increasing the center frequency, or it can be increased with a larger antenna beamwidth. The wide beamwidth approach can significantly improve illumination quality relative to a higher frequency system. Additionally, a wide antenna beamwidth allows for operation at a lower center frequency resulting in less scattering and attenuation due to the clothing. The depth resolution of the system can be improved by increasing the bandwidth. Utilization of extremely wide bandwidths of up to 30 GHz can result in depth resolution as fine as 5 mm. This wider bandwidth operation may allow for improved detection techniques based on high range resolution. In this paper, the results of an extensive imaging study are presented for both planar and cylindrical imaging techniques at frequency ranges of 10-20 GHz, 10 – 40 GHz, 40 – 60 GHz, and 75 – 105 GHz.

8715-8, Session 2

Transceiver array development for submillimeter-wave imaging radars

Ken B. Cooper, Theodore Reck, Cecile Jung-Kubiak, Choonsup Lee, Jose Siles, Robert Lin, Alejandro Peralta, Emmanuel Decrossas, Erich Schlecht, Goutam Chattopadhyay, Imran Mehdi, Jet Propulsion Lab. (United States)

The development of radar transceiver arrays is the surest way to increase the frame rate of active submillimeter-wave imaging radars. We have tackled considerable engineering challenges in building a multi-pixel heterodyne terahertz transceiver and integrating it into a radar in a manner consistent with eventual commercialization. For the transceiver array itself, we have developed and begun testing waveguide blocks fabricated from micromachined silicon, which has advantages over conventional metal blocks in feature tolerance, manufacturing uniformity, production cost, signal routing flexibility, and compatibility with lithographically defined bias circuitry. For the radar's backend electronics, we have built hybrid analog/digital integrated microwave assemblies spanning dc to Ka-band that can be mass-produced. These include a four-channel down-converter unit with low cross-talk and a chirped 36-38 GHz source capable of sweeping as fast as 80 MHz per microsecond, with a phase noise better than -102 dBc/Hz at offsets between 10 and 100 kHz. We have also parallelized our imaging radar signal processing algorithm for multiple channels on an embedded, off-the-shelf PC/FPGA platform. Real-time radar signal processing of four simultaneous channels has been verified with 80 microsecond pulse repetition intervals. Modifications in the radar's scanning optics have also been implemented to increase the imaging speed, and the overall system packaging has been lightened in weight and ruggedized.

8715-9, Session 2

Personnel screening with advanced multistatic imaging technology

Sherif S. Ahmed, Rohde & Schwarz GmbH & Co. KG (Germany)

Personnel screening is demanded nowadays for securing air traffic as well as critical infrastructures. The millimeter-waves are capable to penetrate clothes and detect concealed objects, making them an attractive choice for security screening. Advanced imaging methods based on multistatic architecture can ensure high quality imagery in terms of resolution and dynamic range. Following the advances in

semiconductor technology, fully electronic solutions delivering real-time imaging are becoming feasible. Furthermore, the continuously increasing capabilities of digital signal processing units allow for the utilization of digital-beamforming techniques for image reconstruction, thus offering new opportunities for imaging systems to use advanced operation modes. Based on these modern technologies, an advanced realization addressing personnel screening in E-band with planar multistatic sparse array design is demonstrated.

8715-11, Session 3

Three-dimensional millimeter-wave imaging for concealed threat detection in shoes

Justin L. Fernandes, Douglas L. McMakin, Jonathan R. Tedeschi, David M. Sheen, Pacific Northwest National Lab. (United States)

This paper describes a study performed at the Pacific Northwest National Laboratory investigating the use of active millimeter-wave radar imaging to perform threat detection in non-divested shoes. The purpose of this study was to determine the optimal imaging system configuration for performing this type of task. While active millimeter-wave imaging systems have proven to be effective for personnel screening, the phenomenology associated with imaging within a heterogeneous medium, such as a shoe, dictates limits for imaging system parameters. Scattering, defocusing, and multipath artifacts are significantly exaggerated due to the high contrast index of refraction associated with the boundary at the air and shoe interface. Where higher center-frequency and bandwidth result in much improved lateral and range resolution in the body scanning application, smaller wavelengths are significantly defocused after penetrating the sole of the shoe. Increased bandwidth, however, is essential for the shoe scanning application as well. Obtaining fine enough depth resolution is critical in separating the scattering contribution of each layer of the shoes in range to isolate possible threats embedded within the sole. In this paper the results of this study covering the optimization of the following imaging system parameters is presented: antenna illumination beamwidth, antenna polarization, transceiver bandwidth, and physical scanning geometry.

8715-12, Session 3

Environmental control for improved Passive Millimeter Wave concealed object detection

Thomas D. Williams, Millivision Technologies, Inc. (United States)

Passive Millimeter Wave Imaging for detection of concealed contraband has been demonstrated for decades in various forms. One vexing problem is that when some emissive materials reach body temperature they loose contrast. A solution to this problem is presented where by manipulation of the environmental conditions can tease apart the thermal conditions of materials from their emissive/reflective properties. This manipulation of the environment is thermal, and so projects no energy other than thermal at any wavelength onto the scene. Results of an implementation are presented which demonstrate the ability to detect heretofore undetectable objects of interest.

8715-13, Session 3

Development of passive submillimeter-wave video imaging systems

Erik Heinz, Torsten May, Detlef Born, Gabriel Zieger, Katja Peiselt, Anika Brömel, Solveig Anders, Vyacheslav Zakosarenko, Torsten Krause, André Krüger, Marco Schulz, Hans-Georg Meyer, Institut für Photonische Technologien e.V. (Germany)

Passive submillimeter-wave imaging has been in the focus of interest as a promising technology for security applications for a number of years. It utilizes the unique optical properties of submillimeter waves and promises an alternative to millimeter-wave and X-ray backscattering portals for personal security screening in particular. Possible application scenarios demand sensitive, fast, and flexible high-quality imaging techniques. Considering the low radiometric contrast of indoor scenes in the submillimeter range, this objective calls for an high detector sensitivity that can only be achieved using cooled detectors.

Our approach to this task is a series of passive standoff video cameras for the 350 GHz band that represent an evolving concept and a continuous development since 2007. The cameras utilize arrays of superconducting transition-edge sensors (TES) as radiation detectors. The TES are operated at temperatures below 1 K, cooled by a closed-cycle cooling system, and coupled to superconducting readout electronics. By this means, background limited photometry (BLIP) mode is achieved providing the maximum possible signal to noise ratio. At video rates, this leads to a pixel NETD well below 1 K. The imaging system is completed by reflector optics based on free-form mirrors and integrated mechanical scanners.

We present a new camera prototype featuring a linear array of 64 or 128 detectors and a linear scanner that can be adapted to different types of reflector optics for different object distances. A field of view of 1×2 m^2 and a frame rate of up to 25 Hz is provided.

8715-14, Session 3

Passive three-colour submillimetre-wave video camera

Arttu R. Luukanen, Leif Grönberg, VTT Technical Research Ctr. of Finland (Finland); Markus Grönholm, Asqella Oy (Finland); Mikko M. Leivo, Anssi Rautiainen, Hans Toivanen, VTT Technical Research Ctr. of Finland (Finland)

Stand-off detection for concealed weapons is one of the applications for passive submillimetre-wave imaging. The operating frequency (neglecting technology limitations) is often a compromise between the diffraction-limited angular resolution for a fixed maximum aperture diameter, and the extinction of the signal in obscurant layers: At high frequencies towards the 1 THz mark, excellent angular resolution is readily achievable with modest aperture diameters, while scattering and attenuation by clothing is high which creates potentially more clutter rather than improving detection capability. At lower frequencies towards 100 GHz, attenuation and scattering by clothing is much less pronounced, albeit at significantly reduced spatial definition thanks to increased diffraction.

In order to avoid the above-mentioned compromise, we have constructed a three-band passive imaging system operating at effective centre frequencies of 250 GHz, 450 GHz and 720 GHz. Measurements and imagery acquired with the system will be presented.

8715-15, Session 3

Fully polarimetric differential intensity W-band imager

Bruce E. Bernacki, Jonathan R. Tedeschi, James F. Kelly, David M. Sheen, Thomas E. Hall, Patrick L. J. Valdez, Wayne M. Lechelt, Douglas L. McMakin, Pacific Northwest National Lab. (United States)

We present a novel architecture based upon a Dicke-switched heterodyne radiometer architecture employing two identical input sections consisting of horn and orthomode transducer to detect the difference between the H and V polarization states of two separate object patches imaged by the radiometer. We have constructed and described previously a fully polarimetric W-band passive millimeter wave imager constructed to study the phenomenology of anomaly detection using polarimetric image exploitation of the Stokes images. The heterodyne radiometer used a PIN diode switch between the input MMW energy and that of a reference load in order to eliminate the effects of component

drifts and reduce the effects of 1/f noise. This differential approach differs from our previous work by comparing H and V polarization states detected by each of the two input horns instead of a reference load to form signals delta H and delta V from closely adjacent paired pixels. This novel imaging reduces common mode noise and enhances detection of small changes between the H and V polarization states of two object patches, now given as difference terms of the fully polarimetric radiometer. We present the theory of operation, initial proof of concept experimental results, extension of the differential radiometer to a system with a binocular fore optics, and offer a concept for differential imaging using a single fore optic combined with a novel quasi optical element to allow adjustment of the overlap or shear of the object patches viewed by the differential polarimetric imager.

8715-16, Session 4

SUMIRAD: a low-cost fast millimeter-wave radiometric imaging system

Markus Peichl, Stephan Dill, Daniel Rudolf, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

For many military or peace-keeping operations it is necessary to provide better situational awareness to the commander of a vehicle with respect to possible threats in his local environment (predominantly ahead), at a distance of a few ten to a few hundred meters. Such a challenging task can only be addressed adequately by a suitable multi-sensor system. As a beneficial part of that, an imaging radiometer system with a sufficiently high frame rate and field of view is considered. The radiometer, working 24 hours in all weather and sight conditions, generates quasi-optical images simplifying the microwave image interpretation. Furthermore it offers the advantage to detect and localise objects and persons under nearly all atmospheric obstacles and also extents the surveillance capabilities behind non-metallic materials like clothing or thin walls and thin vegetation. Based on constraints of low costs and the observation of a large field of view, the radiometer still offers a moderate resolution at a moderate scan speed.

The paper describes the challenges for the design of a vehicle-based imaging radiometer system at W band, providing high-quality images of sufficient resolution for a large field of view at a moderate frame rate. The construction is briefly outlined and imaging results for several situations are presented. Those comprise measurements on target detection and investigations on the variations of scenes over time.

8715-17, Session 4

Missile tracking and range safety: Tracking Interferometer Pathfinder System (TIPS)

David Dowgiallo, U.S. Naval Research Lab. (United States)

The tracking of missiles at close range proximity has been an ongoing challenge for many launch environments. The ability to provide accurate missile trajectory information is imperative for range safety and early termination of flight. In an effort to provide a potential solution to tracking issues that have plagued many traditional techniques, the Tracking Interferometer Pathfinder System (TIPS) was developed at the Naval Research Laboratory, Washington, D.C.

In the past, radar and optical techniques have been used for short range tracking with mixed results. Radar systems have experienced issues with multipathing, clutter, and range gating. Expended rocket stages contribute additional problems in tracking by disguising the primary target. Optical systems have had difficulty with varying cloud cover and non-optimal viewing conditions. An alternative to the previous methods is a passive interferometer, offering several benefits over other tracking techniques: all weather operation, constant day/night imaging, no moving parts, and no radio frequency emissions.

The development and field test of the TIPS sensor will be presented, along with the data analysis and imaging of a launch event.

8715-18, Session 4

Realization of a video-rate distributed aperture millimeter-wave imaging system using optical upconversion

Christopher A. Schuetz, Richard D. Martin, Thomas E. Dillon, Peng Yao, Daniel Mackrides, Charles Harrity, Alicia Zablocki, Kevin Shreve, Phase Sensitive Innovations, Inc. (United States); James Bonnett, Petersen F. Curt, EM Photonics, Inc. (United States); Dennis W. Prather, Univ. of Delaware (United States)

Passive imaging using millimeter waves (mmWs) has many advantages and applications in the defense and security markets. All terrestrial bodies emit mmW radiation and these wavelengths are able to penetrate smoke, fog/clouds/marine layers, and even clothing. One primary obstacle to imaging in this spectrum is that longer wavelengths require larger apertures to achieve the resolutions desired for many applications. Accordingly, lens-based focal plane systems and scanning systems tend to require large aperture optics, which increase the achievable size and weight of such systems to beyond what can be supported by many applications. To overcome this limitation, a distributed aperture detection scheme is used in which the effective aperture size can be increased without the associated volumetric increase in imager size. This distributed aperture system is realized through conversion of the received mmW energy into sidebands on an optical carrier. This conversion serves, in essence, to scale the mmW sparse aperture array signals onto a complementary optical array. The optical side bands are subsequently stripped from the optical carrier and optically recombined to provide a real time snapshot of the mmW signal. Using this technique, we have constructed a real-time, video-rate imager operating at 75 GHz. A distributed aperture consisting of 220 upconversion channels is used to realize 2.5k pixels with passive sensitivity. Details of the construction and operation of this imager as well as field testing results will be presented herein.

8715-19, Session 4

VESAS: a novel concept for fully-electronic passive MW imaging

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These days passive microwave (MW) remote sensing has found many applications. For example, in Earth observation missions, it is possible to estimate the salinity of oceans, the soil moisture of landscapes, or to extract atmospheric parameters like the liquid water content of clouds. Due to the penetration capabilities of microwaves through many dielectric materials, and the purely passive character of this kind of remote sensing, this technique nowadays is considered as well in many security and reconnaissance applications (e.g. observation of sensitive areas, detection of concealed objects, trough-wall imaging, etc.). Presently different imaging principles for MW radiometry are possible. Most of them still are based on pure mechanical scanning or they combine this with electronic scanning by using parts of a focal plane array. Due to many advantages, the technological trend is going towards fully-electronic beam steering or two-dimensional focal plane arrays. These systems are able to achieve high frame rates, but they are still very expensive because of a significantly higher number of receiver modules, compared to a mechanical scanning system. In our approach a novel concept for a low cost Ka-band fully-electronic MW imaging radiometer system is introduced. It is based on a combination of beam steering by frequency shift using a slotted waveguide antenna, and the application of aperture synthesis. In the following a proof of concept is outlined by presenting different MW imaging measurement results, using this kind of imaging principle.

8715-20, Session 4

Sparse Interferometric Millimeter-wave Array for Centimeter-level 100-m Standoff Imaging

Jonathan Y. Suen, Philip M. Lubin, Steven L. Solomon, Robert P. Ginn, Acumen Scientific (United States)

We present work on the development of a long range standoff concealed weapons detection system capable of imaging under very heavy clothing at distances exceeding 100 m with a cm resolution. The system is based off a combination of phased array technologies used in VLBI radio astronomy and SAR radar by using a coherent, multi-frequency reconstruction algorithm which can run at video frame rates and high SNR with a multi-tone transceiver. The high power, low noise, and low cost devices available from 30-100 GHz provide a practical solution capable of detecting concealed weapons and IEDs at a reasonable standoff with portable 80-cm aperture antennas.

A major problem with phased-array systems is the need for phase controlled receivers, wiring, element placement, and system calibration. Here, we draw on the systems used for radio astronomy by using GPS position and frequency synchronization to allow for algorithmic correction of phase errors. Our system is portable, can be easily set up, and is self-aligning and battery powered.

We show the flexible design space of our system as well as algorithm development, predicted system performance and impairments, and simulated reconstructed images.

8715-21, Session 4

Passive and active imaging at 94 GHz for environmental remote sensing

David G. Macfarlane, Duncan A. Robertson, Scott L. Cassidy, Univ. of St. Andrews (United Kingdom); Henry M. Odbert, Univ. of Bristol (United Kingdom); Mike R. James, Harry Pinkerton, Lancaster Univ. (United Kingdom); Geoff Wadge, The Univ. of Reading (United Kingdom)

We report on the use of the All-weather Volcano Topography Imaging Sensor (AVTIS) 94 GHz dual mode radar/radiometric imager for environmental monitoring. The FMCW radar yields 3D maps of the terrain whilst the passive radiometer records brightness temperature maps of the scene. AVTIS is a low power portable instrument and has been used operationally to survey terrain at ranges up to 6 km.

AVTIS was originally developed for the ground-based measurement of active volcanoes and has been used successfully to measure the Arenal Volcano in Costa Rica and the Soufrière Hills Volcano on Montserrat. However, additional environmental remote sensing applications are emerging for this technology and we will present details of how the instrument is used to perform terrain mapping and thermal surveys of outdoor scenes.

The extraction of digital elevation maps (DEMs) is the primary function of the AVTIS radar mode. We will review this process covering range drift compensation, radar cross section (RCS) histogram analysis and thresholding, and georeferencing to GPS. Additionally, we will present how careful calibration enables RCS imaging of terrain and the extraction of the intrinsic reflectivity of the terrain material (normalized RCS, or sigma-nought) which can be used to classify terrain types.

We have validated the passive mode imagery against infrared thermal imagery and they show good agreement once the differences in spatial resolution are accounted for. This comparison also reveals differences in propagation due to obscurants (steam, gas, ash) in the two wavebands.

8715-22, Session 4

Nonlinearity and phase noise effects in 340 GHz 3D imaging radar

Duncan A. Robertson, Scott L. Cassidy, David R. Bolton, Univ. of St. Andrews (United Kingdom)

IRAD is a 340 GHz coherent, heterodyne, 3D imaging radar with a frame rate of up to 10 Hz. Recent efforts in the system's development have focused on optimising performance and we plan to report recent results. Phase noise in FMCW radar systems can be a limiting factor when trying to measure low reflectivity targets in the presence of high reflectivity targets, as is the case for high resolution 3D imaging radars operating at submillimeter wavelengths targeting security imaging applications. Ken Cooper of JPL recently reported (IMS 2012) that phase noise is the limiting factor in his system and that effort must be directed to lowering source phase noise rather than increasing raw SNR. We will present measurement of the phase noise of our DDS based chirp generator, its relationship with the phase stability of fixed reference targets, and how it affects the detection of weak reflectors in the presence of strong ones. We have also compared the phase noise of our upconverted DDS chirp generation scheme with that of a PLL based scheme as is often employed in FMCW radars and will discuss the pros and cons of these two approaches. Additionally, we examine the techniques for amplitude and phase nonlinearity compensation in order to optimise the point target response.

8715-5, Session PThur

Dynamic beam steering at submm- and mm-wave frequencies using an optically controlled lens antenna

Tom F. Gallacher, Univ. of St. Andrews (United Kingdom); Rune Sondena, Institute for Energy Technology (Norway); Duncan A. Robertson, Graham M. Smith, Univ. of St. Andrews (United Kingdom)

We present details of our work which has been focused on improving the efficiency and scan rate of the photo-injected Fresnel zone plate antenna (piFZPA) technique that utilizes commercially available visible display technologies.

This approach presents a viable low-cost solution for non-mechanical beam steering suitable for many applications at (sub) mm-wave frequencies that require rapid beam steering capabilities in order to meet their technological goals, such as imaging, surveillance and remote sensing. In particular, the piFZPA method enables rapid beam steering spanning wide field-of-views (FOVs) using a limited number of receivers (commonly singular) which suffer from continued high costs at these frequency bands, and often limits the full potential of these systems. This method has the advantage of being comparatively low-cost, is based on a simple and flexible architecture, enabling rapid and precise arbitrary beam forming, which is scalable to higher frame-rates and higher submm-wave frequencies.

We discuss the various optimization stages of a range of piFZPA designs that implement fast visible projection displays, enabling up to 25,000 beams per second, presenting data which demonstrates near diffraction-limited performance that can be scanned precisely and arbitrarily within a 3D volume. We also discuss the suitability of this technology across mm-wave and submm-wave frequencies as a low-cost and simple solution for dynamic optoelectronic beam steering.

8715-23, Session PThur

20 meters standoff MMW imaging system based on Glow Discharge Detector focal plane array

Daniel Rozban, Ariel Univ. Ctr. of Samaria (Israel); Natan S. Kopeika, Ben-Gurion Univ. of the Negev (Israel); Amir Abramovich, Ariel Univ. Ctr. of Samaria (Israel); Assaf Levanon, Avihai Aharon Akram, Ben-Gurion Univ. of the Negev (Israel)

Glow discharge plasma, derived from direct-current gas breakdown, was investigated in order to realize an inexpensive mm wave room-temperature detector. It was found out that some commercially available ($0.2-$0.5 per lamp) miniature lamps initially intended for lightning purposes can serve as mm wave detectors, called glow discharge detectors (GDDs). Good responsivity and noise-equivalent power were measured. 8X8 and 16X16 GDD's based focal plane array were designed and tested showing quality images of both dielectric and metallic objects. Recently a unique quasi optical setup consisting of a projection system based on Cassegrain design was implemented for the purpose of longer distance detection and imaging. Direct detection signal was obtained by the GDD from a distance of 20m. Experimental work on the GDD showed that heterodyne detection using the GDD can significantly reduce the noise equivalent power and the minimum detectable signal. Based on the results shown here it is indicated that detection of signals from larger distances is feasible. The feasibility of a 3 dimension imaging based on radar principle and heterodyne detection was proven. Based on the results given here we designed a first stage quasi optical system intended for 3 dimensional imaging from a distance of 20m.

8715-25, Session PThur

Embedded electronics for a video-rate distributed aperture passive millimeter-wave imager

Petersen F Curt, James Bonnett, EM Photonics, Inc. (United States); Christopher A. Schuetz, Richard D. Martin, Phase Sensitive Innovations, Inc. (United States)

Because of their unique ability to penetrate fog, dust, smoke, blowing sand, and light-rain, MMW imaging systems are very attractive for many defense applications. However, their use in deployed systems to date has been limited due to the lack of suitable technologies that meet or exceed mission specific criteria, e.g., resolution, sensitivity, speed, latency and SWaP. For this reason, we have developed a real-time hardware accelerated processor to help overcome some these limitations and thereby enable the use of MMW imagers on a broad scale.

The processor we designed is capable of controlling hundreds of distinct MMW channels consisting of RF and optical portions. By tuning the performance of each element, the distributed aperture of a phased array can be effectively focused. In order to maintain focus for real-time imaging, the feedback must be constantly updated to compensate for changes induced by temperature, humidity and vibration. We have demonstrated that the resulting system can maintain accuracy within a few degrees even under the simulated effects of being onboard an H-53 heavy-lift helicopter.

In addition to phase control of the antennas, our electronics also capture the converted signals for processing and display. Using a combination of high-performance hardware and software programming techniques, the overall efficiency of the system has been significantly improved compared to previous generations. Real-time low-latency display of the resulting imagery is now possible and completed embedded within the sensor enclosure.

We present the results of this research, including our architectural design decisions for scalability, reconfigurability and embedded deployment.

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8716-1, Session 1

Broadband photonic terahertz-wave emitter integrating UTC-PD and novel planar antenna *(Invited Paper)*

Hiroshi Ito, Kitasato Univ. (Japan); Toshihide Yoshimatsu, Nippon Telegraph and Telephone Corp. (Japan); Hiroshi Yamamoto, Kitasato Univ. (Japan); Tadao Ishibashi, NTT Electronics Corp. (Japan)

Photomixing is a promising technique for generating continuous terahertz (THz) waves due to its superior features, such as broad bandwidth and capability for long distance transmission of high frequency signals through low loss fibers. To further extend the operation frequency of the photonic THz-wave emitters towards the lower frequency side, considerable increase in chip size due to the increase in antenna area is usually required. To solve this problem, we used a novel compact planar antenna that merges a self-complementary bow-tie antenna and a broad-area dipole antenna, and integrated it with an InP/InGaAs uni-traveling-carrier photodiode (UTC-PD). Then, the fabricated device was mounted on a Si hyper-hemispherical lens, assembled in a compact quasi-optic package, and characterized in detail. The output power peaked at around 160 GHz and decreased gradually with increasing frequency. We detected output powers at frequencies from 30 GHz to 1.6 THz using a single device. The lowest operation frequency was about five times smaller and the peak output power about four times larger than those for a device integrated with a standard bow-tie antenna, while the output characteristics on the higher frequency side were not apparently influenced. These improvements were attributed to the characteristics of the merged antenna. The detected output powers were 120 uW at 200 GHz, 17 uW at 500 GHz, and 2.9 uW at 1 THz for a photocurrent of 10 mA with a bias voltage of only -0.6 V.

8716-2, Session 1

Antenna-coupled uncooled Nb5N6 microbolometers for terahertz imaging

Xue-Cou Tu, Nanjing Univ. (China); Qingkai Mao, Lei Xu, Cao Wan, Zhenlong Sun, Nanjing Univ (China); Lin Kang, Jian Chen, Pei-Heng Wu, Nanjing Univ. (China)

A novel room-temperature microbolometer array chip consisting of a Nb5N6 thin film microbridge and a dipole planar antenna and applied as a terahertz (THz) detector is described in this paper. Due to the high temperature coefficient of the resistance, which is as high as -0.7% K-1, of the Nb5N6 thin film, such an antenna-coupled microbolometer is ideal for detecting signals from 0.22 THz to 0.33 THz. The dc responsivity, calculated from the measured I-V curve of the Nb5N6 microbolometer, is about -760 V/W at the bias current of 0.19 mA. A typical noise voltage as low as 10 nV/√Hz yields a low noise equivalent power (NEP) of 1.3 × 10-11 W/√Hz at modulation frequency above 4 kHz and the best RF responsivity, characterized using infrared device measuring method, is about 580 V/W, with the corresponding NEP being 1.7 10-11 W/√Hz. In order to further test the performance of Nb5N6 microbolometer, we constructed a quasi-optical type receiver by attaching it to the hyperhemispherical silicon lens and the result was that the best responsivity of the receiver is up to 320 V/W. This work could offer another way to develop a large scale focal plane array in silicon with simple technique and low costs.

8716-3, Session 1

Palm-size and real-time Terahertz imager, and its application to development of terahertz sources

Naoki Oda, Tsutomu Ishi, Seiji Kurashina, Takayuki Sudou, Takao Morimoto, Masaru Miyoshi, Tokuhito Sasaki, NEC Corp. (Japan); Taku Tsuboi, Takao Yamazaki, NEC Corp (Japan)

This paper briefly describes features of both uncooled palm-size and real-time Terahertz (THz) camera, and transmission-type THz microscope. The former incorporates high sensitivity 320x240 THz focal plane array with 23.5 m pixel pitch and the camera has three orders of magnitude of dynamic range with good linearity. The latter consists of THz camera and quantum cascade laser (QCL). QCL is cooled at 50~60 K with Stirling cycle cryocooler and can radiate powerful emission line with time-average power of ca. milli-Watt. The combination of these two components provides microscope with good signal-to-noise ratio.

THz images of string with 300 m in diameter were obtained at 4.3 THz and 2.0 THz with the THz camera in combination with Easy QCL (made by LongWave Photonics, LLC). Analyses of these images show that sharper edge-contrast is obtained at higher frequency and spatial resolutions evaluated at two frequencies, using the 10-90% criterion for signal intensity profile, are consistent with Fraunhofer diffraction limit.

The THz cameras have been used by many researchers who have developed THz radiation sources such as photoconductive antenna for time domain spectrometer, amplifier multiplier chain, injection-seeded THz parametric generator, THz free electron laser, QCL, broad-band THz source with tilted-pump-pulse-front scheme and so on. The beam patterns for these THz sources are presented. The experimental results on beam patterns show that the THz camera plays an important role in improving beam patterns of THz sources by adjusting optical elements, non-linear optical crystals and so forth.

8716-4, Session 1

Widely tunable (1-20 THz) narrowband (100 GHz) THz source for spectroscopy and imaging

Mojca Jazbinsek, Tobias Bach, Blanca Ruiz, Carolina C. Medrano, Peter Günter, Rainbow Photonics AG (Switzerland)

We developed a widely tunable coherent THz source emitting from 1 to 20 THz with a narrow bandwidth of below 100 GHz. The source is based on difference-frequency generation in recently developed highly efficient organic electro-optic crystals DSTMS and OH1 by using tunable infrared wavelengths of a BBO based optical parametric oscillator. One operational mode is at a chosen fixed THz frequency within this range for imaging applications, where the frequency can be chosen to match the best sensitivity range of investigated materials. The second mode allows tuning between 1–20 THz for spectroscopy applications.

THz-wave generation in a broadband THz range is possible by using organic electro-optic crystals as THz generators due to their unique material properties, which allow phase-matched frequency conversion from the optical to THz waves with higher second-order susceptibilities compared to inorganic materials. The optimum wavelength range of the pump infrared excitation for both DSTMS and OH1 is at 1400 ± 200 nm.

While most common THz sources based on photoconductive antennas span to a few THz only, a larger range allows to extend the spectroscopy and imaging to a much wider range of materials. The extended fingerprints will allow discriminating with a high level of confidence the presence and the type of hidden materials. Furthermore, large detection

distances for remote sensing can be possible with such a source, since the atmospheric absorption may decrease up to three orders of magnitude when moving from the low-THz frequency range to the 10–20 THz range.

8716-5, Session 2

Terahertz spectroscopy and imaging toward future medical and chemical applications
(Invited Paper)

Chiko Otani, Hiromichi Hoshina, RIKEN (Japan); Shinya Ishii, RIKEN (Japan) and Miyagi Univ. of Education (Japan); Hal Suzuki, RIKEN (Japan); Koji Uematsu, RIKEN (Japan) and Tohoku Univ. (Japan)

[Invited] We will introduce two topics related to future possible medical and chemical applications of Terahertz (THz) wave. The first topic will be the discrimination of cancer and normal regions of human lever cancer by using THz spectroscopic imaging and Chemometrics. Among 4 samples we tried, we have succeeded to discriminate them by three samples. In addition, we have shown that the information of biomedical samples can be extracted from a frozen sample. This means that an instant THz diagnosis of cancer can be possible once we freeze the sample. As the next topic, we will talk about THz spectroscopy of polymers for the identification of the spectral absorption peaks. In this talk, we will present the meaning of terahertz spectroscopy of soft materials, the experimental results of spectroscopy of Nylon, and the experimental results for the control of THz frequency for future activation.

8716-6, Session 2

Detection of covered materials in the TDS-THz setup

Norbert Palka, Military Univ. of Technology (Poland)

We report on a signal processing method which can identify covered materials in a reflection configuration in the Time Domain Spectroscopy (TDS) setup. THz radiation can transmit through most of covering materials like plastic foils, paper, clothes, etc. If the covering layer is far from the sample (more than about 2 mm) it slightly modifies the reflectance of the measured materials. However, if the layer is closer, we obtain two impulses – one reflected from the layer and the second – from the sample. In this case, spectrum of the impulse is heavily deformed and the spectral features of explosives are hard or impossible to identify.

The proposed method of identification of covered materials based on the fact that the TDS signal reflected from a covered sample consists of two peaks and some “waves” after the second peak, which carry the spectral information about the sample. FFT analysis of this part of the signal reveals spectral features of the sample. The presented method is reference-free and bases only on analysis of the signal reflected from the sample.

The method is restricted to frequencies in the range 0.4-1.5 THz and, therefore only some materials with characteristic features in this range, like RDX-based explosives, lactose, paraaminobenzoic acid and tartaric acid can be analyzed. We covered the materials with foils, paper and cotton and obtained good results for solid and powder samples. The method is sensitive to atmospheric water vapour.

8716-7, Session 2

Terahertz atmospheric attenuation and continuum effects

David Slocum, Thomas M. Goyette, Univ. of Massachusetts Lowell (United States); Elizabeth J. Slingerland, Univ. of Massachusetts Lowell (United States) and Metron, Inc. (United States); Robert H. Giles, Univ. of Massachusetts Lowell (United States); William E. Nixon, National Ground Intelligence Ctr. (United States)

Remote sensing over long path lengths has become of greater interest in the Terahertz frequency region. Applications such as pollution monitoring and detection of energetic chemicals are of particular interest. Although there has been much attention to atmospheric effects over narrow frequency windows, accurate measurements across a wide spectrum is lacking. The water vapor continuum absorption spectrum was investigated using Fourier Transform Spectroscopy. The continuum effect gives rise to an excess absorption that is unaccounted for in just a resonant line spectrum simulation. The transmission of broadband terahertz radiation from 300GHz - 1.5THz through air with varying relative humidity levels was recorded for multiple path lengths. From these data, the absorption coefficient as a function of frequency was determined and compared with model calculations. The intensity and location of the strong absorption lines were in good agreement with spectral databases such as the 2008 HITRAN database and the JPL database. However, a noticeable continuum effect was observed particularly in the atmospheric transmission windows. A small discrepancy still remained even after accounting for continuum absorption using the best available data from the literature. This discrepancy, when projected over a one kilometer path length, typical of distances used in remote sensing, can cause an 8dB difference between calculated and observed attenuation. From the experimental and resonant line simulation spectra the air-broadening continuum parameter was calculated and compared with values available in the literature.

8716-8, Session 3

Scanning laser THz emission imaging system
(Invited Paper)

Masayoshi Tonouchi, Osaka Univ. (Japan)

We developed a scanning laser THz emission imaging system employing fs fiber laser and THz emission plates such as DAST, (110)GaAs, and their modified. Near filed emission imaging enable us to visualize a single human hair in a few second for 128x128 pixels. Also is possible to obtain its spectroscopic data from a local position of the hair.In the conference we report its detail and other applications. We examine 2D emission tips for better imaging, we observe a dynamic local response of metamaterials i.e. Meta-Atom., we show how THz waves are generated and propagate in nonlinear medium, and how it affect THz imaging. Some are reported in OE 20(2012) 18397,12959, 3345. In addition to the above, we report our recent application of THz emission microscope to Solar cell, graphene, and so on.

8716-9, Session 3

Compact THz imaging detector with an integrated antennae array matrix

J. Daniel Newman, Paul P. Lee, Andrew P. Sacco, ITT Exelis (United States); Dave Willems, ITT Communications Systems (United States); Robert D. Fiete, ITT Exelis (United States); Mark F. Bocko, Zeljko Ignjatovic, Xi-Cheng Zhang, Univ. of Rochester (United States)

We describe preliminary design, modeling and test results for the development of a monolithic, high pixel density, THz band focal plane array (FPA) fabricated in a commercial CMOS process. Each pixel unit cell contains multiple individual THz band antennae that are coupled to independent amplifiers. The amplified signals are summed either coherently or incoherently to improve detection SNR. The sensor is designed to operate at room temperature using passive or active illumination. In addition to the THz detector, a secondary array of Visible or SWIR context imaging pixels are inter-disposed in the same area

matrix. Multiple VIS/SWIR context pixels can be fabricated within the THz pixel unit cell. This provides simultaneous, registered context imagery and "Pan sharpening" MTF enhancement for the THz image.

The compact THz imaging system maximizes the utility of a ~ 300 um x 300 um pixel area associated with the optical resolution spot size for a THz imaging system operating at a nominal ~ 1.0 THz optical frequency. RF modeling is used to parameterize the antenna array design for optimal response at the THz frequencies of interest. The quarter-wave strip balanced bow-tie antennae are optimized based on the semiconductor fabrication technology thin-film characteristics and the CMOS detector input impedance. RF SPICE models enhanced for THz frequencies are used to evaluate the predicted CMOS detector performance and optimal unit cell design architecture. The models are validated through testing of existing CMOS ROICs with calibrated THz sources.

8716-10, Session 3

THz-vision system with extended functionality

Janez Trontelj, Aleksander Sesek, Andrej Svigelj, The Univ. of Ljubljana (Slovenia)

A near real-time THz-vision system is presented. The most important part of it is the THz sensors focal plain array operating at room temperature, featuring low NEP (10pW/√Hz) and high sensitivity (1e6 V/W). Its architecture allows direct digital processing of output signal. System performance is upgraded with large parallel processing of up to 64 channels.

The second important building block is the FM THz source used for illumination. A wide FM range, of up to ±10% of the central frequency allows using the system for various applications. The THz source is a solid-state source using a GHz range frequency synthetizer followed by frequency multipliers and microwave amplifiers. Such a compact THz source can cover the lower region of the THz spectra, i.e. below 1THz using different frequency bands. The band selection depends on the application. Three different areas of applications are discussed in the paper:

- 3D imaging of hidden objects is one of the most attractive features of the presented system. Examples of 300GHz 3D images are shown.
- An accurate range finder is another feature of the system. The resolution proved to be within a fraction of the wave lengths. The standard deviation of the reading is in the range of a few micrometers, using a 1mm wave-length illumination source. Possible improvements in resolution and absolute accuracy are discussed.
- The system is also used as a narrow band CW spectrometer which operates in the FM range of the source. In this case the bolometer array is built with a broad band micro antenna. This could be used for target material identification.

8716-11, Session 3

Spectral lines dynamics as an effective tool for the identification of substance using reflected THz signal

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One of the modern problems arising in the detection and identification of substances is a development of criteria for the assessment of a presence of explosive (or other dangerous substance) fingerprints in investigating THz signals reflected from a sample. Obviously, criteria depend on using method for the detection and identification of the substance. Taking into account on our previous experience, we use for a solution of this problem the SDA method (method of the spectral dynamics analysis). In this case, we need, at least, developing the method for both getting requiring dynamics of spectral lines and assessment criteria and their algorithmic realization.

In this report we show that the SDA method allows to identify the explosive under real conditions. We compare the spectral lines dynamics of THz pulse reflected from sample with the corresponding spectral lines dynamics of the THz pulse transmitted through the explosive. Used assessment and algorithm show both high probability of the substance identification and a reliability of realization in practice. Simultaneously, we discuss some problems connected with the main problem of the paper.

8716-12, Session 4

Response of plasmonic terahertz detector to large signals: theory and experiment *(Invited Paper)*

Sergey Rudin, Greg Rupper, U.S. Army Research Lab. (United States); Alexey Gutin, Michael S. Shur, Rensselaer Polytechnic Institute (United States)

In the Dyakonov-Shur terahertz (THz) detector, nonlinearities in the plasma wave propagation in the conduction channel of a heterostructure High Electron Mobility Transistor (HEMT) lead to a constant source-to-drain voltage providing the detector output. For a small signal, the perturbation theory treatment shows that the response is proportional to the intensity of the radiation, with the proportionality factor that can have a resonant or a broad dependence on the signal frequency. For submicron HEMTs, the measured response falls within the range of 0.1 to 4 THz. The deviations from this relation have been studied and reported in the approximation of the local Ohm's law and transmission line model for the non-resonant response. Here we present the results obtained with the hydrodynamic model using the electron plasma Navier-Stokes equation, thus fully accounting for the hydrodynamic non-linearity, the viscosity and pressure gradients in the detector response. The model is applicable to both resonant and broadband operations of the HEMT based plasmonic detector. The relation between electron channel density and gate voltage was modeled by the unified charge control model applicable both above and below the threshold voltage. The theoretical results are compared with the response measured in the short channel InGaAs HEMT and the analytical approximation. The THz source was operating at 1.63 THz and the response was measured at varying signal intensities. The response of the detector operated in the open drain mode was measured above and below the threshold. The theoretical and experimental results are in good agreement.

8716-13, Session 4

Broadband THz generation and detection at 10-nm scale

Yanjun Ma, Mengchen Huang, Univ. of Pittsburgh (United States); ChungWung Bark, Gachon Univ. (Korea, Republic of); Chad Folkman, Argonne National Lab. (United States); Chang-Beom Eom, Univ. of Wisconsin-Madison (United States); Jeremy Levy, Univ. of Pittsburgh (United States)

The terahertz region of the electromagnetic spectrum (0.1 THz-10 THz) probes a wealth of information relevant for material, biological, medical and pharmaceutical sciences, as well as applications in chemical sensing and homeland security. To date, there have been no methods capable of controlling THz radiation at scales relevant for single molecules. Here we report the generation and detection of broadband terahertz radiation from 10-nm-scale nanojunctions which are "sketched" at the interface of LaAlO¬3/SrTiO3 (LAO/STO) heterostructure with a conductive atomic force microscope (c-AFM) tip: By applying a positive voltage to the c-AFM tip and scanning over the LAO surface, a conductive pattern at the LAO/STO interface with a characteristic dimension of 10 nm can be created. Insulating nanojunctions are created by applying a negative voltage to the c-AFM tip and crossing the nanowire. Pulses from 30 fs Ti: Sapphire laser are focused onto the nanojunctions and trigger optical rectification via a χ^((3)) process, producing a THz radiation that has spectral content up to 10 THz. These same nanojunctions can detect THz radiation with comparable spatial resolution. As a THz source and sensor, the nanojunction structure offers several advantages: its dimension is comparable to that of a single molecule; it is easy to fabricate and the THz source and detector can be easily integrated in a micron-scale area. These features allow this platform to be a promising lab-on-chip device for THz near-field imaging of individual molecules.

8716-14, Session 4

New modeling techniques for terahertz metamaterials

Mayer A. Landau, Air Force Research Lab. (United States)

Metamaterials are synthetic materials with periodic electromagnetic inclusions. The interactions between inclusions can fundamentally alter the macroscopic response of the material to electromagnetic radiation. Simulating this response is costly in computer resources due to the sheer number of cell elements involved in a 3D materials. It would be ideal to have macroscopic constituitive parameters that capture the essense of the materials response, as index of refraction and impedance due for natural materials. But metamaterials are highly dispersive and their lattice constant is on the cusp of being too large to model effectively with macroscopic constituitive paramaters. Recently (2010)

Andrea Alu at UT Austin derived a theory of macroscopic material parameters permittivity and permeability that are dispersion independent. We use these dispersion independent parameters to simulate scattering from finite slabs. These results are compared to FDTD simulations. We also compare to actual experiments with metamaterial filters, i.e. slabs, built to operate at W band and at 1THz. We find the Alu constituitive parameters give good agreement with experiment and provide much faster scattering calculation compared to standard FDTD.

8716-15, Session 5

Widely tunable THz sources and security applications *(Invited Paper)*

Kodo Kawase, Saroj R. S. R. Tripathi, Nagoya Univ. (Japan); Shin'ichiro Hayashi, RIKEN (Japan)

We report on the development of a high-peak-power (> 1kW), single-longitudinal-mode and tunable injection-seeded terahertz-wave parametric generator (is-TPG) using MgO:LiNbO3, which operates at room temperature. The experimental setup consists of a pumping source, amplifiers, seeding source (ECDL) and the nonlinear crystal (MgO:LiNbO3). The pumping source is a diode end-pumped single-mode microchip Nd:YAG laser passively Q-switched by Cr:YAG saturable absorber. In this experiment, the pumping beam from the microchip laser was amplified by two tandem Nd:YAG amplifiers in double-pass configuration. The pumping beam diameter on the crystal is about 1 mm (FWMH). We used a 50-mm-long nonlinear MgO:LiNbO3 crystal with a Si-prism coupler. The terahertz-wave output was measured using a calibrated pyroelectric detector (SpectrumDetector Inc.: SPI-A-65 THZ). The pumping energy was 14 mJ/pulse (28 MW at peak) and the seeding power was 500 mW (CW). The observed maximum peak power of terahertz-wave was about 1 kW (@ 1.7 THz). This peak power was the highest in our research. The tuning curve (1.0 - 2.8 THz) has a flat region around 1.4 - 2.2 THz. The small footprint size are suitable for a variety of applications. We also report on the security applications using this novel THz source.

8716-16, Session 5

Room temperature terahertz quantum cascade laser sources based on difference-frequency generation

Karun Vijayraghavan, The Univ. of Texas at Austin (United States); Frederic Demmerle, Walter Schottky Institut (Germany); Min Jang, Aiting Jiang, The Univ. of Texas at Austin (United States); Gerhard Boehm, Augustinas Vizbaris, Markus C. Amann, Walter Schottky Institut (Germany); Mikhail A. Belkin, The Univ. of Texas at Austin (United States)

Progress in developing a room temperature terahertz (THz) quantum cascade laser (QCL) has slowed over the years. We report an alternative method of generating room temperature terahertz (THz) emission based on intra-cavity difference-frequency generation (DFG) in dual wavelength mid-infrared quantum cascade lasers with giant optical nonlinearity. Previously reported THz DFG QCL sources are highly inefficient since THz radiation produced more than ~100 µm away from the exit facet is fully absorbed due to high THz losses in mid-infrared QCL waveguides. Our lasers use a Cerenkov DFG scheme to extract THz radiation from the active region. Structures are grown on semi-insulating (SI) InP substrates and devices are fabricated with a lateral contact current extraction scheme. THz radiation is emitted at an angle with respect to the the mid-infrared pumps into the substrate. Since SI InP is virtually lossless to THz radiation, our scheme allows for efficient extraction of THz radiation along the entire length of the waveguide. As a result, our sources demonstrate high mid-infrared-to-THz conversion efficiency and directional THz output over the spectral range of 1.2 to 4.5 THz. Our devices have demonstrated a record conversion efficiency of ~300 µW/W2 and 20µW THz output power. The University of Texas group acknowledges support from the National Science Foundation grants ECCS-09352017 and ECCS-1150449 and by the 'Norman Hackerman Advanced Research Program' award. The Walter Schottky Institute group acknowledges financial support from the excellence cluster 'Nano Initiative Munich (NIM)'.

8716-17, Session 5

Tunable terahertz plasmonic ring resonators

Mustafa Karabiyik, Nezih Pala, Florida International Univ. (United States)

We introduce a new type of plasmonic terahertz ring resonator device operating at deep sub-wavelength regime which supports plasmonic modes with relatively high quality factors.

The device consists of a split ring resonator on top of a AlGaN/GaN HEMT structure. The HEMT structure is etched as a ring with the same inner and outer radius of the split ring on top. We investigated spectral absorption characteristics of the proposed devices using FDTD numerical analysis methods. The plasmonic modes are excited in between the metal split ring and 2 dimensional electron gas (2DEG). The modes are close to each other in the spectrum which makes the device capable of responding at a broad band. The response of the device is in the range of 0.2 to 4 THz for a 3-micron diameter ring and it can be tuned by the geometry or by an applied voltage to the split ring. The wavelength of the plasmonic modes fits in the perimeter of the split ring structure. The split part of the ring causes the excitation of plasmonic resonance.

The quality factor of the plasmonic modes are calculated to be 5 times higher than the HEMTs with linear grating structures with similar parameters. The same ring resonators have also been investigated by replacing the HEMT with graphene. The high quality factor makes the proposed devices attractive.

8716-18, Session 5

THz transmission and detection through glow discharge detectors

Hakan Altan, Kamil Cinar, Middle East Technical Univ. (Turkey); Asaf Behzat Sahin, Yildirim Beyazit Univ. (Turkey)

Glow discharge detectors (GDDs) have been a topic of recent interest after the pioneering work of N. Kopeika and others in the early 1970s. The interaction of the relatively low plasma density with millimeter and/

or THz waves has motivated researchers to study these devices and the mechanisms involved in the detection of terahertz waves. These works have shown that the interaction of the AC field with the glow region is primarily due to the induced oscillations in the plasma that drive a diffusive component to the current through the discharge region of the detector. While studies continue in this area, the majority of them have focused on using CW sources to drive the GDDs, due to their higher average power compared to other sources. Here we have used a time-domain THz spectrometer to characterize the response though the GDD in a wider bandwidth. We have found that the THz transmission has a quite abrupt change (~20dB) at frequencies which scale with the GDD gap. Furthermore, we see that the transmission frequency and strength of the decrease in transmission is also dependent on the strength of the discharge voltage. This change is explained in the context of the structure of the device and plasma generated within the GDD.

8716-19, Session 5

Frequency tunable narrowband THz time domain source

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Abstract: During the last decades, narrowband terahertz (THz) radiation has attracted great interests in both fundamental and applied sciences. Our group has reported a new scheme for bandwidth-tunable narrowband THz radiation in a periodically pole lithium niobate (PPLN) by using a wide-aperture beam [1]. In this technique, the bandwidth can be readily and smoothly tuned from about 17 GHz to a few THz, and the generated THz frequency is determined by the period of the structure of the PPLN. However, many applications require a tunable frequency in addition to a tunable bandwidth. In this paper, a simple scheme to generate high energy, both frequency and bandwidth tunable THz time domain source by optical rectification of femtosecond laser pulses in PPLN is proposed and demonstrated. By changing the angle of incidence of the pump laser beam from normal incidence instead of replace a new PPLN crystal with different period, the central frequency of the THz radiation can be tuned from 0.71 to 0.99 THz for a PPLN structure with = 77 µm having a central frequency of 0.85 THz; the range of tunable frequencies is about ±16% with a high conversion efficiency. The opportunity of easily tuning the bandwidth of THz generation from about 20 GHz to a few THz also exists by changing the pump spot size onto the entrance face of the PPLN crystal, and the energy spectral density of narrowband THz generation is almost independent of the bandwidth.

8716-20, Session 6

Ceramic photonic crystals for THz applications

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A photonic crystal is an optical analogue of a crystal, in which the periodic potential is due to a lattice of macroscopic dielectric media instead of the atoms or molecules. Generally, large contrast in dielectric properties between the high and low dielectric regions is necessary to fabricate useful photonic crystals. Three-dimensional ceramic-resin photonic crystal prepared via sintering with a lattice constant of 500 ?m, a forming resolution of 10 µm, and a full band gap along three different directions have been reported in the literature. A micro-stereolithography system has also been reported to fabricate 3D diamond structure made of copper and alumina ceramics. Point or planar defects can be introduced to localize the modes in these photonic crystals to control of THz waves. We fabricated several photonic structures made of Al2O3, TiO2, and Fe2O3 ceramic powders, via doctor-blade processing followed by sintering. First, slurries of these oxides were prepared using appropriate binders for doctor-blade processing. Then, the dry green flexible sheets of about 100-200 µm thickness were stacked separately as well as alternatively in different sequences, e.g., Al2O3-TiO2-Al2O3 and Al2O3-TiO2-Fe2O3. Finally, these stacks were sintered together to make monolithic samples. These structures were characterized using THz-time domain spectroscopy (THz-TDS). These measurements used a coherent emission and detection system that emits single-cycle THz pulses, and detects them at a repetition rate of around 100 MHz. The frequency-dependent optical and dielectric properties were extracted from the experimental spectra. Our data were compared to the reported data in the literature.

8716-21, Session 6

Employing phase modulation and second harmonic nulling to eliminate interference fringes from the spectrum of a portable coherent frequency-domain THz spectrometer

Joseph R. Demers, K.K. Wong, Bryon Kasper, EMCORE Corp. (United States)

Interpreting the spectrum from a continuous wave frequency domain terahertz spectrometer that employs coherent detection can be challenging due to the presence of an interference pattern. We report on the continued progress of a portable, battery-operated frequency domain terahertz spectrometer with an integrated, fiber-coupled, lithium-niobate optical phase-modulator and how we achieve interference fringe elimination using phase modulation and second harmonic nulling. The implications for both transmission and reflection measurements are discussed and data on the explosive compound RDX will be presented.

8716-22, Session 6

Subterahertz resonance spectroscopy of biological macromolecules and cells

Tatiana Globus, Univ. of Virginia (United States); Aaron Moyer, Vibratess, LLC (United States); Boris L. Gelmont, Igor Sizov, Univ. of Virginia (United States); Tatyana Khromova, Vibratess, LLC (United States); Jerome P. Ferrance, Univ. of Virginia (United States)

Recently we introduced a Sub-THz spectroscopic system for characterizing vibrational resonance features from biological materials. This new, continuous-wave, frequency-domain spectroscopic sensor operates at room temperature between 315 and 480 GHz with spectral resolution of at least 1 GHz and utilizes the source and detector components from Virginia Diode, Inc. In this work we present experimental results and interpretation of spectroscopic signatures from bacterial cells and their biological macromolecule structural components. Transmission and absorption spectra of the bacterial protein thioredoxin, DNA and lyophilized cells of Escherichia coli (E. coli), as well as spores of Bacillus subtillis and B. atrophaeus have been characterized. Experimental results for biomolecules are compared with absorption spectra calculated using molecular dynamics simulation, and confirm the underling physics for resonance spectroscopy based on interactions between THz radiation and vibrational modes or groups of modes of atomic motions. Such interactions result in multiple intense and narrow specific resonances in transmission/absorption spectra from nano-gram samples with spectral line widths as small as 3 GHz. The results of this study indicate diverse relaxation dynamic mechanisms relevant to sub-THz vibrational spectroscopy including long lasting processes. We demonstrate that high sensitivity in resolving specific absorption fingerprints provides conditions for reliable detection, identification and discrimination capability, to the level of strains of the same bacteria, and for monitoring interactions between biomaterials and reagents in near real-time. Additionally, it creates the basis for the development of new types of advanced biological sensors through integrating the developed system with a microfluidic platform for biomaterial samples.

8716-23, Session 6

Comparisons between continuous wave and time-domain terahertz spectroscopy in carbon nanostructures

Ehsan Dadrasnia, Sujitha Puthukodan, Horacio Lamela Rivera, Univ. Carlos III de Madrid (Spain); Guillaume Ducournau, Jean-François Lampin, Univ. des Sciences et Technologies de Lille (France); Mohan-Babu Kuppam, Frédéric Garet, Jean-Louis Coutaz, IMEP-LAHC (France)

Carbon nanotubes (CNTs) and graphene have been considered as an alternative material to Indium-Tin Oxide (ITO) for flexible transparent conductive films since it has unique electrical, optical and mechanical properties (Wu et al., 2004, Bae et al., 2010). Coherent terahertz (THz) electromagnetic waves have been certainly interested in the board of nanotechnology to study properties of semiconductor carbon nanostructures. Terahertz time-domain spectroscopy (THz-TDS) can characterize the precise absorption and dispersion properties of different materials at high frequencies (Jepsen et al., 2011).

Since the first report on THz and Infrared study of CNTs published in the late 90's (Ugawa et al., 1999), THz-TDS technique has been intensively used to study the properties of carbon nanostructures thin-films (Kang et al., 2004, Jung et al., 2010, Lamela et al., 2011). Recently, CNTs samples have been subject to intense research in the THz range and recently have permitted to define precise physical models to describe the THz properties of CNTs films (Jeon et al., 2005, Kang et al., 2007, Parrott et al., 2009).

On the other hand, compact, fast and relatively low-cost continuous wave (CW) sub-THz spectroscopy is considered as well in the region of the electromagnetic spectrum by taking into account the range of 30 GHz-500 GHz (N. Karpowicz et al. 2005). Following our previous studies in THz-TDS (0.1THz-2THz) of CNTs thin-films, in this work we will use the sub-THz CW transmission system to compare those techniques and find the absorption properties of carbon nanostructures at the low frequency ranges (325 GHz -500GHz).

8716-24, Session 7

Graphene active plasmonic metamaterials for new types of terahertz lasers *(Invited Paper)*

Taiichi Otsuji, Takayuki Watanabe, Akira Satou, Tohoku Univ. (Japan); Viacheslav V. Popov, Institute of Radio Engineering and Electronics (Russian Federation); VIctor Ryzhii, Tohoku Univ. (Japan)

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 mass-less relativistic transport of carriers called Dirac Fermions and hence the negative dynamic conductivity in the terahertz (THz) spectral range, which may lead to a new type of THz laser. The two-dimensional Dirac Fermion systems in graphene yield unique plasmonic properties; the dispersion relation of the gated plasmons in graphene take a linear dependence on wave vector and a 1/4-power dependence on carrier density. Starting from the semi-classical Boltzmann's transport equations, one can lead to a set of hydrodynamic equations, giving rise to a new insight for the plasmon dynamics for both heavily doped unipolar and undoped or optically excited bipolar graphene. The former case exhibits a strong damping for any plasmons but non-ionic acoustic sound-like waves are predominated whereas the latter cases are predominated by the majority carriers' plasmons. We theoretically discovered that when graphene carrier populations are inverted by optical or electrical pumping the excitation of graphene plasmons by the THz photons results in propagating surface plasmon polaritons with giant gain in a wide THz range. Furthermore, when graphene is patterned in a micro- or nano-ribbon array by grating gate metallization, the structure acts as an active plasmonic metamaterial, providing a super-radiant plasmonic lasing with giant gain at the plasmon modes in a wide THz frequency range.

8716-25, Session 7

Micromachined probes for characterization of submillimeter-wave on-wafer components *(Invited Paper)*

Robert M. Weikle II, N. Scott Barker, Arthur W. Lichtenberger, Matthew F. Bauwens, Univ. of Virginia (United States)

In recent years, an infrastructure for measurement and characterization of circuits and devices in the terahertz region of the spectrum has begun to emerge. Vector network analyzes operating to 1 THz and above are now commercially available and national metrology laboratories in Europe, Japan, and the United States are currently evaluating standards for waveguides, interfaces, and calibration that are needed for accurate terahertz measurements. At present, terahertz components and devices are typically interfaced with instrumentation and characterized using measurement fixtures equipped with waveguide flanges and/or antennas. However, such fixtures are known to introduce significant uncertainty and error in measurements. It is preferable to characterize such devices in-situ, where the device under test can be measured on-wafer, prior to dicing and separately from the circuit housing to which it is ultimately affixed. This is commonly done in the RF and millimeter-wave region with a probe station equipped with coplanar launchers. Commercial coplanar waveguide probes are generally available through the WR-2.2 band (325—500 GHz) but few options currently exist for on-wafer measurements above this band. This presentation describes recent work at the University of Virginia and Dominion MicroProbes, Inc. to extend on-wafer measurement capabilities to terahertz frequencies through the design and implementation of coplanar probes based on silicon micromachining. At present micromachined on-wafer probes operating to WR1.2 (600 to 900 GHz) have been demonstrated and typically exhibit insertion losses lower than 8 dB with return loss of 15 dB or greater over the full waveguide band.

8716-26, Session 7

Low-loss waveguides and devices for compact THz systems *(Invited Paper)*

Azizur Rahman, Mohammad Uthman, Anita Quadir, Namassivaye Kejalakshmy, Christos Markides, Christos Themistos, City Univ. London (United Kingdom)

The THz technology is emerging strongly particularly for sensing and imaging applications, however, most of the present systems are free space based due to lack of low-loss waveguides. At this frequency range both dielectric and conductive losses of materials are considerably high and novel design approaches necessary to mitigate these effects.

Recently, it has been shown that hollow-core metal clad waveguides can support THz waves in the low-loss air-core. It is also shown that by optimizing a dielectric layer between the air-core and metal layer, waveguide loss for a circular or rectangular bore can be minimised. Similarly, it has also been reported that photonic crystal fibres with porous core can confine most of the power in the low-loss air region to reduce the overall propagation losses. The development of low-loss THz guides is expected to provide impetus on the development of compact THz integrated circuits combining various functional devices.

Design optimization of such low-loss THz waveguides, power splitters, and filters will be presented by using rigorous full-vectorial finite element based numerical approaches.

8716-27, Session 8

Optically switchable matematerials in the terahertz regime *(Invited Paper)*

Ekmel Özbay, Mutlu Gökkavas, Bilkent Univ. (Turkey)

In this talk, we report the design, fabrication and experimental characterization of optically tunable metamaterials in the terahertz (THz) regime. The metamaterial design is based around electric-field-coupled inductor capacitor (ELC) resonators. This results in two potential resonance states, and the photoconductive semiconductor (silicon) settled in the critical region plays the role of intermediary for switching the resonator from mode 1 to mode 2. The metamaterials were fabricated on commercially available silicon-on-sapphire (SOS) wafers. The thin silicon layer was removed by RIE etching of all areas expect the 6x6 micron photoconductive region. In order to measure the tunable response of the metamaterial, an optical pump beam (800 nm) was used to excite photocarriers in the silicon. We observed a tuning range of the fabricated device as high as 26% (from 0.76 THz to 0.96 THz) by controlling the conductivity of the silicon layer via optical illumination. Numerical simulations yielded a simulated resonance around 0.69 THz. Following the increasing pump fluxes, we selected different corresponding values of Si to roughly reproduce the experimental results. The resonance has then shifted close to the final frequency of 0.96 THz. The simulations showed an all-optical blueshift with the tuning range of 40%, compared to 26% in the experiments. The realization of broadband blueshift tunable metamaterial offers opportunities for achieving switchable metamaterials with simultaneous redshift and blueshift tunability and cascade tunable devices. Our experimental approach is compatible with semiconductor technologies and can be used for other applications in the THz re-gime.

8716-28, Session 8

Heterodyne detection at 300 GHz using glow discharge detectors with efficient quasi-optical design

Avihai Aharon Akram, Daniel Rozban, Assaf Levanon, Ben-Gurion Univ. of the Negev (Israel); Amir Abramovich, Ariel Univ. Ctr. of Samaria (Israel); Natan S. Kopeika, Ben-Gurion Univ. of the Negev (Israel)

A miniature neon indicator lamp, also known as a Glow Discharge Detector (GDD), costing about 50 cents, was found to be an excellent room temperature THz radiation detector. A proof of concept of 300 GHz heterodyne detection using GDD is demonstrated in this paper. Furthermore, a comparison to direct detection was carried-out and polarization effects on heterodyne detection were investigated. Preliminary results at 300 GHz showed better sensitivity by a factor of 20 with only 56 microwatt local oscillator power using heterodyne compared to direct detection. Further improvement of the detection sensitivity can be achieved if the Local Oscillator (LO) power (Plo) is increased. Effects of orthogonal polarizations of signal and local oscillator powers on heterodyne sensitivity were found to be surprisingly weak. More efficient quasi optical design for heterodyne detection is presented in this study, experimental results showed above 50% better performance compared to conventional ones.

8716-29, Session 8

Realtime terahertz imaging for laser beam profiling and medical imaging

Lei Zhang, Matthew Erdtmann, Shankar Radhakrishnan, Ning Xue, Jack P. Salerno, Agiltron, Inc. (United States); Sigfrid K. Yngvesson, Amulya Gullapali, Kan Fu, Paul R. Siqueira, Univ. of Massachusetts Amherst (United States)

Terahertz radiation occupies the region between the infrared band and the microwave band (~0.3 – 3 THz). This band offers unique imaging capability. Unlike infrared radiation, which is strongly absorbed by most materials, THz radiation has the ability to “see” through most materials except metal and water. This unique characteristic of THz radiation can be exploited by numerous military and commercial applications. However there has been limited development of real time THz imaging technology. THz imagers demonstrated to date at frequencies > 1 THz require either cryogenic cooling or time consuming scanning. Agiltron and University of Massachusetts Amherst have successfully performed THz imaging of concealed objects using Agiltron’s commercial real time uncooled THz imager with an array size of 130x90 pixels, and employing a gas laser source. We will also present images of medical specimens at the conference. The single pixel detection limit at 1.9THz is 76 pW/Hz1/2. This THz imager has also proven to function exceptionally well as a THz laser beam profiler; capturing, displaying and recording 3D spatial intensity profile of THz laser sources. The uncooled, real time THz imager is commensurate with many military or security applications including detection of concealed weapons, land mines and improvised explosive devices, chemical agents, and void and crack formation on aircraft skins. Major commercial applications include passenger screening for concealed weapons or contraband, product quality control in the pharmaceutical and semiconductor industries, moisture detection for agricultural applications, medical imaging applications, particularly cancer detection and intraoperative imaging, and laser beam profiling.

8716-30, Session 8

Terahertz 3D imaging with a CW source and phase-shifting interferometry

Yoshiaki Sasaki, Chiko Otani, Hiroshi Kasuga, Hitoshi Ohmori, RIKEN (Japan); Masayuki Suga, Tetsuya Yuasa, Yamagata Univ. (Japan)

We will present two kinds of terahertz (THz) 3D imaging performed with a continuous-wave (CW) source and phase-shifting interferometry. The first one is THz computed tomography (CT) by using phase information instead of intensity information. This minimized the effect of change in the signal strength due to diffraction and artifacts especially emerged around the edge of boundary between different materials. The second one is for the depth imaging of the surface of reflecting materials. By using a simple Michelson interferometer, we achieved the depth resolution of 1.1 um, corresponding to 1/440 of the used wavelength (480 um).

8716-31, Session PTues

Polar synthetic imaging

Jonathan George, The George Washington Univ. (United States)

For many applications, imaging in the terahertz and mm wave domain is prohibitively expensive, primarily due to the cost of the focal plane array. Here we show a method for synthetic image reconstruction utilizing two rotating masks. The two masks are disk shaped and made of a material opaque to the frequencies we wish to examine. Each mask is cut with a slit such that energy can only pass through the plane of the mask by transiting the slit. The slits are cut in the pattern of an Archimedes spiral. As the masks rotate at two constant but distinct and non-divisible speeds, the intersection of the two slits forms a small area, which, over time, covers the plane of rotation. By observing the energy passing through this small area, and recording it over time, a synthetic image can be constructed.

A method exists for calibrating the reconstruction algorithm by determining the two beat frequencies generated by the ambient noise and a calibration point source. These beat frequencies are used to determine the rotational velocity of both disks and subsequently the relative position of the spiral intersection. The algorithm is not limited to a single intersection point. Multi-armed spirals will intersect in within a subset of a rotationally cyclic space. The algorithm for reconstruction can be extended to integrate from these multiple intersection points.

The technique is suitable for high dynamic range terahertz imaging and provides an affordable alternative to the focal plane array when imaging stationary targets.

8716-32, Session PTues

Terahertz spectra of materials measured by the OPO-based system

Michal J. Walczakowski, Military Univ of Technology (Poland); Norbert Palka, Tomasz Trzcinski, Mieczyslaw Szustakowski, Military Univ. of Technology (Poland)

Development and implementation of terahertz (0.1-10 THz) technology in security area is connected with unique features of this part of electromagnetic spectrum. Many explosives (e.g., Hexogen, Penthrite, Trinitrotoluene, Octogen) and drugs have characteristic transmission/ reflection features in the THz range, what is of great importance for security and defense related applications. We report on measurements of transmission spectra of chosen materials (Hexogen, Sucrose, Tartaric Acid) in the range 0.7-2.5 THz. The measurements were carried out by means of a setup, which bases on an Optical Parametric Oscillator (OPO) combined with a Hot Electron Beam (HEB) Bolometer. The setup consists of commercially available tunable OPO from MSquared working in the range 0.7-2.5 THz with repetition rate 53 Hz, duration of the impulse of about 10ns and energy 10nJ. The beam was detected by a HEB from Scontel (NEP ~ 10^-13W/Hz^-1/2) in a Pulse Tube cryocooler. The spectra was compared to results obtained from a standard Time Domain Spectroscopy setup (Teraview TPS 3000). Only small discrepancies between spectra measured by both methods are observed. For the range 0.7-2THz typical features can be identified using both methods. Above 2THz the TDS setup seems to have better performance in terms of signal-to-noise ratio and sensitivity.

8717-2, Session 1

Array geometries, signal type, and sampling conditions for the application of compressed sensing in MIMO radar

Juan Lopez, Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

MIMO radar utilizes the transmission and reflection of multiple independent waveforms to construct an image approximating a target scene. Compressed sensing (CS) techniques such as total variation (TV) minimization and greedy algorithms can permit accurate reconstructions of the target scenes from undersampled data. The success of these CS techniques is largely dependent on the structure of the measurement matrix. A discretized inverse scattering model is used to examine the imaging problem, and in this context the measurement matrix consists of array parameters regarding the geometry of the transmitting and receiving arrays, signal type, and sampling rate. We derive some conditions on these parameters that guarantee the success of these CS reconstruction algorithms. The effect of scene sparsity on reconstruction accuracy is also addressed. Numerical simulations illustrate the success of reconstruction when the array and sampling conditions are satisfied, and we also illustrate erroneous reconstructions when the conditions are not satisfied.

8717-3, Session 1

Rate-adaptive compressive video acquisition with sliding-window total-variation-minimization reconstruction

Ying Liu, Duke Univ. (United States); Dimitris A. Pados, Univ. at Buffalo (United States)

We consider a compressive video acquisition system where each frame block is sensed independently. Varying block sparsity is exploited for individual per-block sampling rate allocation with minimal system overhead. At the decoder, video frames are reconstructed via sliding-window inter-frame total variation minimization. Experimental results demonstrate that such rate-adaptive compressive video acquisition improves significantly the rate-distortion performance of the video stream over fixed-rate acquisition approaches.

8717-5, Session 1

Compressive sensing for tomographic SAR inversion in urban environment

Xiao Xiang Zhu, Richard Bamler, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany) and Technische Univ. München (Germany)

Synthetic Aperture Radar (SAR) maps the 3D reflectivity distribution of a scene into the 2D azimuth-range plane. It can be seen as a projection along the third radar coordinate, elevation. This projection handicaps the interpretation of SAR images. SAR tomography (TomoSAR) extends the synthetic aperture principle of SAR into the elevation direction for 3D imaging. It uses acquisitions from slightly different viewing angles (the elevation aperture) to reconstruct for every pixel the reflectivity function along elevation. Modern SAR satellites provide a very high azimuth-range resolution of up to sub-meters. However, the tight orbit control of these sensors limits the elevation aperture size and leads to a low tomographic elevation resolution of about 30-40m. This very anisotropic resolution element calls for superresolution and it also renders the signal sparse in elevation.

A compressive sensing (CS) based algorithm (SL1MMER) is proposed for 4D (space-time) tomographic inversion of urban objects. It combines the advantages of CS, e.g. superresolution capability, with the high amplitude and phase accuracy of linear estimators and features a model order selection step. The proposed SL1MMER algorithm is shown to be efficient. Its superresolution power is derived by simulations and demonstrated with real TerraSAR-X data. E.g., in the typical parameter range of SAR, a super-resolution factor of 1.5~15 can be achieved. 3D reconstructions of buildings are presented including their seasonal thermal deformation history at resolution and coverage levels not possible so far. Although taken TomoSAR as the preferred application, SL1MMER is generally applicable to sparse spectral estimation.

8717-6, Session 2

Compressive moving objects localization techniques based on optical Radon projections

Adrian Stern, Yuval Kashter, Ofer Levi, Ben-Gurion Univ. of the Negev (Israel)

We overview some of the compressive motion detection and tracking developed recently. We focus on two optical compressive techniques we have developed. The first one is based on a compressive imaging technique we have developed earlier. The compressive imaging system reconstructs video frames from Radon projections acquired optically. Then, a conventional motion detection method is applied on the reconstructed video sequence. The second compressive motion detection technique uses a specially designed optical motion detector. The sensor takes concomitantly several Radon projections. The captured data is insufficient to generate full images of the scene however carry sufficient information about small moving targets. Compressive motion tracking with compression ratio of 2-3 orders of magnitude is demonstrated.

8717-7, Session 2

Compressive sensing underwater line scan imaging system

Bing Ouyang, Florida Atlantic Univ. (United States); Fraser R. Dalgleish, Anni K. Vuorenkoski Dalgleish, Harbor Branch Oceanographic Institute (United States); Frank M. Caimi, Walter Britton, Florida Atlantic Univ. (United States)

In the last two years, the OVOL lab has conducted research on CS based underwater laser imager. A frame based CS underwater laser imager that is more advantageous for hover-capable platforms such as HAUV was proposed as a result. Through the integration of the Distributed Compressive Video Sensing (DCVS) concept, this paper intends to study CS Laser Line Scan (LLS) Imaging System that is more compatible with the traditional underwater electro-optical system where images are formed in line-by-line fashion. While DCVS exploits temporal redundancies among frames, here a DCVS-like principle is adopted to exploit the spatial correlation among adjacent lines in the LLS imaging lidar context: the key/non-key line will be the equivalent as the key/non-key frame respectively. Each line will be measured independently with more measurements dedicated to key lines. To measure each individual line, a Digital Mirror Device (DMD) spatially modulates the laser source to illuminate one line on the target plane with a series of random patterns at greater radiant intensity. A receiver consisting of an array of sensitive narrow field of view photo-detection elements will record target reflection, as it is known to improve SNR for underwater lidar applications. EODES model will be used to predict the actual measurement patterns on the target line to be used in the signal reconstruction. As in DCVS, side information (SI) derived from key line reconstruction will be used as initial condition to jointly reconstruct the non-key lines. Simulation and initial experimental results will be presented as part of this work.

8717-8, Session 2

A higher-speed compressive sensing camera through multi-diode design

Matthew A. Herman, James Tidman, Donna Hewitt, Tyler Weston, Lenore McMackin, InView Technology Corp. (United States)

Obtaining high frame rates is a challenge with a single-pixel compressive sensing camera since measurements of the required basis coefficients are obtained sequentially. One strategy for increasing the frame rate is to divide the field of view into smaller areas that are sampled and reconstructed in parallel. Following this strategy, InView has developed a multi-aperture CS camera using an 8 x 4 array of photodiodes that essentially act as 32 individual simultaneously operating single-pixel cameras. Images reconstructed from each of the photodiode measurements are stitched together to form the full field of view.

To account for crosstalk between the sub-apertures, novel modulation patterns have been developed to allow neighboring sub-apertures to share energy. Regions of overlap not only account for crosstalk energy that would otherwise be reconstructed as noise, but they also allow for tolerance in the alignment of the DMD to the lenslet array.

Currently, the multi-aperture camera is built into a computational imaging workstation configuration useful for research and development purposes. In this configuration, modulation patterns are generated in a CPU and sent to the DMD via PCI express. This allows the operator to develop and change the patterns used in the CS data acquisition process and also provides a data path for off-board reconstruction via USB. Depending on the amount of data taken and the amount of overlap between sub-apertures, frame rates of 2–5 frames per second can be achieved. In a stand-alone camera platform, currently in development, pattern generation and reconstruction will be implemented on-board.

8717-9, Session 2

Measurement kernel design for compressive imaging under device constraints

Robert R. Muise, Richard Shilling, Lockheed Martin Missiles and Fire Control (United States)

We look at the design of projective measurements for compressive imaging based upon image priors and device constraints. If one assumes that image patches from natural imagery can be modeled as a low rank manifold, we develop an optimality criterion for a measurement matrix based upon separating the canonical elements of the manifold prior. We then describe a stochastic search algorithm for finding the optimal measurements under device constraints based upon a subspace mismatch algorithm. The algorithm is then tested on a prototype compressive imaging device designed to collect an 8x4 array of projective measurements simultaneously.

8717-10, Session 3

An efficient sparse microwave imaging algorithm based on range-azimuth decoupled Lq regularization method

Bingchen Zhang, Chenglong Jiang, Zhe Zhang, Yao Zhao, Wen Hong, Yirong Wu, Institute of Electronics (China)

In recent years, as the sparse signal processing methods are introduced to radar imaging, sparse microwave imaging is proposed as a novel concept, theory and methodology of microwave imaging technology. The imaging quality of current synthetic aperture radar data benefits from adopting the sparse microwave imaging algorithms in improving the distinguishing ability, reducing side-lobes and ambiguity. However, comparing with traditional matched filtering imaging algorithms, the sparse microwave imaging algorithms have much higher spatial-temporal complexity when they are directly applied to the raw data.

In this paper, we mainly focus on the Lq regularization based sparse microwave imaging method with range-azimuth decoupled by a Chirp Scaling operator. An accelerating algorithm is proposed, which exploits the sparse microwave imaging model to establish the Lq regularization optimization problem, constructs the decoupling operator by using the principle of the chirp scaling algorithm and recovers the radar backscattering with decoupled iterative shrinkage thresh-holding algorithm. Since the decoupling operator is used in the recovery algorithm, there is no need to construct the observation matrix of two-dimensional reconstruction or to carry out large-scale matrix-vector complex multiplications, thus the demands on memory and computing are reduced and the imaging procedure is much accelerated. In this paper, the details of the proposed algorithm are discussed, and then we analyze the performance and calculate the computational complexity of it. The results of simulations and real data experiments verify the effectiveness of the proposed method in speeding up the imaging procedure and exhibit the improvement in imaging quality.

8717-11, Session 3

Multistatic compressive imaging under quasi-invariant occlusion models

Raghu G. Raj, U.S. Naval Research Lab. (United States)

A practical and significant complication that arises in radar imaging applications is the phenomenon of occlusion whereby scatterers can exhibit anisotropic behavior with respect the various aspects in which the desired target or imagery is sensed. Compressive sensing (CS) thus far has primarily been confined to the case where the scatterers exhibit isotropic behavior owing to the technical difficulties arising in incorporating non-linear occlusion models into the CS framework.

In this paper we offer a methodology whereby an important sub-class of occlusions effects can be modeled in a tractable manner. We focus on the multistatic scenario wherein a stationary target or scene of interest is surrounded by widely spaced pairwise bistatic sensors that transmit waveforms Ψ_i (t).

Given this the occlusion modeling is set-up as follows. First we consider the simple case wherein the effective response seen by a virtual sensor can be modeled by a LSI blurring of the scene. For this case we derive precise gradient equations for updating the optimal blurring levels for each channel. In the second step we generalize this to a much more realistic scenario where the occlusion effects for each virtual sensor is modeled by a Quasi invariant Spatially Varying filtering operation for which we develop gradient equations that respect the quantitative approximation bounds that we developed in [1].

The resulting framework is general in the sense that the spatially varying filtering profiles can be chosen in a completely arbitrary manner based on adaptively learnt structure of the scene etc.

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8717-12, Session 3

Compressive Sensing for Sparse Time-Frequency Representation of Nonstationary Signals in the Presence of Impulsive Noise

Irena Orovic, Srdjan Stankovic, Univ. of Montenegro (Montenegro); Moeness G. Amin, Villanova Univ. (United States)

A modified robust two-dimensional compressive sensing algorithm for the reconstruction of sparse time-frequency representation (TFR) is proposed. The ambiguity function domain is assumed to be the domain of observations. The two-dimensional Fourier bases are used to linearly relate the observations to the sparse TFR, in lieu of the Wigner distribution. We assume that a set of available samples in the ambiguity domain is heavily corrupted by an impulsive type of noise. Consequently, the problem of sparse TFR reconstruction cannot be tackled using standard compressive sensing optimization algorithms. One approach is to change the entire minimization problem, i.e., adjust the norm and the constraints to be consistent with the noise model assumptions. This approach, however, proves difficult when searching for the optimal parameter values and achieving stable and computationally efficient solutions. Instead, we introduce a two-dimensional L-statistics based modification into the transform domain representation so as to provide suitable initial conditions that will further provide efficient convergence of the reconstruction algorithm. This approach does not use a priori knowledge about the impulsive noise distribution, but rather applies sorting and weighting operations to discard an expected amount of samples corrupted by noise. In other words, a two-dimensional L-statistics is employed to sort out the ambiguity function samples and select those of high signal to noise ratio. In so doing, the employed dictionary will map only those time-lag frequency-lag ambiguity domain samples chosen by the L-statistics to a high resolution sparse TFR, which is similar to the case of noise-free data. In essence, the L-statistics approach provides an impulse noise resistant transition to the sparse TFR. In the full-length paper, we dwell on these theoretical considerations and furnish supporting examples.

8717-13, Session 3

Approximate message passing algorithm for compressive sensing with random circulant system matrices

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The problem of compressively imaging targets using ultra-wideband noise radar waveforms involves solving linear systems characterized by partial circulant random system matrices. The performance of such systems has been characterized and unique and stable solutions have been shown to exist. Convex optimization approaches outperform other classes of compressive signal recovery algorithms in terms of the recovery-error. However, convex optimization algorithms are computationally expensive. Radar target recovery can involve solving linear systems with dimensions as high as 10**6. In solving such large systems, convex optimization solvers may take hours or even days to converge to and compute the solutions. Further, it is difficult to derive theoretical results about the distribution of the recovery-error in the context of convex optimization recovery. In order to overcome these problems, the iterative approximate message passing (AMP) algorithm has been proposed for compressive signal recovery. The AMP algorithm is faster and for random system matrices, in the large system limit, the recovery-error has been theoretically shown to be equivalent to convex optimization. However, the characterization of AMP for partial circulant random system matrices remains an open problem. In this paper we generalize the AMP algorithm for compressive sensing with random circulant system matrices. We study the performance of the estimation error through theoretical and empirical investigations. We also analyze the behavior of the algorithm in the presence of non-idealities specific to ultra-wideband radar imaging.

8717-14, Session 3

High-efficiency imaging via system compression

Xiteng Liu, Univ. of Toronto (Canada)

In this talk, I will introduce the logical mechanism, methodology and applications of system compression. System compression theory describes a new computational phenomenon. It reveals that a linear system may be compressed to a lower dimension and may be completely reconstructed afterward. The principle of system compression is akin to that of data compression. In a large data set, data elements may have different importance. The task of data compression is to identify and eliminate unessential data elements. Likewise, in a large linear system, equations may have different importance. System compression is purported to identify and eliminate unessential equations, in an effort to reduce dimension of linear systems. Solution of a linear system can be found only from its essential equations, whence the entire system can be reconstructed. As one application, a signal may be reconstructed from its partial samples. New mathematical transforms and visual thresholding methods are specifically designed for implementation of system compression. Moreover, a variety of practical system compression methods are designed for industrial applications. Experiment results may well demonstrate the significance of new discoveries. Demo software and simulation results are downloadable at website http://qualvisual.net .

8717-15, Session 4

Optimization of pseudorandom coded apertures for spectrally selective compressive imaging

Henry Arguello, Univ. of Delaware (United States) and Univ. Industrial de Santander (Colombia); Gonzalo R. Arce, Alejandro Parada, Univ. of Delaware (United States)

Compressive spectral imaging (CSI) senses the spectral information of a scene by using 2 Dimensional (2D) coded projections which are then employed to recover the underlying discretized spectral information by solving an l1 norm based optimization algorithm. An efficient architecture implementing CSI is the Coded Aperture Snapshot Spectral Imager (CASSI). Our previous work determines a matrix system model for multi-frame CASSI, which is used to design sets of spectrally selective coded apertures. There, the required number of CASSI measurements for reconstruction is dictated by the desired profile of spectral bands. This work presents a new pseudorandom coded aperture design framework for multi-frame CASSI, aimed at optimizing the set of selective coded apertures such that the number of Focal Plane Array (FPA) CASSI measurements is reduced to a desired number of shots, regardless of the targeted spectral profile. First, a matrix representing the ensemble of spectrally selective coded apertures is determined. Then, a rank minimization algorithm is designed to estimate a set the pseudorandom components of the coded apertures. The optimization of the coded apertures is subjected to a user-defined number of shots. Further, the optimal coded apertures are designed so as to satisfy a Restricted Isometry Property (RIP) with high probability. Given a profile of desired bands, the simulations shows that the PSNR achieved by the optimized codes is up to 4dB higher than the systems using Hadamard or random coded aperture sets.

8717-16, Session 4

Accurate reconstruction of hyperspectral images from compressive sensing measurements

Justin C. Flake, Booz Allen Hamilton Inc. (United States); John B. Greer, National Geospatial-Intelligence Agency (United States)

The emerging field of Compressive Sensing (CS) provides a new way to capture data by shifting the heaviest burden of data collection from the sensor to the computer on the user-end. This new means of sensing requires fewer measurements for a given amount of information than traditional sensors. We investigate the efficacy of CS for capturing HyperSpectral Imagery (HSI) remotely. We also introduce a new family of algorithms for reconstructing HSI from CS measurements with Split Bregman Iteration [Goldstein and Osher, 2009]. These algorithms combine spatial Total Variation (TV) with smoothing in the spectral dimension. We examine models for three different CS sensors: the Coded Aperture Snapshot Spectral Imager-Single Disperser (CASSI-

SD) [Wagadarikar et al., 2008] and Dual Disperser (CASSI-DD) [Gehm et al., 2007] cameras, and a hypothetical random sensing model closer to CS theory, but not necessarily implementable with existing technology. We simulate the capture of remotely sensed images by applying the sensor forward models to well-known HSI scenes - an AVIRIS image of Cuprite, Nevada and the HYMAP Urban image. To measure the accuracy of the CS models, we compare the scenes reconstructed with our new algorithm to the original AVIRIS and HYMAP cubes. The results demonstrate the possibility of accurately sensing HSI remotely with significantly fewer measurements than standard hyperspectral cameras.

8717-17, Session 4

Block-based reconstructions for compressive spectral imaging

Claudia V. Correa, Henry Arguello, Univ. of Delaware (United States) and Univ. Industrial de Santander (Colombia); Gonzalo R. Arce, Univ. of Delaware (United States)

Coded Aperture Snapshot Spectral Imaging system (CASSI) captures spectral information of a scene using a reduced amount of focal plane array (FPA) projections. These projections are highly structured and localized such that each measurement contains information of a small portion of the data cube. Compressed sensing reconstruction algorithms are then used to recover the underlying 3-dimensional (3D) scene. The computational burden to recover a hyperspectral scene in CASSI is overwhelming for some applications such that reconstructions can take hours in desktop architectures. This paper presents a new method to reconstruct a hyperspectral signal from its compressive measurements using several overlapped block reconstructions. This approach exploits the structure of the CASSI sensing matrix to separately reconstruct overlapped regions of the 3D scene. The resultant reconstructions are then assembled to obtain the full recovered data cube. Typically, block-processing causes undesired artifacts in the recovered signal. Vertical and horizontal overlaps between adjacent blocks are then used to avoid these artifacts and increase the quality of reconstructed images. The reconstruction time and the quality of the reconstructed images are calculated as a function of the block-size and the amount of overlapped regions. Simulations show that the quality of the reconstructions is increased up to 6 dB and the reconstruction time is reduced up to 4 times when using block-based reconstruction instead of full data cube recovery at once. The proposed method is suitable for multi-processor architectures in which each core recovers one block at a time.

8717-18, Session 4

Spatial versus spectral compression ratio in compressive sensing of hyperspectral imaging

Yitzhak August, Chaim Z. Vachman, Adrian Stern, Ben-Gurion Univ. of the Negev (Israel)

Hyperspectral images are used in numerous fields such as bio-medical imaging applications, remote sensing, food industry, art conservation and restoration and many more. The amount of data typically captured with hyperspectral imaging systems is very large and is often highly compressible. This has motivated the application of compressive sensing techniques for hyperspectral imaging. Compressive hyperspectral imaging is based on the fact that hyperspectral data is highly redundant. There is asymmetry between the compressibility of the spatial and spectral domains, which should be taken in account for optimal compressive hyperspectral imaging design. Here we present a study on the influence of the ratio between the compression in the spatial and spectral domains on the performance of a 3D separable compressive hyperspectral imaging we developed. Separable sensing architecture is used to reduce the computational complexity associated with compressive sensing of large data, which is typical to hyperspectral imaging. We show that for the same number of total compress sensing measurements with different compression sensing ratios for the spectral/spatial, we can get hyperspectral reconstructed cubes with different qualities. This asymmetry with some prior knowledge about the scene can be used in order to achieve the highest reconstructed image quality for a constant number of total compress sensing measurements.

8717-29, Session PThur

Information theoretic bounds for compressed sensing in SAR imaging

Jingxiong Zhang, Ke Yang, Wuhan Univ. (China); Jianzhong Guo, Wuhan Textile Univ. (China)

Compressed sensing (CS) is a new framework for sampling and reconstructing sparse signals from measurements significantly fewer than those prescribed by Nyquist rate in the Shannon sampling theorem. This new strategy, applied in various application areas including synthetic aperture radar (SAR), relies on two principles: sparsity, which is related to the signals of interest, and incoherence, which refers to the sensing modality. An important question in CS-based SAR system design concerns sampling rate necessary and sufficient for exact or approximate recovery of sparse signals. In the literature, bounds of measurements (or sampling rate) in CS have been proposed from perspectives including information theory. However, these information-theoretic bounds need to be reviewed and, if necessary, validated for CS-based SAR imaging, as there are various assumptions made in the derivations of lower and upper bounds on sub-Nyquist sampling rates, which may not hold true in CS-based SAR imaging. In this paper, information-theoretic bounds of sampling rate will be analyzed. For this, the SAR measurement system is modeled as an information channel, with channel capacity and rate-distortion characteristics evaluated to enable the determination of sampling rates required for recovery of sparse scenes. Experiments based on simulated data will be undertaken to test the theoretic bounds against empirical results about sampling rates required to achieve certain detection error probabilities.

8717-30, Session PThur

Color-dependent PRNU (photo response non-uniformity) on CMOS image sensor

Changhui Ye, Sungsu Lee, Pixelplus Co., Ltd. (Korea, Republic of)

To get higher resolution and higher SNR image, characterizing noise of image is one of the most important procedures.There are lots of manners with regards to characterizing image quality of CMOS image sensors. And one of the most important performances of FPN(fixed-pattern-noise) of sensor can be measured by using PRNU method. PRNU is the meaning of Photo response non-uniformity of each pixel on image sensor and it depends on the uniform performance of sensitivity among pixels. Additionally this uniformity of sensitivity is different from each color filter channels depending on the distribution of it. In this paper, in order to diagnose the tendency of PRNU regarding each color filter channel, it is introduced that techniques to minimize other noise sources excluding PRNU from target images. And it also introduces that the result of measuring PRNU and spatial resolution of mono sensor, RGB color sensor by using various color temperature light sources. And it suggests ways how to understand these results with simple manner as well.

8717-19, Session 5

Sparse microwave imaging radar: initial system design and performance analysis

Yirong Wu, Wen Hong, Bingchen Zhang, Zhe Zhang, Chenglong Jiang, Institute of Electronics (China)

In this paper, we study the system design of sparse microwave imaging radar and report initial results of ground-based and airborne experiments. Sparse microwave imaging is a novel concept, which introduces the sparse signal processing theory to microwave imaging to reduce the system complexity and enhance system performance. According to the relationship among SNR, under-sampling ratio and scene sparsity, we designed the radar parameters such as waveform, bandwidth and PRF. We also analyzed the distinguishing ability, ambiguity, radiation resolution and sidelobe level of designed radar. Finally, the validation of our design was verified via ground-based and airborne experiments.

8717-20, Session 5

Enhanced through-the-wall radar imaging using Bayesian compressive sensing

Van Ha Tang, Abdesselam Bouzerdoum, Son Lam Phung, Fok Hing Chi Tivive, Univ. of Wollongong (Australia)

In recent years, compressive sensing (CS) has been introduced in through-the-wall radar imaging (TWRI) to reduce the data acquisition time while achieving high-resolution imaging. During the sensing operation, each antenna emits a set of random frequencies to interrogate the scene. Then, compressive sensing is used to recover the un-measured data samples before a backprojection method is applied for image reconstruction. The recovery of the data samples at each antenna is formulated as a CS inverse problem, which is solved independently by using a greedy or convex relaxation sparse recovery method. However, this approach leads to a prolonged processing time and high computational complexity. Furthermore, this recovery approach ignores the statistical dependencies between data samples that are useful for the signal recovery.

In this paper, we propose a distributed CS model based on Bayesian theory for recovering the un-measured data samples across the array aperture simultaneously. The proposed CS model takes into account of the statistical correlations among the acquired measurements by jointly reconstructing the high resolution radar profiles across the antennas as full posterior distributions rather than point estimates, without the prior knowledge of the data noise variance. After the recovery of the range profiles, a backprojection method such as delay-and-sum beamforming is applied, in time or frequency domain, to form the radar image. Experimental results based on real TWRI data demonstrate that the proposed CS-TWRI method is more effective than existing approaches and produces better radar images with high target-to-clutter ratio values.

8717-21, Session 5

A capon beamforming method for clutter suppression in colocated compressive sensing based MIMO radar

Shunqiao Sun, Yao Yu, Athina P. Petropulu, Rutgers, The State Univ. of New Jersey (United States)

It has been shown that in compressive sensing (CS) based multi-input multi-output (MIMO) radar systems that explore the sparsity of targets in the illuminated space enable to achieve either the same localization performance as traditional methods but with significantly fewer measurements, or significantly improved performance with the same number of measurements. It is well known that in radar systems, clutter would significantly degrade the detection performance. Clutter suppression has been widely studied in traditional radar systems, while little has been done in CS based MIMO radar systems. In this paper, we propose a clutter suppression method in the colocated CS based MIMO radar systems to improve the targets' DOA estimation performance. The compressed receive signals first go through a Capon beamformer, and then are fed to the CS estimator. It is shown that the signal-to-clutter-noise ratio (SCNR) at the CS estimator is much higher than that without beamforming. The estimation performance can be further improved by doing power allocation. An approach is proposed for allocating the available power among the transmit antennas so that the coherence between the target returns from different search cells, or equivalently, the coherence of the columns of the sensing matrix is minimized. Numerical results show that in the colocated MIMO radar systems with presence of clutter, the DOA estimation performance under our proposal is much better than Capon or CS method, respectively. Numerical results also show that the estimation performance further benefits from the power allocation.

8717-22, Session 5

Improved interior wall detection using designated dictionaries in compressive urban sensing problems

Eva Lagunas, Univ. Politècnica de Catalunya (Spain); Moeness G. Amin, Fauzia Ahmad, Villanova Univ. (United States); Montse Najar, Univ. Politècnica de Catalunya (Spain)

Detection of walls and wall boundaries is part of a broader paradigm of detecting indoor stationary targets of interest in through-the-wall radar applications. For these targets, change detection of Doppler processing cannot be applied since targets and clutter are both of the same nature. In this paper, we address the problem of localizing interior walls. We propose a technique to detect the location and extent of internal building structures when a large number of measurements are missing. Dealing with reduced number of observations in space and/or time (frequency) for surveillance and indoor imaging can be driven by the need for fast data acquisition and quick gathering of actionable intelligence. It can also be attributed to logistic difficulties to sense the behind-the-wall scene at specific frequencies and antenna positions.

Within the compressive sensing (CS) framework, we propose a dictionary that is consistent with building construction practices, where interior walls are either parallel or perpendicular to the exterior walls. With a ground-based SAR system, and considering radar returns from walls, the antenna at each position would receive reflections from the walls parallel to the synthetic aperture, as well as from the corners between two meeting walls. We propose a two-step approach. In the first step, a dictionary of possible wall locations is built to sparsely represent the interior wall layout. Conventional CS recovery algorithms are then applied to recover the positions of both interior and exterior walls. A follow on step is to use a dictionary of possible corner reflectors, which is the type of reflection caused by the junction of walls perpendicular to each other. Determining corner reflectors along the wall segments can indicate the wall extent. The utility of the proposed approach is demonstrated using both real and simulated data. It is shown that accurate determination of interior wall positions can be achieved with substantial reduction in data volume.

8717-23, Session 5

Detection Performance of Radar Compressive Sensing in Noisy Environments

Asmita Korde, Tinoosh Mohsenin, Univ. of Maryland, Baltimore County (United States); Damon Bradley, NASA Goddard Space Flight Ctr. (United States)

Compressive sensing is a novel technology which allows the reconstruction of a sparse signal by sampling at a much lower rate than the nyquist rate. By using this technique in radar, the use of matched filter can be eliminated and high rate sampling can be replaced with low rate sampling. Radar compressive sensing reconstruction in noisy environments can lead to inaccurate results. Different reconstruction algorithms can improve the detection probability and false alarm probability in noisy environments. While CS has several advantages, CS reconstruction algorithms are complex and high power consuming. In this paper, several different reconstruction algorithms for Radar Compressive sensing are analyzed and their detection performance and also hardware

complexity are compared against each other. We will compare algorithms including L1 minimization and orthogonal matching pursuit (OMP) for different scenarios. The type of random mask transmitted and the type of reflectivity function used can also have an effect on the reconstruction of the signal and their impact will be analyzed. False alarm probability and detection probability will be analyzed using Receiver operating characteristics (ROC) curves for different SNR values by running Monte Carlo simulations. We also propose a modified OMP reconstruction algorithm which leads to faster reconstruction. The OMP algorithm is implemented using both Xilinx Virtex-5 FPGA and also 65-nm CMOS technology for a 256 length input vector. The FPGA and ASIC implementations run at 85 MHz and 165 MHz respectively which result in total reconstruction time of 27 and 13 us respectively.

8717-24, Session 5

UWB radar echo signal detection based on compressive sensing

Shugao Xia, Jeffrey Sichina, Fengshan Liu, Delaware State Univ. (United States)

Ultra-wideband (UWB) technology has been widely utilized in radar system because of the advantage of the ability of high spatial resolution and object-distinction capability. A major challenge in UWB signal processing is the requirement for very high sampling rate under Nyquist sampling theorem which exceeds the current ADC capacity.

Recently, new approaches based on the Finite Rate of Innovation allow significant reduction in sampling rate. A system for sampling UWB radar echo signal at an ultra-low sampling rate and estimation of time-delay is presented in the paper. An ultra-low rate sampling scheme based on Xampling framework is applied, which often results in sparse parameter extraction for UWB radar signal detection. The parameters such as time-delays are estimated in the framework of compressed sensing based on total-variation norm minimization. With this system, the UWB radar signal can be accurately reconstructed and detected with overwhelming probability at the rate much lower than Nyquist rate. The simulation results show that the proposed method is effective for sampling and detecting UWB radar signal with ultra-low sampling rate.

8717-25, Session 6

Towards the use of learned dictionaries and compressive sensing in wideband signal detection

Jerry Carreon, Novita Research Labs Corp. (United States); Sergio D. Cabrera, The Univ. of Texas at El Paso (United States)

Recent literature on Compressive Sensing (CS) indicates an enormous potential for reduced sampling rates and can bring cutting edge capabilities to signal collection systems. Modern radio frequency (RF) receivers gather and process large amounts of data in order to detect, classify and or record targets. Today's communication and radar systems are becoming more complex and receivers have to accommodate to emerging emitter capabilities. A need to improve the collection paradigm has been shown by the U.S. government's interest to alternative methods of data sampling. In this work we introduce a framework that can be used to detect and classify signals of interest. The novelty of our work lies in the choice of reconstruction basis because we use a generative approach. This approach finds the basis where the signal of interest shows the sparsest representation. Representative data will be used to simulate detection and classification of wideband signals. The results of this work will contribute to the CS community by offering an alternative to technology deployment. The demonstration from this work will be a monitor that detects, classifies, and or records complex emitters. Issues and tradeoffs will be identified and addressed.

8717-26, Session 6

L-Statistic Combined with Compressive Sensing

Srdjan Stankovic, Ljubisa Stankovic, Irena Orovic, Univ. of Montenegro (Montenegro)

The L-estimation signal analysis was introduced for signals disturbed with high additive impulse noise. It has been employed in problems involving Fourier transform, Cosine transform, and Hadamard transforms, as well as in the time-frequency formulations of nonstationary with time-varying spectra signals. The basic idea is that a certain, usually large, number of arbitrary positioned signal samples is declared as heavily corrupted by noise, using the L-statistics. These samples are then discarded from further processing and considered as absent or unavailable. As a result, fewer samples, compared to the original data, are considered for L-estimation signal representations. On the other hand, compressive sensing, which is emerging as a power tool for signal reconstruction, also deals with reduced observations. However, unlike the L- estimation, it attempts to reconstruct the missing samples using the sparseness property of the signal when viewed over particular basis.

This paper examines the performance of both L-estimation and compressive sensing for signals that are sparse in the Fourier domain. We discuss how the L-estimation can benefit from compressive sensing solutions. In particular, we provide the analysis of the signal errors in the Fourier-domain based on the application of the L-estimate and compressive sensing. It will be shown that, in the case of a sparse random signal with several realizations available, the mean of L-estimation representations produces an ideal transform, providing that the remaining samples are disturbance-free. When only one realization is available, the minimization algorithms, developed for the compressive sensing, may be used to further improve the results obtained by the L-estimation transforms. In the examples included in the full-length paper, discrete forms of the Fourier transform, short time Fourier transform and Wigner distribution, are used to demonstrate the effective integration of the two techniques.

8717-27, Session 6

Compressive detection of frequency-hopping spread spectrum signals

Feng Liu, BIO5 Institute (United States); Michael W. Marcellin, The Univ. of Arizona (United States); Nathan A. Goodman, The Univ. of Oklahoma (United States); Ali Bilgin, The Univ. of Arizona (United States)

This paper introduces compressive detection strategies for detection of Frequency-Hopping Spread Spectrum (FHSS) signals. In 2012, Liu et al. introduced a compressive receiver architecture for interception of FHSS signals. An underlying assumption in that work was that the presence of the FHSS signal was already confirmed. In practice, detection of communication signals is an important prerequisite in interception applications. FHSS signals avoid detection by rapidly switching the carrier frequency using a pseudorandom sequence known only to the transmitter and a cooperative receiver. Since the transmission can occur within a very large bandwidth, analog-to-digital converters (ADCs) that can sample fast enough to capture the full communication spectrum are needed ideally but such ADCs are often prohibitively expensive to build. The conventional approach to detect such signals is to rapidly scan small segments of the full spectrum in a sequential manner. In this paper, we propose compressive detection strategies that can sample the full spectrum in a compressive manner. We introduce a simplified model for FHSS signals and use this model to study theoretical detection performances of full-bandwidth Nyquist-sampled, scanning, and compressive detectors. We present the results from simulations that show agreement with the proposed theory. Finally, the proposed techniques are evaluated using Gaussian Frequency-Shift Keying (GFSK) modulated FHSS signals at varying signal-to-noise and compression ratios.

8717-28, Session 6

How to find real-world applications of compressive sensing

Leslie N. Smith, U.S. Naval Research Lab. (United States)

The field of Compressed Sensing (CS) has seen significant growth in the past few years with recent work focused on the development of CS cameras. Such cameras offer the possibility that low-cost, low-resolution focal plane arrays (FPAs) can replace their expensive, high-resolution brethren yet still provide comparable performance. Given data from a low-resolution FPA, alternative methods of increasing resolution include interpolation and super-resolution. In theory, CS methods should retain high-frequency information that the interpolated solution discards.
We quantify performance differences by calculating the peak signal-to-noise ratio (PSNR) between original high-resolution imagery and reconstructed results. Frequency performance is also quantified for the two competing methods. Super-resolution works by requiring multiple observations spread over time. Alternatively, certain CS architectures allow reconstruction of a high-resolution result from a single observation of the scene. We quantify these time and performance trade-offs for the two techniques. Finally, we consider the reduction in performance of the CS solution versus a high-resolution-plus-compression architecture. For a given task (such as detection) we can determine the cost savings of a CS solution that offers acceptable performance relative to the more expensive compression option. We use the outcome of software simulations on a set of common imagery to map the trade-space between cost and performance for all four competing acquisition solutions.

8718-1, Session 1

Innovative Raman spectroscopic concepts for in situ monitoring of chemicals in sea-water

Kay Sowoidnich, Maria Fernandez Lopez, Heinz-Detlef Kronfeldt, Technische Univ. Berlin (Germany)

Recently, Raman spectroscopy is increasingly moving from the lab to field applications to enable analysis of samples in their native environment. This is accompanied by the ongoing development of compact microsystem diode lasers. Applying such devices, we present a multi-spectral concept with excitation wavelengths in the blue, red, and NIR spectral range for in situ investigations of water incorporating surface-enhanced Raman spectroscopy (SERS) and shifted excitation Raman difference spectroscopy (SERDS). Each laser source emits at two slightly different wavelengths with a spectral distance in the order of 10 cm-1 necessary for SERDS operation.

SERS was applied for high sensitive chemical detection in water and SERDS effectively reduces the fluorescence interference. With that concept, i.e. combined SERS/SERDS measurements, for the first time we achieved detection limits of pyrene in sea water in the pmol/l range. Furthermore, specially tailored SERS substrates which are well suited for long term in situ monitoring in sea-water were realized. This offers a great potential for environmental control with respect to the water body.

Applying a specially designed miniaturized Raman and SERDS measurement system suited for applications in the water body, we are able to record spectra in seconds, minutes, or hours according to the different measurement scenarios for buoys, moorings or sea trials demonstrating the capability for rapid in situ investigations. Due to its modular construction principle, the applied Raman system can be easily modified and optimized to meet the demands of other analytical applications, as e.g. food inspection, medical diagnosis, forensics, and homeland security usage.

8718-3, Session 1

THz absorption spectra and stability of Fe water complexes calculated by density functional theory

Lulu Huang, Samuel G. Lambrakos, U.S. Naval Research Lab. (United States); Andrew Shabaev, George Mason Univ. (United States); Lou Massa, Hunter College (United States); Constantine Yapijakis, The Cooper Union for the Advancement of Science and Art (United States)

Monitoring of water contaminants implies a need for determining their dielectric response properties with respect to electromagnetic wave excitation at various frequencies. Iron is a naturally occurring water contaminant resulting from decaying vegetation, which is at much higher concentrations than any other metal contaminant. The present study uses density functional theory (DFT) for the calculation of ground state resonance structure and molecular stability analysis for Fe water complexes. The calculations presented are for excitation by electromagnetic waves at frequencies within the THz range. Dielectric response functions calculated by DFT can be used for the analysis of water contaminants. These 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. In addition, with respect to qualitative analysis, DFT calculated absorption spectra provide for molecular level interpretation of response structure. The DFT software GAUSSIAN was used for the calculations of ground state resonance structure presented here.

8718-4, Session 2

A paper-based inkjet-fabricated substrate for SERS detection and differentiation of PCR products

Eric P. Hoppmann, Ian M. White, The Univ. of Maryland, College Park (United States)

Surface enhanced Raman spectroscopy (SERS) is a highly sensitive sensing technique, offering sensitivity comparable to that of fluorescence while providing structure-dependent analyte information. In recent years, we have developed an innovative optofluidic SERS substrate by inkjet printing metal nanoparticles onto paper. By virtue of generating a SERS substrate on cellulose, we gain a flexible SERS sensing device, as well as the ability to harness the intrinsic wicking properties of paper to enable both separation and concentration of analytes. Here we demonstrate the application of paper-chromatographic separation to allow on-substrate separation, concentration and discrimination. By using inexpensive single-labeled DNA probes in a typical PCR amplification, we obtain a mixture containing whole probes (negative result) and probes which have been hydrolyzed by the Taq polymerase (positive result). Leveraging the solubility differences between the whole and hydrolyzed probes and the cellulose separation matrix, we are able to perform a multiplexed interrogation of the targets. Notably, this does not require the use of dual labeled DNA probes (expensive) or multiple excitation sources and filter sets needed for a multiplexed fluorescence measurement (expensive and bulky). We examine the dependence of migration on DNA length and solvent polarity, two key factors which make this discrimination possible. All SERS measurements are performed using a portable spectrometer and diode laser; in combination with a portable low-power DNA amplification system, this technique has the potential to be used for rapid on-site multiplexed genetic detection, without requiring complex optical equipment.

8718-5, Session 2

UV spectral behavior of Ag coated Al plasmonic band gap nanocraters

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There is a great potential to use plasmonic band gap structures for better biosensing in UV spectra since understanding some molecular interactions in UV is very vital in medical sciences. In this study plasmonic band gap surface structures (nanocraters) with 44 - 93 nm in diameter and 85 - 152 nm in inter-crater distance were fabricated by anodizing aluminum foils and chemically removing the oxide layer. Fabricated Aluminum surface nanocraters were coated with 40- and 150-nm silver films in order to investigate effect of the coating thickness on the UV reflectance (250 nm – 400 nm). Reflectance measurements were taken with a UV/Vis/IR spectroscopy. Characterization of surface morphologies was carried out with SEM and AFM. It was understood that amplitude, location and number of the plasmonic resonance modes in UV spectra can be altered by changing the dimensions of nanocraters and the thickness of the Ag coating. Location of the main plasmon resonance mode shifts left or right relative to the resonance location of the thin Ag film with a flat surface. Existence of nanocraters on the surface generates another resonance point wider than the main one. Strength of the resonance strongly depends on dimensions of nanocraters. As the coating thickness increases, an additional plasmonic resonance mode emerges. These features of the surface nanostructures studied promises to develop novel plasmonic and hybrid biosensors in UV spectra.

8718-6, Session 2

SERS barcoding for quick identification of pathogens enabled by engineered plasmonic nanostructure arrays

Qiuming Yu, Jiajie Xu, The Univ. of Washington (United States); Jeffrey Turner, Mark Strom, Northwest Fisheries Science Ctr. (United States)

Surface-enhanced Raman scattering (SERS) is a near field effect. The highly confined electromagnetic energy in the nanoscale volume greatly enhances the Raman spectroscopic signals of molecules adsorbed on the nanostructured noble metal surfaces. Utilizing this unique property, we designed novel quasi-3D plasmonic nanostructure arrays (Q3D-PNAs) with the strongest electric filed ("hot spots") at the top gold/air interfaces, where bacterial cells land. In this way, we can acquire the SERS spectra of bacterial outer membranes. The complex chemical and biological components embedded in cell outer membranes carry specific molecular information related to strains, growth stages, expressions to stimulation, and even maybe geographic differences. Therefore, the SERS spectra can be used to quick identify bacteria. In this work, we used marine pathogen vibrio parahaemolyticus as a model system. Seven different strains were selected to perform the SERS detection. The strains were isolated from various sources including Pacific Northwest clinic and environmental clones (stool, water, oyster, and phytoplankton) and belong to four different rep-PCR and MLST groups. All strains were cultured under the same condition to the exponential-phase growth to ensure the uniformity of bacterial cell walls and yield consistent SERS spectra for each sample. SERS spectra were acquired in-situ by immersing the SERS-active substrate in a bacterial solution. The high sensitivity and reproducibility provided by the unique SERS-active substrates enable us to construct a color SERS barcoding for each strain. Unknown samples and mixtures of the two out of seven strains can be quickly identified by comparing the SERS barcoding. Furthermore, SERS barcoding of strains belonging to the same genomic group exhibit some common characteristic peaks that are dramatically different from other groups, indicating the correlation of genomic and phenotypic variation.

8718-7, Session 2

SERS plasmonic systems for environmental, biodefesnse, and food safety applications

Hsin-Neng Wang, Tuan Vo-Dinh, Duke Univ. (United States)

No Abstract Available.

8718-8, Session 3

Monolithic Y-branch dual wavelength DBR diode laser at 671 nm for Shifted Excitation Raman Difference Spectroscopy (SERDS) *(Invited Paper)*

Martin Maiwald, Jörg Fricke, Arnim Ginolas, Johannes Pohl, Bernd Sumpf, Götz Erbert, Günther Tränkle, Ferdinand-Braun-Institut (Germany)

Mobile Raman spectroscopy becomes more and more important for various application fields e.g. food safety, detection of explosives, or medical diagnostics. However, weak Raman signals can be obscured by fluorescence or elastic scattering. Amongst others, shifted excitation Raman difference spectroscopy (SERDS) is a promising technique to separate Raman signals from a disturbing background.

In this work a monolithic Y-branch dual wavelength distributed back reflection (DBR) diode laser at 671 nm for SERDS will be presented.

The semiconductor chip consists of two laser cavities. On the rear side two ridge waveguide (RW) sections with different deeply etched surface DBR gratings are realized. The DBR mirrors were designed for a spectral spacing suitable for SERDS. A Y-branch coupler section is implemented for the realization of one output aperture at the front facet. Individual contacts at all sections allow a separate trigger for both excitation wavelengths. The device has a footprint of 0.5 x 3 mm2.

At a heatsink temperature of 25°C in cw-operation mode for both wavelengths at 670.5 nm and 671.0 nm an output power of 100 mW was achieved with an electric power consumption of about 1 W. The spectral width was smaller than 0.02 nm (0.5 cm-1). In the power range up to 100 mW the spectral distance between both emission lines was (0.46 ± 0.02) nm, i.e. (10.2 ± 0.5) cm-1. An electro-optical and spectral characterization of this light source will be given. Raman experiments demonstrate the suitability of this monolithic Y-branch dual wavelength diode laser for SERDS.

8718-9, Session 3

Threefold enhancement in refractive index sensitivity of internally bent long period grating

Francesco Chiavaioli, Francesco Baldini, Cosimo Trono, Ambra Giannetti, Sara Tombelli, Riccardo Falciai, Istituto di Fisica Applicata Nello Carrara (Italy)

It was recently demonstrated that, by inducing an external bending along the portion of an optical fiber containing a long period grating, this structure shows a refractive index sensitivity higher than the straight counterpart, for values of external refractive indexes lower than that of silica. On the basis of this principle, a novel structure of long period grating (LPG) characterized by a specially-designed refractive index profile has been developed for the first time. In the proposed structure, each grating plane, placed at a distance equal to the grating pitches in the refractive index modulation, is tilted at increasing angles with respect to the axis orthogonal to the optical fiber, as moving away from the center of symmetry of the structure towards its both edges. This internally-manufactured geometric structure, which basically simulates the bending of the optical fiber, increases the LPG refractive sensitivity to the surrounding medium, maintaining a straight configuration. The internally-bent LPG shows a sensitivity of 68 nm RIU-1 against 22 nm RIU-1 of the straight counterpart, for the same refractive index range from 1.333 RIU to 1.4 RIU. Therefore, an improvement of three-order of magnitude in the refractive index sensitivity has been experimentally proved, thus providing the basis for another step forward in the field of refractive index sensors based on optical fiber gratings.

8718-10, Session 3

Optical properties of plasmonic sensor structures consist of gold coated over nanostructured alumina films

Mustafa M. Aslan, TÜBITAK Marmara Research Ctr. (Turkey)

Plasmonic sensor structures consist of the gold coated over nanostructured alumina (GCON-A) films were investigated for layer thicknesses and optical properties in between 400 and 800 nm. For this purpose we have used a spectroscopic ellipsometry and a visible spectroscopy. Layer thicknesses, effective refractive indices and absorbtion coefficients of films were determined through regression analysis on the ellipsometry data. To investigate the optical properties of the GCON-A films further, reflection measurements were taken by the visible spectroscopy. Our results indicate that the GCON-A films fabricated have wide ranges of effective refractive index, absorbtion coefficent and reflectivty values in the spectrum of the interest. Such nanostructured films with tuned optical properties may find place in many plasmonic applications including sensor developments.

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8718-11, Session 3

Rapid prototyping via 3D-printing of solar-powered, battery-operated microplasmas on sugar-cube sized chips used either as a light source or for elemental analysis by portable optical spectrometer

X. Zhang, D. Devathasan, Vassili Karanassios, The Univ. of Waterloo (Canada)

A variety of battery-operated, atmospheric-pressure, self-igniting microplasmas have been rapidly prototyped [1, 2]. Some of them have been used as light-sources and others for elemental analysis of microsamples using a portable, fiber-optic spectrometer. In this presentation, these applications will be briefly discussed.

1. S. Weagant, V. Chen and V. Karanassios, Battery-operated, argon-hydrogen microplasma on hybrid, postage stamp-size plastic-quartz chips for elemental analysis of liquid microsamples using a portable optical emission spectrometer, Analytical and Bioanalytical Chemistry, 401(9), 2865-2880 (2011)

2. S. Weagant, G. Dulai, L. Li and Vassili Karanassios, Characterization of rapidly prototyped, battery-operated, argon-hydrogen microplasma on a hybrid chip for elemental analysis of liquid microsamples by a portable fiber-optic spectrometer, Analytical and Bioanalytical Chemistry (submitted)

8718-12, Session 3

Integrated electrophoretic capillary nanofluidic biochip (ECField-Nanochip) for the fast-throughput separation and analysis of biological molecules

Edgar A. Mendoza, Redondo Optics, Inc. (United States)

The design and manufacture of custom genes or long DNA biomolecules has become an indispensable tool in the life sciences, synthetic biology, and protein engineering. Nanofluidic biochips have recent emerge as a viable solution to manipulate and analyze biological samples in extremely small quantities with fast analysis throughputs. This paper describes the work conducted by our group in collaboration with Center for High Technology Materials at the University of New Mexico towards the development and demonstration of an integrated electrophoretic capillary nanofluidic biochip (ECField-Nanochip) spectroscopic sensor platform suitable for the effective, reliable, and fast-throughput separation and analysis of biological molecules for use in the detection, identification, and classification of biological species. The predicted simple, effective, and fast-throughput operation of the ECField-Nanochip™ sensor platform will provide solutions to the fast growing biochip market for the scientific investigation of biological materials as well as for the real time detection of biological treats, and extended to gene expression, drug-discovery, immunology, disease control, medical diagnosis, and food quality among many other possibilities.

8718-13, Session 4

Miniaturized diode laser-based light sources for in-situ shifted excitation Raman difference spectroscopy *(Invited Paper)*

Bernd Sumpf, Martin Maiwald, Ferdinand-Braun-Institut (Germany); Kay Sowoidnich, Heinz-Detlef Kronfeldt, Technische Univ. Berlin (Germany)

The weak Raman bands are often covered by pronounced background signals due to fluorescence or Rayleigh scattering. Several techniques to separate Raman lines from the background are known. In this paper, selected diode laser based light sources will be presented suitable for shifted excitation Raman difference spectroscopy (SERDS). The two wavelengths are realized by varying the injection current, by addressing two micro-integrated ECLs or by temperature tuning.

Due to the freedom of choice in the wavelengths using diode lasers, the emission wavelength can be selected with respect to the addressed application (e.g. the required penetration depth) or the plasmonic resonances of the substrates for surface enhanced Raman spectroscopy. Devices were developed for the wavelengths 488 nm, 671 nm, and 785 nm. The two emission wavelengths each were selected to have a spectral distance of 10 cm-1 according to the typical width of Raman lines of solid or liquid samples. Output powers between 20 mW for the shorter wavelength devices and 200 mW for the red emitting lasers were achieved at electrical power consumptions below 1 W. With a footprint of only 25 x 25 mm2 including all collimation and filter elements, these devices are well suited for portable applications.

The microsystem diode lasers were implemented into portable Raman measurement systems. Experiments from food sciences for the control of meat ripeness and spoilage, and to detect colorants in drinks or candies will be presented. The signal-to-background ratio could be improved by several orders of magnitude. Perspectives for future applications will be given.

8718-14, Session 4

High-performance orthogonal spectroscopic sensing system and algorithm for identification of molecular fingerprints

Samar K. Guharay, The MITRE Corp. (United States)

Significant improvement in detection technology and algorithms is needed for rapid detection and identification of molecular fingerprints, especially in the presence of clutter or interference. Toward this goal, a novel sensor system uniquely employs the best features of two complementary sensor modalities, namely, ion mobility spectrometry (IMS) and surface enhanced Raman scattering (SERS). These two sensor modalities, if effectively harnessed to work together, offer a significantly improved solution in detection technology. In addition to registering the IMS response, the IMS unit acts as a pre-filter for SERS. This operation enhances operational reliability of SERS. As a final step in identification of the analyte, the detection system needs “smart” algorithms for data analysis enabling classification and identification of analytes of interest. Systematic studies through modeling and experiments are made to address the underlying science and engineering questions for the hybrid IMS-SERS system. A compact IMS system has been developed, and this unit is coupled to a SERS substrate. Experimental measurements showing characteristic spectra of numerous analytes including trace targeted chemicals (explosives) and commonly-used materials have been obtained. The crux of the data analysis is centered on several metrics, namely, root-mean squared error, weighted cross-correlation average, and earth mover’s distance. Illustrative results including discussions on applications will be presented.

*Acknowledges Wansheng Su, Edward Danyliw, Burhan Necioglu and Christopher Saunders for collaboration in activities including experiments and data analysis. Thanks are due to Prof. Herb Hill and his team for constructing IMS.

8718-15, Session 4

Toward aerosols LiDAR scattering plots classification and analysis

Amr H. Yousef, Khan M. Iftekharuddin, Mohammad A. Karim, Old Dominion Univ. (United States)

A compact light detection and ranging (LiDAR) is used for the purpose of aerosols profile measurements. Aerosols are stable suspensions of solid or liquid particles in air ranging in size from 1 nanometer to 10 microns. LiDAR is a powerful tool for atmospheric aerosol profiling as it resolves the aerosol vertical distribution of an atmospheric column. It produces a color plot that is a relation between the aerosol altitude and its scattering ratio. These color plots can be treated as images with high intensities referring to high scattering ratios and low intensities referring to low scattering ratios. Usually, these plots split into different colored horizontal layers. Some of these layers may have uniform color pattern and sometimes they may contain many mixed colors and appear as a random dot patterns that makes their classification a challenging problem. In this paper, we are stressing on the clustering of these plots and classifying them into high, moderate and low scattering ratios regions. In that sense, we revisited some of the unsupervised clustering and classification techniques such Bayesian models as in mixture models and fuzzy techniques and evaluate their performance on this type of data. In addition, we propose a new clustering technique to work efficiently on this type of images and compare its results against these regular techniques. Furthermore, we do similarity analysis between different aerosols profiles captured at different days and at different times with different climate conditions to evaluate their information content. Based on these results, we can describe the aerosol existence structure in addition to finding linkage between these different profiles that leads to understanding of the aerosols behavior in the atmospheric layers.

8718-27, Session 4

A multimodal image reconstruction method using ultrasonic waves and electrical impedance tomography

Mahmoud Meribout, The Petroleum Institute (United Arab Emirates)

In this paper, a new method that improves the image obtained by an array of ultrasonic sensors using electrical impedance tomography (EIT) is presented. One of its target applications can be in automatic exploration of soft tissues, where different organs and eventual anomalies exhibit simultaneously different electrical conductivities and different acoustic impedances. The exclusive usage of the EIT technique usually leads to some significant uncertainties around the interior inclusions' boundaries and usually generates images with relatively low resolutions. The proposed method shows that by properly combining this technique with an ultrasonic-based method, which can provide good localization of some edge points, the accuracy of the shape of the internal inclusions can be improved. The performance of the proposed reconstruction method was assessed by conducting extensive tests on some simulated phantoms which mimic soft tissues. The obtained results clearly show the performance of this method over single modalities techniques that use either ultrasound or EIT imaging.

8718-17, Session 5

Polarized imaging nephelometer for field and aircraft measurements of aerosol phase function

Gergely Dolgos, Jose V. Martins, The Univ. of Maryland, Baltimore County (United States); Andreas J. Beyersdorf, NASA Langley Research Ctr. (United States); Jan D. Cieslak, Reed W. Espinosa, The Univ. of Maryland, Baltimore County (United States); Johnathan W. Hair, NASA Langley Research Ctr. (United States); Eric Meyer, Haotian Sun, Bryant Szelistowski, The Univ. of Maryland, Baltimore County (United States); Luke D. Ziemba, NASA Langley Research Ctr. (United States)

Aerosols have a significant impact on the radiative balance and water cycle of our planet through scattering and absorbing solar light. Remote sensing of aerosols relies on scattering phase matrix information to retrieve aerosol properties with frequent global coverage. At the Laboratory for Aerosols, Clouds and Optics (LACO) at the University of Maryland, Baltimore County we developed a new technique to directly measure the aerosol phase function and the degree of linear polarization of the scattered light (two elements of the phase matrix). We designed and built a portable instrument called the Polarized Imaging Nephelometer (PI-Neph). The PI-Neph successfully participated in dozens of flights of the NASA Development and Evaluation of satellite ValidatiOn Tools by Experimenters (DEVOTE) project and the Deep Convective Clouds and Chemistry (DC3) mission. The ambient aerosol enters the PI-Neph through an inlet and the sample is illuminated by laser light (wavelength of 532 nm); the scattered light is imaged by a stationary wide field of view camera in the maximum scattering angle range of 2 degrees to 178 degrees. The phase function data was validated by comparison to Mie scattering by polystyrene spheres. Measurements of ambient phase function and the AERONET (AErosol Robotic NETwork) retrievals have been compared in cases when the aircraft spiraled over AERONET sites. The flight data showed good agreement between the PI-Neph measurements of volume scattering coefficient and the parallel TSI integrating nephelometer measurements. Further analysis of the DEVOTE and DC3 flight data is underway.

8718-18, Session 5

H2S sensing characteristics of Au: Fe2O3 thin films deposited using electron beam evaporation method

Vishal Baloria, Guru Nanak Dev Univ. (India); Niranjan S. Ramgir, Ajay Singh, Anil K. Debnath, Bhabha Atomic Research Ctr. (India); Aman Mahajan, Ratish K. Bedi, Guru Nanak Dev Univ. (India); Dinesh K. Aswal, Shiv K. Gupta, Bhabha Atomic Research Ctr. (India)

α-Fe2O3, an intrinsically n-type semiconductor has been widely exploited as a gas sensitive material. In order to improve the sensing performance it is often being modified with noble metals such as Au, Pt and Pd. H2S is a colorless, highly flammable and toxic gas. As the lower exposure limit (LEL) for H2S is 10 ppm, there is a need for its detection in either ppm or sub ppm level. In the present work, an improved H2S sensor based on Au modified Fe2O3 thin film has been demonstrated.

Fe2O3 thin films were prepared in two steps. Fe film was first deposited by electron-beam evaporation and subsequently subjected to thermal oxidation at 800°C/ 2 h under oxygen flow of 50 sccm. Au modification was achieved by RF sputtering under 30 W power and duration of 30, 60 and 90 s corresponding to Au incorporation of 1.2, 2.33 and 3.7 at. %, respectively. Both pure and Au incorporated films were found to be selective towards H2S. Au incorporation (Au: 2.33 at. %) resulted not only in increasing the base conductance but also enhancing the sensor response towards H2S (~540% [(G/Ga) * 100] towards 10 ppm, response time ~90 s) with maximum at 250°C. Sensor response was linear in the concentration range of 1–50 ppm. Au is known to impart the sensitivity to the host material as per the electronic sensitization mechanism. Wherein it not only increases the adsorption of test gases but also facilitates the interaction with the sensor surface.

8718-19, Session 5

Ambient detection of CH4 and N2O by Quantum Cascade Laser

Paulo C. Castillo, Ihor Sydoryk, Barry M. Gross, Fred Moshary, The City College of New York (United States)

A Quantum Cascade Lasers (QCL's) [1] have been successfully used for sensing of atmospheric pollutants in the mid-infrared (mid-IR) region. In this paper we report both laboratory and field measurements/results for ambient simultaneous detection of green house gases (GHG), Methane and Nitrous Oxide performed by tunable direct diode absorption

spectroscopy (TDLAS). CH4 and N2O are long-lived greenhouse gases in the atmosphere with significant global warming effects [2].

Gas spectra were recorded by tuning of the quantum cascade laser wavelength over 1298 - 1300cm-1 spectral window. To achieve ultrafast wavelength sweeping, a thermal down chirp technique [3] is used.

Based on careful optimization of the spectral window for absorption features of CH4 and N2O as well as interfering gases, a dual-species, cost-effective, robust and rapid response open-path laser based monitor has been developed for ambient trace gas monitoring.

SNR /link budget analysis of our laser pulse detection approach obtained over different ranges as well as limits of detection (LOD) will be presented. Special focus will be on the stability of the laser spectra and wavelength tuning. Finally, a demonstration of the open path system over a 200 meter range will be reported and compared to link budget analysis.

References:

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[3] E. Normand, M. McCulloch, G. Duxbury, and N. Langford, “Fast, real-time spectrometer based on a pulsed quantum-cascade laser”, Opt. let. 28, pp. 16-18, 2003.

8718-20, Session 5

Recent progress in extended-length fiber optic carbon dioxide monitoring

Robert A. Lieberman, Jesus Delgado-Alonso, Intelligent Optical Systems, Inc. (United States)

No Abstract Available.

8718-21, Session 6

Comparative analysis of alternative spectral bands of CO2 and O2 for the sensing of CO2 mixing ratios

Denis V. Pliutau, Narasimha S. Prasad, NASA Langley Research Ctr. (United States)

We performed comparative studies to establish favorable spectral regions and measurement wavelength combinations in alternative bands of CO2 and O2, for the sensing of CO2 mixing ratios (XCO2) in missions such as ASCENDS. The analysis employed several simulation approaches including separate layers calculations based on pre-analyzed atmospheric data from the modern-era retrospective analysis for research and applications (MERRA), and the line-by-line radiative transfer model (LBLRTM) to obtain achievable accuracy estimates as a function of altitude and for the total path over an annual span of variations in atmospheric parameters. Separate layer error estimates also allowed investigation of the uncertainties in the weighting functions at varying altitudes and atmospheric conditions. The parameters influencing the measurement accuracy were analyzed independently and included temperature sensitivity, water vapor interferences, selection of favorable weighting functions, excitations wavelength stabilities and other factors. The results were used to identify favorable spectral regions and combinations of on / off line wavelengths leading to reductions in interferences and the improved total accuracy.

8718-22, Session 6

Studies on sensitive Raman gas detectors

Duluo Zuo, Yongyue Xu, Xingbing Wang, Huazhong Univ. of Science and Technology (China); Youhui Xiong, Wuhan Cubic Optoelectronics Co., Ltd. (China)

Gas analysis is an important tool in industrial process control and environmental monitoring, in which laser Raman spectroscopy gets more and more attentions due to its wide suitability. In this paper, the recent studies on the signal enhancement of laser Raman scattering for gas analysis will be reported.

The first work we will report is on the improvement of collection efficiency. A hollow fiber gas cell and a newly designed collector are tested separately. The pumping laser is a diode-pumped solid state laser with 50 mW output of 532 nm laser radiation. High sensitivity is obtained in the case of hollow fiber gas cell, usually signal of major consistent in air can be obtained in less that 1 sec. But strong background of scattering from the fiber wall constricts its application in detecting of minor consistent. In the case of newly designed parabolic collector, continuous background becomes much smaller, but still exists, it seems that high quality reflecting coating is a key factor to obtain high contrast signal.

The second work we will report is on the improvement of laser intensity. Intra-cavity Raman scattering of gases in a He-Ne lasers is studied. There’s no continuous background in the Raman scattering spectrum, and the rotational spectral structure of molecules can be recognized clearly after a little longer integration.

The last work we will report is on the shortening of laser wavelength. We are now building an experimental setup for Raman scattering of gases based on a home-made narrow-linewidth 405 nm diode laser. We believe that a robust, compact and sensitive gas sensor will be possible based on diode laser and cavity-enhancement technology.

8718-23, Session 6

Fast response cavity-enhanced ozone monitor

Anthony Gomez, Elias P. Rosen, Southwest Sciences, Inc. (United States)

Ozone is an important atmospheric gas due to its role in air quality and radiative forcing. Using an optically resonant cavity, sensitive and rapid monitoring of ambient ozone is achieved in a compact platform using relatively inexpensive components. Based on Incoherent Broadband Cavity Enhanced Absorption Spectroscopy (IBB-CEAS), the device utilizes an optical cavity of just 14.5 cm and moderately high reflectivity mirrors (R = 99.3%). Performance of the instrument has been compared to direct absorption measurements in a single-pass measurement cell. Currently, the IBB-CEAS ozone instrument can achieve 1 ppb sensitivities at 0.1 s integration time with a dynamic range over four orders of magnitude, accessing relevant ozone concentrations in both the stratosphere and troposphere. This technology will enable improved ozone mapping by airborne platforms.

8718-24, Session 6

Relaxation of photoconductivity in porous silicon for gas sensing

Liubomyr S. Monastyrsky, Ivan Franko National Univ. of L’viv (Ukraine)

One of urgent today’s problem is control of toxic and other harmful substances in air atmosphere, drinking-water, foods of feed and others. In this connection there is a necessity for development of microelectronic systems of detection of gases for industrial, office and housing apartments which can be components of integral systems of protection of human’s life and health. Of special interest is the sensors based on nanoporous semiconductors, in particular porous silicon. Optical sensers of such type are described in a number of papers . Among such sensors one can distinguish the structures from porous silicon, based on the change of photoconductivity and its kinetics under the action of different gas environments which can be used as effective gas analyzers.

For designing such sensors it is necessary to know dependences of photoconductivity of porous silicon on the state of surface, depending on a gas environment which it is in, as well as on the degree of porosity of a material and geometry of pores.

Adsorption of gas molecules results in rising the surface recombination velocity of photocarriers at the expense of increasing the capture of charge carriers on the trap energy levels created by adatoms, as well as the change of structure “dangling bond” Si - Si bonds . Change of amount of trap centers was observed at adsorption of a number of gases : N, NO2, Cl2, Br2J2, and others.

The model of relaxation of photoconductivity of porous silicon, in which recombination of photocarriers is taken into account on the surface of spherical pores at the shutdown of illumination, is presented and numerically investigated. By the finite element method it is calculated time evolution of the photoconductivity of porous silicon and dependence of the relaxation time of photoconductivity on the surface recombination velocity, which is determined by a concentration and nature of adsorbed gas, as well as on the radius of pores and avarage distance between them

8718-25, Session 6

Miniature and non-invasive multiparameter integrated optic respiratory monitor (ResHealth™) device

Edgar A. Mendoza, Yan Esterkin, Connie Kempen, Sonjian Sun, Redondo Optics, Inc. (United States)

Periodic breathing disorders associated with hypoxemia in infants suffering from apnea or at risk of sudden infant death syndrome (SIDS) can become life threatening in a few minutes. According to the American Hospital Association non-invasive continuous monitoring of breathing activity in infant and children patients suffering with respiratory breathing disorders is critical, and appropriate breathing monitoring equipment could be life saving. Our strategy in addressing this need is to develop and provide a new, unintrusive, multi-parameter integrated optic respiratory breathing monitor (ResHealth™) device to continuously monitor, with near-zero false alarms, the inspiratory and expiratory breathing activity of infants and children suffering from SIDS and apnea in high risk, life threatening, clinical conditions. The ResHealth™ device is based on the use of a miniature optical sensor microchip that incorporates an array of self-referenced, accurate, and highly reliable, fluorimetric breathing gas sensors for the real time measurement of oxygen, carbon dioxide, and humidity gas concentration, as well as exhaled and inhaled gas temperature in nasal, oral, or oro-nasal breathing activity, all integrated in a miniature disposable microchip. The miniature sensor microchip is placed unintrusively in close proximity to the nose or mouth of the infant or child patient.

8719-1, Session 1

Fitness approach for inferring intent in markerless mutated genomes

Dontcho V. Jelev, Mia Hunt, Anna Le, Christopher Dupuis, Suelynn Ren, U.S. Army Research Lab. (United States); Henry S. Gibbons, U.S. Army Edgewood Chemical Biological Ctr. (United States)

Whole genome profiling is a benchmark for new strain identification and determining intent in forensic genomics. However, whole genome profiling alone often reveals more mutations than are easily assigned to a specific phenotype. The utility of this approach is further challenged by the emergence of markerless recombineering techniques. There is a need for developing alternative approaches for characterizing minimally engineered genomes. We argue that wild type bacterial strains are optimally adapted to their natural environments and the introduction of phenotype enhancing mutations is likely to adversely affect strain fitness. We use strains from a recently sequenced collection of Bacillus atrophaeus var. globigii (BG) strains which reveals clear evolutionary trajectory beginning with an archival 1942 culture from the University of Wisconsin and proceeding through Camp Detrick and several other military laboratories into modern day strains (Gibbons et al., 2011, PLoS ONE 6:e17836). Mutation of metabolic genes in strain Detrick-1 appeared to precede the emergence of a hypersporulating mutant Detrick-2 (Spo0F H101R), variants of which have been utilized as anthrax simulants since the 1940's. We show that the culturing of wild type BG strains in corn steep liquor (CSL) during 1940's has resulted in the emergence of strain Detrick-1; adapted for growth in the presence of lactic acid. This adaptation impairs the strain fitness in media lacking lactic acid. Similarly, the acquiring of sporulation-enhancing mutation in Spo0F has resulted in impairment of strain fitness. Based on these findings we propose a four stage fitness approach for inferring intent in markerless engineered genomes.

8719-2, Session 1

Developing a cell-based sensor for the detection of Autoinducer-2

Matthew D. Servinsky, Patrick C. Allen, U.S. Army Research Lab. (United States); Chen-Yu Tsao, The Univ. of Maryland, College Park (United States); Christopher M. Byrd, Christian J. Sund, U.S. Army Research Lab. (United States); William E. Bentley, The Univ. of Maryland, College Park (United States); Katherine Germane, U.S. Army Research Lab. (United States)

Bacteria are now known to utilize an intricate communication system for sensing and interpreting environmental cues that coordinate population-based behavior. Quorum sensing is one of these systems, and it involves the production, release, and detection of small chemical signaling molecules. Recent research has revealed the role of these quorum sensing molecules in control of microbial activities such as biofilm formation. In this presentation, we outline the development of an enhanced E. coli cell based sensor for detection of the quorum sensing molecule Autoinducer-2 (AI-2) as well as engineering strategies to remove sugar and anoxic inhibition of the sensor.

8719-3, Session 1

Quantum dot FRET-based rapid detection of biological pathogens

Christopher Anton, Episensors, Inc. (United States)

The ability to detect the presence of a biological specimen in air, water, solid surfaces and food is of critical importance. In order to address these needs, a biological detection platform based on a novel quantum dot (QD) fluorescent resonant energy transfer (FRET) technology has been developed. A variety of surface functionalizations are applied to the nanoscale QDs to create colloidal sensing elements. These elements link the QDs to the quencher molecules and are selected based upon the target organism, with monoclonal antibodies being most commonly used due to their high specificity and binding affinity. Quencher molecules are bound to the sensing elements in order to greatly reduce the initial optical output of the QDs under ultraviolet excitation. When the sensing elements are exposed to the pathogens of interest, the quencher molecules are displaced by live pathogens and an increase in fluorescence is observed. A variety of experimental results will be presented, ranging from bench-top studies demonstrating the capabilities of the QD FRET technology, to field tests of a fully-integrated prototype sensor system capable of simultaneously collecting, detecting, and identifying biological pathogens. Through these experiments, a rapid (2-5 minute assay time), sensitive (102 CFUs/ml), and versatile (multiplexed detection of up to 8 pathogens simultaneously) detection system has been demonstrated.

8719-4, Session 1

Zinc oxide nanorod platforms in highly sensitive biodetection *(Invited Paper)*

Jong-in Hahm, Georgetown Univ. (United States)

The talk pertains to high sensitivity biodetection enabled by the exquisite optical property of well-controlled zinc oxide nanorods that are assembled into arrays directly after their CVD synthesis. Many different biosystems including cytokines, helicase, telomerase, and B. anthracis are used to demonstrate such ability of our zinc oxide nanorod platforms. The efforts will be highly beneficial for large population screening, early biomarker studies and biosecurity-related detection.

8719-5, Session 1

Surface functionalization for sensitive detection of glucose in complex medium using SERS

Fang Sun, Shaoyi Jiang, Qiuming Yu, The Univ. of Washington (United States)

Surface-enhanced Raman scattering (SERS) spectroscopy has emerged as a powerful analytical and sensing tool for use in biomedical diagnostics. However, protein fouling is a major issue for SERS detection under physiological condition. Fouling could cover the entire sensing surface preventing the analytes from diffusion to the sensing surface, resulting in significantly reduced sensitivity. Here, we report several new approaches to modify the SERS sensing surface to allow specific binding of glucose and in the meantime to reduce fouling. It is known that glucose binds to boronic acid. Molecules with phenylboronic acid were immobilized on SERS surfaces. The binding of glucose induces the change of vibrational peaks of benzene ring providing a sensitive detection of glucose. We demonstrated the detection of glucose in the physiological care range not only in buffer but more importantly in

serum and plasma. We used quasi-3D plasmonic nanostructure arrays developed in our group as SERS-active substrates. The nanostructures were designed and optimized using finite-difference time-domain (FDTD) simulations and fabricated in PDMS using soft lithography for low cost mass production of SERS chips. Furthermore, the SERS nanopatterns were made in microfluidic systems to allow in-situ dynamic detections.

8719-6, Session 2

Biological engineering approaches for cellular and biomolecular detection and sensing *(Invited Paper)*

D. Marshall Porterfield, NASA Headquarters (United States) and Purdue Univ. (United States)

Sensor technologies have broad applications and benefit from broad interdisciplinary approaches for sensor technology development are also important in drawing upon various technologies in the development of new sensing and detection systems. The Physiological Sensing Facility in Purdue University's Discovery Park is a collaborative core facility, organized and physically housed in order to bridge the resources of the Birck Nanotechnology Center, and the Bindley Bioscience Center. Ongoing work does integrate the fundamental sciences with engineering to create the tools and technologies for discovery across the life sciences. Research includes advanced sensing and biosensing technology based on nanomaterial development, bioMEMS and lab-on-a-chip systems, optrodics, and self-referencing microsensor technology. These technologies are engineered in the context of hypothesis driven science to facilitate physiology, the study of form and function, for agriculture, the environment, biomedical, and space science applications. Inspiration is from biology to engineering for new technology, but also from engineering for biology to advance interdisciplinary development. These new technologies have been developed and used for in many innovative scientific studies. The knowledge gained in the application of these new sensor technologies has advanced basic biological sciences, but also strengthens interdisciplinary ties for future engineering advances.

8719-7, Session 3

Optical fiber nanotips coated with molecular beacons for mRNA detection in cells

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Molecular beacons (MB) are single-stranded DNA molecules that possess a stem-and-loop structure. The loop portion of the molecule can form a double-stranded DNA in the presence of a complementary sequence. A MB is labeled with a fluorophore and a quencher on the two ends of the stem. The stem keeps these two moieties in close proximity to each other, causing the fluorescence of the fluorophore to be quenched by energy transfer. The fluorophore fluorescence is restored when the MB hybridizes to the target sequence. In this paper we present a molecular beacon used as bioreceptor for mRNA detection immobilized at the distal end of a tapered fiber. The attention was focused on the mRNA for survivin, a protein highly expressed in most types of cancer. Survivin-MB was characterized by hybridization studies with a complementary sequence to prove its functionality both free in solution and once immobilized onto the fiber tip. The nanotips were fabricated by chemical etching, starting from 500 micron diameter multimode optical fiber and tapering it down to about 100 nm at the tip. Next, the MB was attached to the nanotips via covalent binding and the fluorescence of the MB fluorophore was externally collected after direct excitation through the optical fiber ending with the tip. The MB coated nanotips are proposed as innovative tool for entering the cytoplasm of living cells, and directly measure the intracellular RNA.

8719-9, Session 3

Biodiscovery of aluminum binding peptides

Bryn L. Adams, Deborah A. Sarkes, Amethist S. Finch, Margaret M. Hurley, Dimitra N. Stratis-Cullum, U.S. Army Research Lab. (United States)

Cell surface peptide display systems are large and diverse libraries of peptides (7-15 amino acids) which are presented by a display scaffold hosted by a phage (virus), bacteria, or yeast cell. This allows the self-sustaining peptide libraries to be rapidly screened for high affinity binders to a given target of interest, and those binders quickly identified. Peptide display systems have traditionally been utilized in conjunction with organic-based targets, such as protein toxins or carbon nanotubes. However, this technology has been expanded for use with inorganic targets, such as metals, for biofabrication, hybrid material assembly and corrosion prevention. While most current peptide display systems employ viruses to host the display scaffold, we have recently shown that a bacterial host, Escherichia coli, displaying peptides in the ubiquitous, membrane protein scaffold eCPX can also provide specific peptide binders to an organic target. We have, for the first time, extended the use of this bacterial peptide display system for the biodiscovery of aluminum binding 15-mer peptides. We will present the process of biopanning with macroscopic inorganic targets, binder enrichment, and binder isolation and discovery. A modeling approach will also be present to explore the interaction of the peptides with aluminum surface target.

8719-10, Session 3

XPairIt: novel toolkit design for smart reagent development

Margaret M. Hurley, Michael S. Sellers, U.S. Army Research Lab. (United States)

The development of smart peptide binders requires an understanding of the fundamental mechanisms of recognition which has remained an elusive grail of the research community for decades. Recent advances in automated discovery and synthetic library science show great promise for the development of recognition elements with improved stability, affinity and specificity. In addition, these advances provide a wealth of information to probe these fundamental details and develop improved models for a priori prediction of affinity and specificity. Here we present the modeling portion of an iterative experimental/computational study to produce high affinity peptide binders to the Protective Antigen (PA) of Bacillus anthracis. The result is a general usage, HPC-oriented, python-based toolkit based upon powerful third-party freeware, which is designed to provide a better understanding of peptide-protein interactions and ultimately predict and measure new smart peptide binder candidates.

8719-11, Session 3

Modeling of CdZnTe single crystals growth for detectors and sensors *(Invited Paper)*

Liliana Braescu, Institut National de la Recherche Scientifique (Canada) and West Univ. of Timisoara (Romania)

CdZnTe is a promising semiconductor material for its potential as a room temperature X-ray and γ-ray detection medium. The industrial applications require high structural quality and homogeneous single crystals with a very low dislocation density, no grains nor twins. These improvements are facilitated by dewetting phenomenon in which the crystal is grown detached from the ampoule wall by a liquid free surface at the level of the solid-liquid interface, called liquid meniscus, which creates a gap between the grown crystal and the ampoule wall.

Toward the goal of obtaining a more complete understanding of dewetting phenomenon, computational models of crystal growth processes are developed and applied. For evaluating numerically the effect of the menisci shapes on the Zn distribution in CdZnTe crystals grown by dewetted Bridgman technique using a pyrolitic boron nitride (pBN)-coated quartz ampoule, a pseudo quasi-steady state model is considered in the framework of a 2D axisymmetric geometry containing two types of stable menisci: (i) a "S" shape meniscus that correspond to the sum-of-the-angles criterion α_e+θ_c<180° (α_e is growth angle and ?_c is wetting angle); (ii) a globally convex meniscus that correspond to chemical contamination, i.e., α_e+θ_c>180°. Numerical computations including incompressible fluid flow in the Boussinesq approximation, heat and mass transfer, and Marangoni effect, prove that a convex meniscus assures the best Zn distribution.

8719-12, Session 4

From microfluidic modules to an integrated Lab-on-a-Chip system for the detection of Francisella tularensis

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Lab-on-a-chip (LoC) systems translating the whole process of pathogen analysis to an integrated, miniaturized, and automatically functioning microfluidic platform are generally expected to be very promising future diagnostic approaches. The development of such a LoC system for the detection of bacterial pathogens applied to the example pathogen Francisella tularensis is described in this report. To allow functional testing of the whole process cascade before final device integration, various bio-analytical steps such as cell lysis, DNA extraction and purification, continuous-flow PCR and analyte detection have been adapted to unique functional microfluidic modules. As a successive step, positively tested modules for pathogen detection have been successfully assembled to an integrated chip. Moreover, technical solutions for a smooth interaction between sample input from the outer world as well as microfluidic chip and chip driving instrument have been developed. In conclusion, a full repertoire of analytical tools have been developed and successfully tested in the concerted manner of a functionally integrated microfluidic device representing a tool for future diagnostic approaches.

8719-13, Session 4

Effect of surface structuring onto the efficiency of the in- and out-coupling of light from a chip in Lab-on-a-chip approaches with optical detection

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Optical detection methods have been implemented on chips with micro-fluidic channels or cavities in different geometries e.g. for colorimetry or fluorescence measurements with excitation in the chip plane [1-2]. The most prominent problem of the read-out from a chip is the limitation of the optical yield. Without e.g. an immersion liquid for compensation of the total reflection on the boundary, only about 12-13% of rays cross over the boundary from a mostly polymer chip to air. One of the efficient methods to increase the optical yield from a chip is a ray reorientation inside the chip using an additional surface structuring creating new refraction boundaries before leaving the chip. The use of 45°-tilted mirror arrangements for in- and out-coupling of the fluorescence signal from a micro-fluidic chip and approaching of this principle for realization of low-cost fluorescence detection unit have been recently published [3].

Our report here includes the investigation of the effect of different tilt angles of total reflection and metallized-surface mirrors for a volume emitted analyte using the ray-tracing simulation tool OptiCAD10. Furthermore, an estimation of the influence on the out-coupling efficiency of a surface-emitted signal for different geometries of metallized walls of the detection cell with or without a combination with external lenses will be presented. The best result - 10-fould out-coupling efficiency increase – was achieved for a combination of a structured and metallized detection cell with an external short-focus lens.

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[3] T. Mairal, I. Frese, E. Llaudet, C. Bermudo Redondo, I. Katakis, F. von Germar, K. Drese, C. O'Sullivan, LAB on a Chip(2009)9, 3535-3542, DOI:10.1039/b914635k

8719-14, Session 4

Purification of Bacillus thuringiensis DNA with polymer-based, microfluidic lab-on-a-chip systems

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We present results obtained in the course of the development of lab-on-a-chip systems to be applied for the detection of bacterial B-agents using Bacillus (B.) thuringiensis as simulant for B. anthracis that can be handled outside BSL-3 laboratory conditions.

To enable reliable detection purification of the sample matrix is usually required. Methods for chip-based sample preparation of select pathogens using magnetic beads with special surface modifications were established and evaluated in comparison to commercial routine methods. Quantification of DNA yield was achieved using real-time PCR assays with TaqMan probes targeting the cryT gene.

The assays were optimized regarding sample and elution volume as well as bead quantity. Methods for cell lysis and sample concentration on chip were also tested. PCR assays with two-step protocols and uniform temperature and time settings were chosen in order to allow simultaneous detection.

Lab-on-a-chip systems are intended for point-of-care analysis and provide several advantages in comparison to conventional diagnostic techniques. Analysis can be faster, purification of DNA and PCR analysis can be integrated and the instrumentation can be miniaturized. Therefore, such tests can be useful in medical and veterinary diagnostics.

8719-15, Session 4

Microchannel impedance for quasi Newtonian fluids with spatial modulated viscosity

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Using the Navier-Stokes equation and assuming a viscosity radially modulated for a quasi-Newtonian fluid, we obtain the impedance of a fluid through microchannels and their corresponding electrical analogs. To solve the Navier Stokes equation will use the Laplace transform, the Bromwich integral, the residue theorem and Bessel functions. This will give a formula for the impedance in terms of Bessel functions and from these equations to be constructed equivalent electrical circuits. These solutions correspond to the case of quasi-Newtonian fluid it is to say a fluid that does not stagnate in the channel wall as is the case if the fluid is Newtonian. The formulas obtained may have applications in the general theory of microfluidics and microscopic systems design for drug delivery.

8719-16, Session 4

Cylindrical matrix device with a circular release area with inhomogeneous diffusivity *(Invited Paper)*

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Cylindrical Matrix Device with a Circular Release Area with Inhomogeneous Diffusivity.

A cylindrical matrix device with a circular release area with inhomogeneous diffusivity was analyzed using a Laplace transform–based method, using Bromwich integral and residue theorem. The two-dimensional model represented a pharmaceutical agent uniformly distributed in a polymeric matrix with a diffusivity spatially modulated, surrounded by an impermeable layer. The pharmaceutical agent could be transferred only through a small hole centered at the top surface of the cylinder. A closed-form solution was obtained in terms of Bessel functions with the aim to help study the effects of design parameters and geometries on the cumulative amount of pharmaceutical agent released. The cumulative flux of pharmaceutical agent increased with the mass transfer and diffusion coefficients and decreased with any increment in the device's length and variations of the diffusivity coefficients. The delivery rate was described by an effective time constant calculated from Laplace transforms and using Bessel functions and their zeros. Reducing the orifice diameter or fabricating a longer system would delay transport of the medication. Simplified expressions for the release profile and the time constant were derived for special design cases.

8719-17, Session 5

Lignin and silicate based hydrogels for biosensor applications

Stephanie L. Burrs, Suguna Jairam, Diana C. Vanegas, Zhaohui Tong, Eric S. McLamore, The Univ. of Florida (United States)

Immobilization of biorecognition elements on nanomaterial platforms is an efficient technique for developing high fidelity biosensors. Advances in biocompatible materials and electrocatalytic nanomaterials have extended and enhanced the field of biosensors by allowing development of nanomaterial platforms. While single layer (i.e., Langmuir–Blodgett) films and ordered nanomaterial platforms are highly efficient, fabrication is often expensive and time consuming. In addition, application of some of these devices in complex solutions can be subject to surface fouling and signal error. Thus, there is a need for facile biosensor nanomaterial platforms which can be developed in laboratories (i.e., outside class rooms). In recent years high purity nanomaterials are widely available, and high performance biomaterials are being developed from waste products. In this research, we develop high fidelity nanomaterial platforms for developing electrochemical biosensors using sustainable biomaterials and user-friendly deposition techniques. Catalytic nanomaterial platforms are developed using a combination of self assembled monolayer chemistry, electrodeposition, and pulsed electrosonication. High performance biomaterials (e.g., nanolignin) are recovered from paper pulp waste. These facile techniques have been used to develop electrochemical biosensors to study physiological transport in biomedical, agricultural, and environmental applications.

8719-18, Session 5

Compatibly interfacing electrochemical sensors with biology

Lauren Schoukroun, Samiullah Wagan, Ryan J. White, The Univ. of Maryland, Baltimore County (United States)

Biosensors have the potential to revolutionize how we study living systems and provide detailed information about the molecular basis of organism function. This new information can lead to new paradigms in biology and the life sciences. Unfortunately, while examples of new biosensor platforms continue to grow, two major barriers impede utilization of devices outside the controlled laboratory setting: 1) Sensors fail to respond when challenged in complicated biological sample matrices due to "biofouling," which masks the true biological response of interest, and/or 2) The sensor perturbs the environment and thereby elicits an unnatural response by the biological system being studied. New biosensor designs are thus needed to enable proper interfacing with the biological environment. Herein, a new general sensing interface that couples the sensitive, specific and selective detection properties of electrochemical, aptamer-based (E-AB) sensors with the biocompatibility of hydrogel membranes is introduced. By employing this multidisciplinary approach we are able to obtain stable, quantitative measurements of small molecule targets directly in complex sample matrices including undiluted serum. Specifically, by encapsulating an electrochemical, aptamer-based sensor for the specific detection of aminoglycoside antibiotics with polyacrylamide hydrogel membranes, we achieve quantitative and reliable detection of the small molecule directly in unadulterated serum while mitigating sensor biofouling from serum proteins. Furthermore, we explore the effects of hydrogel properties including mesh size and membrane thickness on analytical sensor performance.

8719-19, Session 5

Utilizing metalized fabrics for liquid and rip detection and localization

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This paper proposes a novel technique for utilizing conductive textiles as a distributed sensor for detecting and localizing liquids (e.g., blood), rips (e.g., bullet holes), and potentially biosignals. The proposed technique is verified through both simulation and experimental measurements. Circuit theory is utilized to depict conductive fabric as a bounded, near-infinite grid of resistors. Solutions to the well-known infinite resistance grid problem are used to confirm the accuracy and validity of this modeling approach. Simulations allow for discontinuities to be placed within the resistor matrix to illustrate the effects of bullet holes within the fabric. A real-time experimental system was developed that uses a multiplexed Wheatstone bridge approach to reconstruct the resistor grid across the conductive fabric and detect liquids and rips. The resistor grid model is validated through a comparison of simulated and experimental results. Results suggest accuracy proportional to the electrode spacing in determining the presence and location of discontinuities in conductive fabric samples. Future work is focused on refining the experimental system to provide more accuracy in detecting and localizing events as well as developing a complete prototype that can be deployed for field testing. Potential applications include intelligent clothing, flexible, lightweight sensing systems, and combat wound detection.

8719-20, Session 5

Noninvasive mechanical properties estimation of embedded objects using tactile imaging sensor

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Non-invasive mechanical properties estimation of an embedded object can be used in medicine for characterization between malignant and benign lesions. We developed a tactile imaging sensor which consists of a flexible and transparent sensing probe, light sources, and a camera. Here we investigate the capability of a non-invasive optical tactile imaging sensor to differentiate malignant and benign tumors through elasticity. Studies show that stiffness of tumor is a key physiological discerning parameter for malignancy. As our sensor compresses the tumor from the surface, the sensing probe deforms, and the light scatters. This forms the tactile image. Using the features of the image, we can estimate the mechanical properties such as size, depth, and elasticity of the embedded object. To test the performance of the method, a phantom study was performed. Silicone rubber balls were used as embedded objects inside the tissue mimicking substrate made of Polydimethylsiloxane. The average relative errors for size, depth, and elasticity were found to be 67.5%, 48.2%, and 69.1%, respectively. To test the feasibility of the sensor in estimating the elasticity of tumor, a pilot clinical study was conducted on six breast cancer patients. The estimated elasticity was correlated with the biopsy results. Out of six tumors, three were malignant. Preliminary results show that the sensitivity of 67% and the specificity of 67%. Results from the clinical study suggest that the tactile imaging sensor may be used as a tumor malignancy characterization tool.

8719-21, Session 5

Ambulatory EEG neuromonitor platform for engagement studies of children with development delays

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Engagement monitoring is crucial in many biomedical diagnostics applications such as evaluation of teaching strategies for children with developmental delays including autism spectrum disorder, attention-deficit hyperactivity disorder, or cerebral palsy; as it is challenging for the instructors to gauge responses of these children to determine the effectiveness of the teaching strategies. This paper presents an ambulatory EEG neuromonitor platform to study such brain activities. In comparison to commercial EEG system, the developed miniature (size: 1.4" x 2.2" x 0.7", weight: ≤150gm) and low-power (active mode: <18 mA, sleep mode :<100 μA) EEG module can have 1 or 2 channels with flexible leads to record activities of the subject and can be embedded within a headband or a visor. The signals from the electrodes at the frontal lobe are amplified with a low-power instrumentation amplifier, then a 4th-order low-pass Chebyshev-I filter (fc = 80Hz) followed by a notch filter (fc = 60Hz) are used for signal conditioning. A PSoC ADC (16-bit, 256 Hz) samples this filtered signal and transmits it through a Class-2 Bluetooth transceiver to a PC or a handheld device for real-time analysis. This battery-powered device (~40 hours runtime) will be used to monitor the engagement of children with developmental delays in classroom settings, to study the effectiveness of various teaching strategies towards the development of personalized instruction plans. The ambulatory EEG neuromonitor platform offers its applications for many biomedical diagnostics studies in real-life settings of brain engagements or disorders such as epilepsy and post-traumatic stress disorder.

8719-22, Session 5

Remote sensing of heart rate using millimeter-wave interferometry and probabilistic interpolation

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Using a 94-GHz homodyne interferometer employing a highly-directional quasi-optical lens antenna aimed at a human subject's chest, we can measure chest wall displacement from up to 10m away and through common clothing. Within the chest displacement signal are motions due to cardiac activity, respiration, and gross body movement. Our goal is to find the heart rate of the subject being monitored, which implies isolation of the minute movements due to cardiac activity from the much larger movements due to respiration and body movement. To accomplish this, we first find a subset of the true heartbeat temporal locations (called "confident" heartbeats) in the displacement signal using a multi-resolution wavelet approach, utilizing Symlet wavelets. Although the chest displacement due to cardiac activity is orders of magnitude smaller than that due to respiration and body movement, wavelets find those heartbeat locations due to several useful properties, such as shape matching, high-pass filtering, and vanishing moments. Using the assumption that the "confident" heartbeats are randomly selected from the set of all heartbeats, we are able to find the maximum likelihood statistics of an inverse Gaussian probability distribution modeling the inter-heartbeat times. We then analyze each interval between "confident" heartbeats and decide how many interpolated heartbeats belong in that interval based on the inverse Gaussian distribution we calculated earlier. The union of the "confident" set and the interpolated set forms a very close approximation to the true heartbeat temporal location set, and thus allows us to accurately calculate a heart rate.

8719-23, Session 6

Non-invasive microsensors for studying cell/ tissue physiology

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Self-referencing (SR) is a microsensor modality designed to quantify biophysical flux. This technique uses phase sensitive detection through amplification of differential concentration signals to "self-correct" for ambient drift and noise and increase spatial and temporal resolution. SR enhances the ability to measure the physiological activity of an organism, tissue, or cell while maintaining a high signal to noise ratio. The SR technique can be run with potentiometric, optical or amperometric sensors. SR is used to measure ions (e.g., Ca^{2+}, H^+, K^+, and Na^+), oxygen, electroactive molecules (e.g., nitric oxide, indole acetic acid) and biomolecules (glucose, glutamate, lactate). Incorporating new biocompatible materials preserves the fragile three dimensional structures of sensor biorecognition elements, improving selectivity and hysteresis. Furthermore, addition of catalytic nanomaterials (e.g., multi/ single walled carbon nanotubes, graphene oxide, and nanoplatinum) increases sensor sensitivity, response time and operating range.

SR sensors allow researchers to ask new hypothesis driven questions in a number of agricultural, biomedical, and environmental research problems. For example, SR sensors are being used to study the role of gravitropism and Ca^{2+} flux in Ceratopteris richardii, methyl-jasmonate induced proton flux in Arabidopsis thaliana guard cells, oxygen flux and stress signaling in plants (Glycine max L merrand Brassica Napus), methanol and acetic acid production in methanogenic biofilms for biofuel production, and xanthine and hypoxanthine flux from contaminated seafood. Non-invasive SR microsensors allow rapid determination of

temporally and spatially dynamic transport at the cell, tissue, organ, and organismal level.

8719-24, Session 6

A multiplexing fiber optic microsensor system for monitoring oxygen concentration in plants during simulated climate change

Prachee Chaturvedi, Bernie Hauser, Eric S. McLamore, The Univ. of Florida (United States); Eric Karplus, Science Wares, Inc. (United States); L. H. Allen, U.S. Dept. of Agriculture (United States); K. J. Boote, The Univ. of Florida (United States)

In biological systems, real-time measurement of oxygen levels and flux provides critical information for understanding the dynamics and physiology of this metabolite. Our research focus investigates the unknown effect of limited oxygen availability in plants due to climate change. Global atmospheric carbon dioxide levels and temperatures are predicted to increase rapidly in coming centuries. This may reduce oxygen availability in seed and reproductive structures, because higher temperature is expected to decrease oxygen solubility and increase metabolic demand for oxygen more than it increases oxygen molecular diffusivity. These changes are expected to adversely impact the reproductive processes and grain yield of seed-producing plants. For example, rising temperature decreases oxygen availability in soybean ovules, which in turn increases seed failure. To improve our understanding of the underlying physiological mechanism related to these adverse effects, we developed a multiplexing fiber optic microsensor system for monitoring oxygen concentration near or within different parts of plants, such as developing ovules, pollen grains and flowers. The fiber optic sensor tip diameters range in size from 0.1 mm to 800nm, and the sensors interface with a mechanical fiber multiplexer for multichannel monitoring. The detection system includes a frequency modulated LED for excitation (400nm), a B-390 filter to block longer wavelength emission, blue dichroic beamsplitter, and photomultiplier tube with O-56 filter and 10x objective. Sensor performance was enhanced by immobilizing titanium dioxide nanoparticles on the sensor surface. Selection of optical components may be easily optimized to improve sensitivity if desired, and real time flux of other biologically significant molecules in plant systems, such as calcium, pH, and nitric oxide is also possible. This versatile, mobile microsensor platform allowed us to measure real time oxygen concentration in up to ten different soybean flowers, ovules, or seed-pods under various temperature and oxygen concentration conditions.

8719-25, Session 6

Towards a modular, robust, and portable sensing platform for biological and point of care diagnostics

Amethist S. Finch, Justin R. Bickford, Marvin A. Conn, Matthew B. Coppock, Deborah A. Sarkes, Dimitra N. Stratis-Cullum, U.S. Army Research Lab. (United States)

The ability to conveniently and immediately test and diagnose in a diverse and rapidly changing environment is critical for field diagnostics. Smart biomedical sensors employ many different diagnostic/therapeutic methodologies; however, an ideal system would include the ability for results to be shared instantaneously with all members of the team through a software interface. We discuss our efforts towards the development and use of a robust, mobile platform (Android based smart phone) that incorporates stable molecular recognition elements in sensor development. The inexpensive, compact, robust, archival, and portable design is ideal for rapid field diagnostics.

8719-26, Session 6

High-sensitivity pulsed laser vibrometer for detection of biological life signatures and microphone applications *(Invited Paper)*

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A highly sensitive pulsed laser vibrometer has been developed using an advanced photo-emf detector. Using a high repetition rate diode laser in an interferometric setup, vibrations are detected from a vibrating diaphragm or a target surface located in one of its arms. So far, less than 4 pm displacements from a vibrating surface have been detected. Using this approach, detailed, time-phased mechanical workings of various parts of the human heart have been recorded and analyzed. Results are validated by electrocardiography and accelerometer readings. Sensitivities greater than conventional ECG's have been achieved. This technique allows remote and nonintrusive operation with no contact wires. Furthermore, applications in photoacoustics for detecting explosives have been explored. In this paper, we present the principles of operation of this new kind of laser vibrometer together with experimental validations for detection and monitoring of biological life signatures and for microphone based applications for detection of explosives.

8719-27, Session 6

Nanowire-nanocluster hybrid sensor technology for environmental, industrial, and security monitoring *(Invited Paper)*

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Next-generation of environmental monitors suitable for integration with smart-phone and other mobile platforms require single-chip, ultra low-power sensor technology capable of recognizing multiple threats. Traditional sensor technologies, such as electrochemical, catalytic, and photoionization based detectors all have significant limitations in terms of physical size, power requirement, sensitivity, selectivity, range, and operating life.

We have developed a novel chemical sensor architecture by combining the sensitive transduction capability of gallium nitride (GaN) nanowires together with the enhanced catalytic efficiency of metal and metal-oxides nanoclusters (with diameters in the range of 2 – 10 nanometers). Using multicomponent nanocluster design, we can produce sensors with high selectivity to any small set of chemicals, currently not possible with any other technology. We have shown that GaN nanowires decorated with nanoclusters of titanium dioxide can be used to detect volatile organic compounds, such as benzene, toluene, ethylbenzene, and xylene – commonly referred to as BTEX at concentration levels as low as 50 ppb. The photocatalytic metal-oxide nanoclusters allowed room-temperature sensor operation using only UV excitation. These sensors also detected nitroaromatic explosive compounds such as trinitrotoluene at levels of 500 ppt in air. By adding platinum to the titanium dioxide nanoclusters, the same sensors can be "retuned" to respond to hydrogen, methanol, and ethanol. The unique strength of our technology is that it allows us to design sensors for variety of applications by simply re-designing the metal/metal-oxide nanocluster. This enables fabrication of arrays of multiple sensors on a single chip capable of identifying various types of chemical threats.

8719-28, Session 6

Tunable graphene-based SPR sensors

Ergun Simsek, The George Washington Univ. (United States)

No Abstract Available.

8719-29, Session 7

Development and characterization of two-photon fluorescent miniemulsion nanoparticles for targeted drug delivery

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Side effects of chemotherapy are major problems associated with current cancer treatment. One way to improve the efficacy of cancer treatment and decrease side effects is to deliver drugs specifically targeted to tumors. This can be achieved by encapsulating chemotherapy drugs inside nanoparticles that aggregate in tumors due to the enhanced permeability and retention effect. In order to monitor the delivery of nanoparticle-drug conjugates, it is important to develop systems to image the nanopaticles. Towards that goal we have developed two-photon fluorescent nanoparticles through the miniemulsion process, using poly [2-(3-thienyl)ethanol butoxycarbonyl-methyl urethane], a conjugated polymer developed in our laboratory, and two surfactants, sodium dodecyl sulfate (SDS) and cetyl trimethylammonium bromide (CTAB). Two-photon fluorescent probes can lead to significant reduction of background fluorescence compared to single photon fluorescent probes.

Nanoparticle size decreased as surfactant concentration increased, and particle size remained constant for surfactant concentrations above the critical micellar concentration (CMC), which was 8.2 µM for SDS and 1 µM for CTAB. The average size of the nanoparticles with surfactants at CMC was 31.67 nm for SDS nanoparticles and 25.60 nm for CTAB nanoparticles. Both nanoparticle systems exhibited strong one-photon and two-photon fluorescent signals. We evaluated the cell penetration ability of the nanoparticles in rat cardiomyocytes using fluorescent micrscopy. Our results suggest that these nanoparticles may be used for high-contrast imaging of tumor cells.

8719-30, Session 7

Bifunctional gold nanoparticles for targeted dual imaging of angiotensin converting enzyme *(Invited Paper)*

Marie-Christine F. Daniel, William E. Ghann, The Univ. of Maryland, Baltimore County (United States)

The aim of nanodiagnostics is to identify disease at its earliest stage, particularly at the molecular level. Nanoparticle-based molecular imaging has set a unique platform for cellular tracking, targeted diagnostic studies, and image-monitored therapy. In the preclinical setting, several modalities, such as fluorescence, positron emission tomography (PET), magnetic resonance imaging (MRI), computed tomography (CT) and ultrasound imaging are used for imaging of the cardiovascular system. Although this conventional imaging describes extent and severity of cardiovascular diseases such as atherosclerosis or ischemia, molecular imaging is needed to identifying precursors of disease development and progression. Bringing multimodality capability to the molecular imaging will harness the complimentary abilities of different techniques, thus optimizing the overall resolution and sensitivity of the resulting scans. The enhanced imaging details will permit more precise diagnosis and control of treatments.

In this paper, we present the synthesis and characterization a dual-imaging contrast agent based on bifunctional gold nanoparticles designed for the targeting of tissue ACE (angiotensin-converting enzyme) and monitoring of cardiovascular diseases. Lisinopril was derivatized with thioctic acid to form the targeting ligand and the complex Gd(DOTA) was also modified to provide a ligand for MRI imaging. The gold core served as the CT contrast agent.

The new nanoprobes prepared could not only target tissue ACE but also provided bimodal imaging capabilities (CT and MRI). This bimodal molecular imaging will improve the ability to accurately target diseased tissue at a very early stage, thus diagnosing and then treating patients in the most efficient way.

8719-31, Session 7

Imaging spectral techniques with applications to biomedical science *(Invited Paper)*

Richard G. Madonna, Andrew Paylor, Northrop Grumman Electronic Systems (United States)

This paper provides an overview to the different spectral imaging techniques developed largely in the remote sensing community, and describes how these techniques can be used in the biomedical field. The discussion of spectral imaging techniques embraces both the hardware (imaging spectrometers, fixed filters, etc.) and the algorithms used to understand the spectral images. Extension of these remote sensing based techniques is made to the biomedical field through applications such as quality control screening in drug manufacturing, and detection of foreign matter in tissues.

8719-32, Session 7

Performance of acousto-optical imagers for chemical and biological detection

Narsingh B. Singh, Bradley Arnold, The Univ. of Maryland, Baltimore County (United States); Mohan Singh, Veer Bahadur Singh Purvanchal Univ. (India); Milton Gottlieb, Dennis Suhre, DRS Scientific, Inc. (United States)

Thre is a strong need for spectral and imager sensor for chemical biological detection. Although a variety of hyperspectral imagers are available, but these require huge processing problems. We propose technology for sweeping a wide range of transparency and capability to achieve desired sensitivity in the region of interest.

8719-33, Session 7

Hyperspectral imaging system to discern malignant and benign canine mammary tumors

Amrita Sahu, Temple Univ. (United States); Cushla McGoverin, Temple Univ. (United States) and Temple Univ. (United States); Nancy Pleshko, Temple Univ. (United States); Karin Sorenmo, The Univ. of Pennsylvania (United States); Chang-Hee Won, Temple Univ. (United States)

Hyperspectral imaging is an emerging technology in the field of biomedical engineering which may be used as a non-invasive modality for cancer characterization. In this project, a hyperspectral imaging system was used to characterize malignant and benign canine mammary tumors. The system consisted of a CCD camera, a liquid crystal tunable filter and a controller. The filter operated in the near-infrared spectral

range of 650-1100 nm. Using the hyperspectral data, the spectral signatures of malignant and benign canine mammary tumors were extracted and analyzed. The reflectance intensities of malignant tumor spectra were generally lower than benign tumor spectra over the entire wavelength range. Previous studies have shown that cancerous tissues are associated with higher hemoglobin and water content, and lower lipid concentration with respect to benign tissue. The decreased reflectance intensity observed for malignant tumors is due to the increased microvasculature and therefore higher blood content of cancerous tissue relative to benign tissue. Peaks at 700, 840, 900 and 970 nm were observed in the second derivative absorption spectra, these peaks were attributed to deoxy-hemoglobin, oxy-hemoglobin, lipid and water respectively. A 'Tissue Optical Index' was developed that enhances contrast between malignant and benign canine tumors. This index is based on the ratio of the reflectance intensity values corresponding to the wavelengths associated with the four chromophores. Preliminary results with 22 canine mammary tumors showed that the sensitivity and specificity of the proposed method is 85.7% and 94.6% respectively. This study shows promise in the optical diagnosis of canine mammary cancer.

8719-34, Session 8

Modeling photothermal safety for pulsed laser diagnostic systems: experimental validation and applications

Taylor Gould, Quanzeng Wang, Do-Hyun Kim, Joshua Pfefer, U.S. Food and Drug Administration (United States)

Photothermal safety is a primary concern for in vivo pulsed laser diagnostic devices such as novel photoacoustic imaging systems. While much progress has been made in development of these technologies, there has been relatively little study of the factors that influence temperature rise and thermal damage. To assess laser-tissue interaction mechanisms and factors of safety, a three-dimensional computational model including (1) a Monte Carlo light propagation algorithm, (2) a finite difference heat transfer routine and (3) an Arrhenius thermal damage calculation was developed, validated and implemented. The model provides estimates of fluence distributions as well as transient temperature and damage profiles in bulk tissue and discrete blood vessels. Thermal imaging and fast flash photography of the thermal damage front were used to experimentally confirm the simulation results using tissue-simulating phantoms. The effect of factors such as wavelength, beam diameter, beam energy and pulse duration were studied. Overall, the model indicated good agreement with experimental results. For a constant radiant exposure, increased beam diameter causes both local fluence and temperature to rise in subsurface blood vessels. The relationship between repetition rate, thermal superpositioning and potential for tissue injury by repetitive laser pulses was characterized. Computational modeling provides a powerful tool for elucidating photothermal mechanisms and effects in novel pulsed laser diagnostic devices.

8719-35, Session 8

Characterization and application of 3D-printed phantoms for biophotonic imaging

Jianting Wang, The Univ. of Maryland, College Park (United States) and U.S. Food and Drug Administration (United States); Du V. N. Le, The Catholic Univ. of America (United States) and U.S. Food and Drug Administration (United States); James Coburn, U.S. Food and Drug Administration (United States); Nicholas C. Woolsey, Yu Chen, The Univ. of Maryland, College Park (United States) and U.S. Food and Drug Administration (United States); Jessica C. Ramella-Roman, The Catholic Univ. of America (United States) and U.S. Food and Drug Administration (United States); Joshua Pfefer, U.S. Food and Drug Administration (United States)

The emerging technique of three-dimensional (3D) printing provides a simple, fast, and flexible way to fabricate structures with arbitrary spatial features. Acrylonitrile Butadiene Styrene (ABS) is commonly used in the printing process, given its low cost and strength. In this study, we evaluate 3D printing as an approach for generating phantoms for evaluation of biophotonic imaging systems, through optical property measurements, optical coherence tomography (OCT) imaging and hyperspectral imaging. The initial phase of this work involved characterization of absorption and scattering coefficients using spectrophotometric and fiberoptic diffuse reflectance approaches. The morphology of phantoms incorporating vessel-like channels with diameters on the order of hundreds of microns was examined by microscopy and OCT. A near-infrared absorbing dye was injected into channels located at a range of depths within the phantom and imaged with a near-infrared hyperspectral reflectance imaging (HRI) system (650-1100 nm). ABS was found to have scattering coefficients comparable to biological tissue and low absorption throughout much of the visible and infrared range. Channels with dimensions on the order of the resolution limit of the 3D printer (~200 microns) exhibited pixilation effects as well as a degree of distortion along their edges. Contrast-enhanced channel visualization with HRI was possible to a depth of nearly 1 mm – a level similar to that seen previously in biological tissue. Overall, our ABS phantoms demonstrated a high level of optical similarity to biological tissue. While limitations in printer resolution, matrix homogeneity and optical property tunability remain challenging, 3D printed phantoms have significant promise as samples for objective, quantitative evaluation of performance for biophotonic imaging modalities such as HRI.

8719-36, Session 8

Biomimetic self-assembly of polymer-inorganic hybrid nanocompartments with biomedical applications

Zhihong Nie, The Univ. of Maryland, College Park (United States)

The controllable self-assembly of inorganic nanoparticles (NPs) into larger specific structures provides an effective route for the fabrication of new materials with unique optical, electronic, and magnetic properties. In particular, the incorporation of inorganic NPs into polymeric assemblies can endow them with new advanced functionalities (e.g. plasmonic and magnetic properties), while preserving the well-established properties of the organic components. Inspired by self-assembly in nature, we have been devoted to design synthetic polymer-inorganic hybrid nanocompartments that mimic viral capsids from the aspects of such as surface, topology, and mechanical properties. These nanostructures may find applications in biological imaging, controlled drug/gene release, biosensors, and catalysis. This talk will present a new paradigm to the organization of NPs (i.e., metal NPs, magnetic NPs, and quantum dots) into a diverse range of complex hierarchical nanostructures such as clusters, wires, vesicles, tubules, and so on by controlling the thermodynamic or kinetic pathways of assembly. I will also present our preliminary experimental results on the biomedical applications of the assembled hydrid structuers, including remote-controlled release, photo-thermal therapy, and two-photon luminescence imaging.

8719-37, Session 8

Characterization and determination of endogenous species involved in brain tumors using multiphoton photoacoustic spectroscopy

Sudhir Dahal, Brian M. Cullum, The Univ. of Maryland, Baltimore County (United States)

It has been shown that using non-resonant multiphoton photoacoustic spectroscopy (NMPPAS), excised brain tumor and healthy tissue can be differentiated with over 99% accuracy. This powerful technique bears a great potential for use as a surgical guidance technique for tumor margining with up to cellular level spatial resolution. Our research focuses on characterizing the NMPPAS spectra obtained from excised tissues to determine the endogenous chemicals responsible for producing such spectra.

Previously, NMPPAS spectra were obtained in the optical diagnostic window (740nm-1100nm) for excised healthy brain tissues and brain tumor (grade III astrocytoma). Normalized spectra for healthy and tumor tissues were different in terms of intensity and a distinct peak in tumor spectra at 970nm. Such differences are suspected to be caused by variations in certain endogenous biochemical species between healthy and malignant tissues. Species such as NAD+, NADH, collagen, tryptophan, collagen, elastin and porphyrin were analyzed using NMPPAS at the wavelength range of 740nm-1100nm. Each species was embedded into gelatin tissue phantoms and NMPPAS measurements were performed. Additionally, the effects of hemoglobin on these spectra were also investigated as it is the major source of background when studies with blood perfused tissues are conducted. The talk will discuss the potential roles of each of the species for tumor determination and the effect of hemoglobin background.

8720-1, Session 1

Fiber optic oxygen sensor detection system for harsh environment of aerospace applications *(Invited Paper)*

Alex A. Kazemi, The Boeing Co. (United States); Edgar A. Mendoza, Redondo Optics, Inc. (United States); Kishology Goswami, InnoSense, LLC (United States); Lothar U. Kempen, Hochschule Ruhr West (Germany)

This paper describes the first successful Plastic Optical Fiber (POF) oxygen detection sensor systems developed for the Boeing Delta IV Launch Vehicle harsh environment of engine section. It illustrates a novel multi-point fiber optic microsensor (optrode) based on dynamic luminescence quenching that is being developed for measuring oxygen leak detection for space applications. The sensor optrodes employ the quenching by oxygen of the fluorescence from a ruthenium complex. These optrodes were fabricated using Ruthenium-based fluorescent indicator immobilized in a porous glass rod placed at the end of multimode fiber. The light from a blue LED is launched into the optrode via a fiber optic bundle and used as the excitation source. The optrode's fluorescent emission intensity in the range of 0% to 10% oxygen is measured as a function of time. The measuring system is based on high reliability and low cost. The system consists of four units: 1) temperature compensated oxygen optrodes combined with a optical setup, 2) multipoint sensor communication fiber optic network cable, 3) digital/analogue optoelectronic signal processing unit with built-in micro controller for control of data acquisition and processing, and 4) a laptop computer for data display and storage. In testing, the sensor exhibited excellent response time and reversibility. To qualify the POF and glass cables, performed detail investigation of POF + glass cables for attenuation loss, tension, bend, thermal, humidity, temperature, vibration and accelerate testing for life expectancy and harsh environmental of engine section. Extensive networking using MatLab were carried out for lab and actual field demonstrations.

8720-2, Session 1

Translucent triboluminescent coatings for particle detection

Melissa E. Jansen, Leo R. Gauthier Jr., David R. Bisson, John R. Meyer, Johns Hopkins Univ. Applied Physics Lab. (United States)

Triboluminescent phosphors provide a method for converting kinetic signals to optical signals for particle detection. Several methods, including vapor deposition, electron beam, and spray-on were evaluated for depositing a thin translucent coating of ZnS:Mn phosphor material onto transparent substrates. The objective was to be able to optically detect impact events on the back side of the substrate while still retaining some capacity to view distant optical events. During the experiments, optical detectors within a light-tight test chamber were used to measure the optical signals generated by the coatings. The measurements resulted from optical signals that were generated by particle impacts and sample phosphorescence, along with electrical interferences between the particle sources, the ambient background, and the detectors. Signal levels and translucency measurements from various coatings are described, along with lessons learned about the coating processes, the detectors, and the limitations of the measurements.

8720-3, Session 1

Investigation of the losses in coupling polymer optic fiber link for avionics data network

Sandy Cherian, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

With the objective of integrating polymer fiber based physical layer for avionic data network, the present paper studies the impact and causes of coupling losses on power distribution at the fiber optic interconnect.

As there are several disconnects in any avionic data links and as they are functioning under wider and unique operating conditions, it is important to know the losses at each coupling point for the system performance analysis. Since there is an air gap at the end face of military connectors, the coupling loss at the fiber optic interconnect is mainly due to the fundamental mechanical misalignment and Fresnel loss under extended operating conditions. Mechanical misalignment includes lateral, longitudinal and angular misalignment. Apart from the mechanical misalignment, coupling losses are also caused from the reflection occurring at the interfaces, by virtue of the differences in refractive indices such as PMMA to air and air to PMMA.

Therefore, in this study we consider two different sections of fiber coupling for avionics links: temporary connections or connectorized coupling and permanent connections or splicing. To analyze the coupling losses at any interconnect in the data link, the power distribution among the modes, field patterns associated with the modes and other geometrical characteristics are studied. Characterizations of modal power distribution using field patterns are conducted for attaining reproducible and accurate coupling loss measurements. An equilibrium launch condition is also considered for all test cases.

8720-4, Session 1

Study of a fiber optic sensor for hydrogen leak detection

Nicolas Javahiraly, Univ. de Strasbourg (France)

We present a study of a fiber optic sensor for leak detection based on Surface Plasmon Resonance (SPR). We use Palladium as the sensitive material for hydrogen detection. In this configuration, the transducer layer is a multilayer stack made of a silver, a silica and Pd layer. The spectral modulation of the light transmitted by the fiber allows to detect hydrogen on the environment. The multilayer thickness defines the sensor performance. The silica thickness tunes the resonant wavelength whereas the silver and Pd thickness determines the sensor sensitivity. The study of the sensor performance as function of several thicknesses (Pd/Si/Ag) is achieved and we present the optimal configuration at a concentration of 4% hydrogen in argon.

8720-5, Session 1

Distributed fiber optic fuel leak detection system

Edgar A. Mendoza, Yan Esterkin, Sunjian Sun, Redondo Optics, Inc. (United States)

With the increase worldwide demand for hydrocarbon fuels and the vast development of new fuel production and delivery infrastructure installations around the world, there is a growing need for reliable fuel leak detection technologies to provide safety and reduce environmental risks. Hydrocarbon leaks (gas or liquid) pose an extreme danger and need to be detected very quickly to avoid potential disasters. Gas leaks have the greatest potential for causing damage due to the explosion risk from the dispersion of gas clouds. This paper describes progress towards the development of a fast response, high sensitivity, distributed fiber optic fuel leak detection (HySense™) system based on the use of an optical fiber that uses a hydrocarbon sensitive fluorescent coating to detect the presence of fuel leaks (vapors and liquids) present in close proximity along the length of the sensor fiber. The HySense™ system operates in two modes, leak detection and leak localization, and will trigger an alarm within seconds of exposure contact. The fast and accurate response of the sensor provides a reliable vapor and fluid leak detection for pipelines, tanks, airports, pumps, and valves to detect and minimize any potential catastrophic damage.

8720-6, Session 2

No-reference image quality assessment for horizontal-path imaging scenarios

Carlos Rios, Szymon Gladysz, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Obtaining visual information through turbulence is challenging, more so when imagery is being recorded along horizontal line of sight. For such scenarios, software rather than hardware solutions seem to be more appropriate. It is foreseen that real-time image sharpening algorithms would find application in surveillance and reconnaissance over the next few years.

A large variety of image restoration methods have been proposed for these tasks. On the other hand there has been little effort directed toward objective assessment of the actual usefulness of these methods in operational scenarios such as person, or weapon ID. Simulating the effect of strong turbulence on electromagnetic waves along horizontal paths and over wide fields of view is hard, and therefore there is an interest in developing metrics that can be used on the raw, and processed field data which is easier to get. The metrics have to be "blind" in the sense that they cannot depend on the existence of a pristine reference image of the scene. The applications of no-reference image quality metrics include: performance comparison of de-blurring methods, stopping criteria for iterative image processing algorithms, "lucky imaging"-type fusion, and image registration.

We have addressed all of these tasks using simulated and real data. The field data comes from experiments performed by the NATO SET 165 research group over a 7km distance in Dayton, Ohio, USA. Using this data we have tested several metrics found in the literature, and also some new metrics. We discuss ways of evaluating the usefulness of these metrics even when a fully objective comparison is impossible (because of the lack of reference image and/or human observers for mean opinion score tests).

8720-7, Session 2

Rugged spinel windows and optics for harsh environments

Shyam S. Bayya, Guillermo Villalobos, Woohong R. Kim, Lynda E. Busse, Jasbinder Sanghera, U.S. Naval Research Lab. (United States); Ish D. Aggarwal, Sotera Defense Solutions, Inc. (United States)

Rugged window materials with good visible and IR transmission and high thermal conductivity are needed for high speed applications. We have been developing transparent spinel ceramics in different shapes and sizes for various DoD applications in the visible to mid-IR wavelength region. We have focused on improving the physical properties, such as reducing absorption and scattering losses as well as increasing strength and environmental ruggedness. We have demonstrated excellent transmission from 0.2 – 5.0 µm, thus covering the UV, visible, near IR and midwave IR wavelength regions. Spinel has better IR transmission than sapphire and AlON in the 4-5 µm wavelength region. We demonstrated record low absorption loss of 6 x 10-6 cm-1 at 1.06 µm. Spinel possesses thermal shock resistance superior to that for glass windows and has significantly superior strength and ruggedness as compared to zinc sulfide. We have also demonstrated its environmental ruggedness through successful rain and sand erosion resistance tests at speeds at or greater than 460 mph. Because of these superior optical and mechanical properties, we have been developing spinel for various DoD applications. These include low absorption loss windows for High Energy Laser systems, thick windows for submarine photonic masts, large windows for reconnaissance, and low scattering loss domes for Infrared Countermeasure jam heads. The status of these development efforts will also be discussed at the meeting.

8720-8, Session 2

Image enhancement for deep turbulence propagation scenario using hybrid adaptive optics and image processing compensation: preliminary experimental results

Mathieu Aubailly, The Univ. of Maryland, College Park (United States); Gary W. Carhart, Jony J. Liu, U.S. Army Research Lab. (United States); Mikhail A. Vorontsov, The Univ. of Dayton (United States)

Adaptive optics (AO) systems were originally developed for astronomical applications. Conventional AO systems allow compensation of turbulence-induced wavefront aberrations and typically result in image quality improved over a narrow field-of-view (FOV) with size related to the isoplanatic angle. However under strong (deep) turbulence conditions – which are typical for optical systems operating over long and/or near-horizontal atmospheric propagation paths – anisoplanatism prevents them from performing well. In a different approach, numerous digital image processing techniques have been recently developed for mitigating image degradation over full FOVs. We present preliminary experimental results for a hybrid system combining both approaches: AO based on image quality optimization and image processing based on the "lucky-region" fusion algorithm. Results are obtained for a near-horizontal 2.3km propagation path and show significant improvement of image quality compared to either of the two approaches applied individually.

8720-9, Session 2

Recent development in cryogenic optical and mechanical design

Simon Thibault, Univ. Laval (Canada)

Making a lens design working at cryogenic temperature is a real challenge. Both optical and mechanical designer must work together to prevent problems during operation. This paper describes the process from the first preliminary design to the final cryogenic system for both optical and mechanical design to achieve cryogenic working solution. We present the most recent data regarding cryogenic optical material properties such cold index of refraction, CTE including coating behaviors. We present different optomechanical mounting geometry. We also discussed the assembly procedure (room temperature vs cryogenic compensation) and the test support equipments.

8720-10, Session 3

A review of head-mounted displays (HMD) technologies and applications for consumer electronics *(Invited Paper)*

Bernard C. Kress, Google, Inc. (United States)

The main optical element in a see through HMD is the optical combiner.

In military HMDs, traditional 45 degrees tilted 50/50 windows or free form refractive combiners have been used, however the industrial design constrains for consumer electronics see through HMDs are triggering an interest on other technologies, slim and light weighted optical combiners, such as guided wave and holographics.

8720-11, Session 3

Hardware acceleration of lucky-region fusion (LRF) algorithm for image acquisition and processing

William Maignan, David Koeplinger, The Univ. of Delaware (United States); Gary W. Carhart, U.S. Army Research Lab. (United States); Mathieu Aubailly, The Univ. of Maryland, College Park (United States); Fouad Kiamilev, The Univ. of Delaware (United States); Jony J. Liu, U.S. Army Research Lab. (United States)

“Lucky-region fusion” (LRF) is an image processing technique that has proven successful in enhancing the quality of images distorted by atmospheric turbulence. The LRF algorithm extracts sharp regions of an image obtained from a series of short exposure frames, and “fuses” them into a final image with improved quality. In previous research, the LRF algorithm had been implemented on a PC using a compiled programming language. However, the PC usually does not have sufficient processing power to handle real-time extraction, processing and reduction required when the LRF algorithm is applied not to single picture images but rather to real-time video from fast, high-resolution image sensors. This paper describes a hardware implementation of the LRF algorithm on a Virtex 6 field programmable gate array (FPGA) to achieve real-time video processing. The novelty in our approach is the creation of a “black box” LRF video processing system with a general camera link input, a user controller interface, and a DVI video output.

8720-12, Session 3

Optical gesture sensing and depth mapping technologies for head-mounted displays: an overview

Bernard C. Kress, USI Photonics, Inc. (United States)

Head mounted displays (HMD), and especially see through HMDs have gained renewed interest in the last months, for the first time outside the traditional military and defense realm, due to several high profile consumer electronics companies presenting their products to hit market soon. Consumer electronics HMDs have very different requirements and constrains as their military counterparts.

Voice comments are the de-facto interface for such devices, but when the voice recognition does not work (not connection to the cloud for example), gesture sensing technologies have to be used to communication information to the device.

We review in this paper the various technologies developed today that can integrate such optical gesture sensing in a small footprint, as well as the various related 3d depth mapping sensors.

8720-13, Session 3

Key challenges to affordable see-through wearable displays: the missing link for mobile AR mass deployment

Khaled Sarayeddine, Kayvan Mirza, OPTINVENT S.A. (France)

The market for augmented reality wearable displays (or AR glasses) is potentially massive. Some estimates say that in a relatively short time, AR glasses could be the user interface of choice and will replace the conventional hand held smart-phone touchscreen interface. The target market therefore is the ubiquitous use of mobile video, navigation, augmented reality, and gaming. See through wearable AR displays that don’t obstruct the line of sight of the end user allow a non-intrusive, hands free, large screen experience and are therefore a very desirable alternative which will allow full use of the available computing power of smart devices. Wearable displays are compelling because they offer the ability to run video, navigation, messaging, AR, and gaming applications on a large virtual screen hands free. However, any such device will need to be affordable and should have a form factor that is discrete enough so that users will easily adopt it. If a wearable display device can hit the sweet spot of price, performance, and form factor, then it will enable this “Wearable Smartphone” revolution. The wearable display will be nothing less than the creation of a brand new product category that will open up a world of possibilities. We present in this paper an overview of several see-through wearable glasses techniques and detail recent development of Optinvent see-through technology.

8720-14, Session 3

Real-time polarization difference imaging (rPDI) reveal surface details and textures in harsh environments

Denis Brousseau, Univ. Laval (Canada); Jim Plant, Q5 Innovations, Inc. (Canada); Simon Thibault, Univ. Laval (Canada)

Extensive peer reviewed scientific research has demonstrated the utility of polarization difference imaging (PDI) to reveal subtle surface details and textures in poor lighting conditions caused by fog, smoke, clouds or turbid water. However, real world use of polarimetric imaging and sensing has been limited by the sequential rather than simultaneous capture of the polarization states. A prototype of a custom polarization beam-splitting assembly, developed and patented by Q5 Innovations Inc., has been built and tested by our group. This real-time polarization difference imaging (rPDI) camera simultaneously captures two (orthogonal) polarization states on two imaging sensors and uses the captured images to compute a contrasted enhanced output image.

We present sample results showing the ability of the camera to enhanced imaging in fog and turbid water.

8720-15, Session 4

Using high-power LED in harsh environment

Simon Thibault, Sébastien Bouchard, Univ. Laval (Canada)

Light-emitting diodes (LEDs) are becoming common as energy efficient light sources. Their long life, small footprint and their low energy consumption are great promises to use it in many applications including harsh environment. However, to design efficient light source, a mathematical model is required. The development of such a mathematical model was pointed as a priority task by U.S. Department of Energy in 2010 for general lighting. In this presentation, we report an experimentation for two high-power white LED models which were stressed with different currents and junction temperatures. It shows the large variation between different models and stress conditions that takes place in the degradation process. This is part of an effort to develop a tool for the simulation of LED degradation for harsh environment lighting condition.

8720-16, Session 4

LED-based solid state lighting: challenges and opportunities

Allen S. Panahi, Pentair, Inc. (United States)

Solid state Lighting technology has made great advances over the last decade and has become the technology of choice to displace legacy incandescent and as well as the more efficient fluorescent lights. While efficiencies have been improved and cost of the LEDs have been steadily lowered still many challenges exist in the thermal, electrical, optical, and packaging implementations.

8720-17, Session 4

Use of formal derivative for extremizing real-valued functions of complex variables

Sudarshan R. Nelatury, Penn State Erie, The Behrend College (United States); Charles W. Nelatury, Charles F. Nelatury, The Pennsylvania State Univ. (United States)

Maxima and minima of real-valued functions of several variables can be found from the critical points that are found by equating the gradient to zero. In order to confirm whether a critical point corresponds to a minimum or maximum is determined by standard tests. The Hessian H, which is defined as the Jacobian of the gradient is found at the given critical point and whether the Hessian is positive definite or negative definite must be ascertained. All the eigen values of H are positive or negative depending on whether the critical point is minimum or maximum. If the Hessian is indeterminate, the critical point corresponds to a saddle point. In the unfortunate case when the Hessian is singular, the test fails.

Many an objective function to be extremized, although is real-valued, is a function of complex variables and their conjugates. These functions do not satisfy Cauch-Riemann equations and hence cannot be differentiated in the traditional sense. However, using a formal gradient, and a corresponding a formal Hessian, we can still find the critical points and perform the necessary tests from the eigen profile thereof. Such operations are extremely necessary in the field of array processing, and problems like maximum power transfer in case of multiport network described by their Thevenin model involving NxN matrices. Of special significance is the problem of maximizing power when the NxN load matrix is real-valued. This paper shows how optimization can be addressed using the formal gradient and formal Hessian.

8720-18, Session 5

Micro-Packaging in High Power LED

Alex A. Kazemi, The Boeing Co. (United States); Allen Panahi, Pentair (United States)

In this paper describe an improved micro soldering method of hermetic seal mini-DIL (dual in line) laser diode module. Normally, reliable, reproducible, high-yield packaging technologies are essential for meeting the cost, performance, and service objectives for the harsh environment of aerospace applications. The decision to use a softer solder of indium resulted in failure mechanisms of mini-DIL laser diode module in laser firing unit (LFU) for ordinance ignition of a missile system. These include: (1) catastrophic failure in light output pulse power, (2) fiber pigtail damage inside the package snout which cause low LFU production yield and mission failure. One of the challenges for the package was its very small size. For this package a new technique for the hermetic seal using a patented micro-soldering process was developed. The process is able to confine the solder seal to a small region inside the snout near the fiber feed-through hole on the wall of the mini-DIL package. After completing the development, the final process which included temperature and thermal cycling, X-rays showed the improved method had no fiber damage after the micro-soldering seal. The new process resulted in 100% success in our packaging design.

8720-19, Session 5

Damage-tolerant modeling validation of wireless sensory composite panel of structural health monitoring system

Frank Abdi, AlphaSTAR Corp. (United States)

The paper proposes the modeling and test validation of Wireless/Integrated Strain Monitoring and Simulation System (WISMOS).. The effort verifies a hardware and software web based tool that will be able to evaluate and optimize sensorized aerospace structures. The tool will be extension of an existing suite of structural health monitoring (SHM) and diagnostic prognostic system (DPS). The goal of the extended SHM-DPS is to apply multi-scale nonlinear physics-based finite element analyses to the “as-is” structural configuration to determine residual strength, remaining service life, and future inspection intervals and procedures. The proposed solution will meet the JTI GRA goals in low weight and durable/reliable commercial aircraft. It will take advantage of the current developed European Clean Ski JTI “Wismos Project with capability to process/store/transmit network of sensors data (e.g., FBGA, Wireless Sensors), and realization of DPS-based condition based inspection and maintenance.

Information from a distributed system of sensors is used to determine the “as-is’ state of the structure versus the “as-designed” target. Two stiffened panels is instrumented with wireless sensors; the second with an optimized sensor network. It is shown that the sensor system output is routed and integrated into a nonlinear multi-scale physics-based finite element analysis (FEA) tool to determine the panel’s residual strength, remaining service life, and future inspection interval. The FEA utilizes the GENOA Multi-Scale Progressive Failure Analysis (MS-PFA), a web based software suite, which is applicable to metallic and advanced composites.

As part of the Prognostic system validation of models, two composite stiffned panel models were analyzed and verifieid against tests under compressive loading: 1) Undamaged stiffened buckling panel; 2) Stiffened buckling panel including an initial diamond cut. For analyzing the damage behavior we utilized GENOA MS-PFA tool: 1) deriving the micromechanical properties from a set of ASTM standard coupon experimental test results. The calibrated fiber/matrixa stress-strain curves for five ASTM standard coupon tests were compared with experimental coupon test data. In Longitudinal tension/ Transverse tension

Longitudinal compression/ Transverse compression and In-plane shear directions. Next. The adhesive material between the stiffeners and the plate were modeled using cohesive elements. MS-PFA Analysis results showed fiber failure during compression and predicted matrix cracks for the model with the diamond cut. Damage evolution process of predicted delamination initiation at the cut, as well as delamination growth pattern, and detachment of the stringer with the skin were predicted and compared with test data with close agreement.

8720-20, Session 5

In-flight fiber optic acoustic emission sensor (FAESense) system for the real time detection, localization, and classification of damage in composite aircraft structures. *(Invited Paper)*

Edgar A. Mendoza, Yan Esterkin, Connie Kempen, John Prohaska, Sunjian Sun, Redondo Optics, Inc. (United States)

Acoustic emission sensing is a leading structural health monitoring technique use for the early warning detection of structural damage associated with impacts, cracks, fracture, and delaminations in advanced materials. This paper describes progress towards the development of a wireless in-flight distributed fiber optic acoustic emission monitoring system (FAESense™) suitable for the onboard-unattended detection, localization, and classification of damage in avionics and aerospace structures.

8720-21, Session 5

Performance impact of optical interconnects as a result of mechanical and environmental testing

Roger Rutz, Experior Labs., Inc. (United States)

Experior Laboratories, a DLA Land and Maritime and Verizon approved qualification test facility, with an expertise in fiber optic component and sub-system testing, will present information relating the performance impact and possible degradation of optical interconnect systems due to mechanical and environmental stress exposure. Experior will compare Singlemode, Multimode and Expanded Beam contacts and connectors based on mechanical shock, vibration, thermal shock and humidity cycling testing.

8720-22, Session 5

Selection of fiber optic system passive components and installation training

Douglas A. Parker, Deutsch UK (United States)

A fiber optic system can be designed, assembled and installed with many options for active and passive components and system elements. Interconnection systems should be designed with a detailed BOM, including fiber/cable, connectors, ruggedization materials and other passive components for the desired application. The selection of these items should be specific to the requirements of the system when considering environmental and mechanical limitations, and from the standpoint of the users who will be installing, maintaining and possibly repairing the system sometime in the future.

The paper will review various up-to-date alternatives available when selecting components at design-in stage and discussing options for different scenarios of required optical performance. Considerations of component selection with regard to capabilities of the installers, maintenance and repair personnel and other key people who will be responsible for the success of the system will also be discussed. Training resources will be discussed.

A fiber optic system when compared to an electrical system is not necessarily more difficult to install and maintain, but training for key different issues is a must. With appropriate component selection at the design stage and adequate training of installers/handlers is completed, the fiber optic system will be successful.

8720-23, Session 6

Optical latches using optical amplifiers

Wenbo Li, Hongyu Hu, Niloy K. Dutta, The Univ. of Connecticut (United States)

Optical latches are important for a wide range of applications including communication systems, optical logic systems, optical random access memory (RAM) and encryption. All optical logic operations using quantum dot (QD) based semiconductor optical amplifier (SOA) and Mach-Zehnder interferometer (MZI) have been studied. The building block of an optical latch such as NAND gate has been fabricated and their operation experimentally demonstrated at ~ 80 GHz. This SOA-MZI was fabricated using hybrid integration technology. The waveguides of the MZI (which include attenuators, phase shifters, splitters) are fabricated using silica based planar lightguide circuits and the SOA is fabricated using InP/InGaAsP based semiconductor materials.

A rate equation model has been developed for the QD-SOA-MZI and it has been used to analyze the Boolean logic operation. The model has been used to analyze the Set-Reset (S-R) latch and the D-Flip-Flop (DFF) devices. The DFF has the property that the output Q is the same as D (data) if the gate (G) is high and Q will remain latched to whatever state it was in before the high to low transition in gate (G). The DFF is the basic device for building larger logic circuits. The results show that the latches would work to speeds of ~ 250 Gb/s

8720-25, Session 6

Compact wavelength monitor for remote sensing applications suitable to precisely measure the wavelength of individual laser pulses *(Invited Paper)*

Peter Kiesel, Palo Alto Research Center, Inc. (United States)

Remote sensing of chemicals in a cloud can be accomplished, for example, with a tunable LIDAR system. The principle is to direct a series of laser pulses with different wavelengths at the cloud and measure the response (amount of reflected, scattered, or transmitted light) for each wavelength. The observed features in the recorded spectra reveal information on the constituents in the cloud. The most informative spectral bands for chemical identification are the wavelengths near 3 and 10um where gas molecules have characteristic vibrational modes that contribute characteristic structure in the spectra. For chemical identification it is essential to have precise wavelength information for each individual laser pulse.

We will describe a compact and fast wavelength monitor that can determine the wavelength of individual laser pulses with a resolution of a few pm. It combines a position sensor with a linear-variable-filter optical coating that converts the wavelength information of the incident light into a spatial intensity distribution on the photo-detector. Differential read-out of the position detector is used to determine the centroid of this distribution. Wavelength change between individual laser pulses is detected as a shift of the centroid of the spatial light distribution on the detector.

We tested our wavelength monitor with a wavelength-tunable fiber laser which can produce randomly accessible sequences of laser pulses. The laser emits 100ns long laser pulses at 2kHz with selectable, well-defined wavelengths in the spectral range from 1030 to 1075nm. Such lasers can be used in combination with an OPO to convert the wavelength sequences in the 3um band for remote sensing. Our wavelength detector can measure the wavelength of each individual laser pulse with a resolution better than 10pm over the entire wavelength range.

8720-26, Session 6

Spectral observation of fuel additives in gasoline-ethanol blends using a Fourier-transform Raman spectrometer prototype

Valentin Ortega Clavero, Hochschule Offenburg (Germany) and Ecole Nationale Supérieure de Physique de Strasbourg (France); Nicolas Javahiraly, Ecole Nationale Supérieure de Physique de Strasbourg (France); Andreas Weber, Werner W. Schröder, Hochschule Offenburg (Germany); Patrick P. Meyrueis, Ecole Nationale Supérieure de Physique de Strasbourg (France)

The combination of fossil fuels with bio-fuels, specially ethanol and methanol, has acquired relevance and attention in several countries in recent years. A variety of factors have induced this trend: market prices, constant geopolitical events, new sustainability policies and laws, etc. The fuels used in the automotive industry, including bio-fuels, normally contain additives as anti-shock agents and as octane booster. These additives may endanger (beside the high volatility implied) public health or environment due to the nature of its chemical composition.

Raman spectral information from different additives, specially toluene, contained in E10 gasoline-ethanol blends has been obtained by using an own-design Fourier-Transform Raman spectrometer (FT-Raman). This information has been also compared with Raman spectra from pure additives and with standard Raman lines in order to validate its accuracy in frequency. The spectral information is presented in the range of 0 cm-1 to 3500 cm-1 with a resolution of 1.66 cm-1 . The Raman spectra obtained shows a reduced frequency deviation (less than 0.4 cm-1 when compared to standard Raman spectra from different calibration materials, e.g. cyclohexane and toluene, without compensation for instrumental response).

The Fourier-Transform Raman spectrometer prototype used for the spectral analysis, consisting of a Michelson interferometer and a self-designed photon counter cooled down on a three stage Peltier element arrangement, is able to extract high resolution and precise Raman spectra from the additives in the fuels analyzed. The proposed FT-Raman prototype has no additional complex hardware or software control. The mechanical and thermal disturbances affecting the FT-Raman system are mathematically compensated by extracting the optical path information from the generated interference pattern of a λ = 632.8 nm Helium-Neon laser (HeNe laser), which is used at the spectrum evaluation. This allows the device to be used in complicated environments where certain level of security is required (e.g. fuel production, storage, transportation, etc.).

8720-47, Session 6

Intersatellite laser communication systems

Alex A. Kazemi, The Boeing Co. (United States)

Recent Advanced High Power LED (HPL) is poised to replace traditional lighting sources such as Fluorescent, HID, Halogen and conventional incandescent bulbs in many applications. Due to the solid state compact nature of the light source it is inherently rugged and reliable and has been the favored lighting source for most indoor and outdoor applications including many hazardous locations that impact, and safety environments including mining, bridge, Aerospace, Automotive . In order to accelerate this transition many enhancements and advances are taking place to improve on the reliability, and thermal performance of these devices.

With the use of large LED arrays, it is possible to generate large heat loads at the system level which can cause challenges for overall heat dissipation, especially when cooling requirements call for passive methods. These two challenges work together to cause elevated LED die temperatures, which have been linked to lower quantum efficiencies, shorter lifetimes, emission wavelength shifts and catastrophic device failure. It has been predicted previously that the lifetime of a device decays exponentially as the temperature increases. This can result in a lifetime decrease from 42,000 hours to 18,000 hours when the device temperature increases from 40°C to 50°oC

This paper explores the various improvements and advances made in the packaging of LEDs to enhance their performance.

8720-27, Session 7

Depth perception camera for autonomous vehicle application

Philipp G. Kornreich, Syracuse Univ. (United States)

The application of a camera that can measure the distance from each pixel to the point on the object that is in focus at the pixel is described. In the 2006 and 2007 DARPA autonomous vehicle challenges it was found that information from binocular cameras was insufficient to guide the vehicles. Additional range information from a rotating LIDAR on the roof of the vehicle was required. To this day autonomous vehicles use a LIDAR for range information. This camera would eliminate the need for the LIDAR. A single Depth Perception Camera would be sufficient to guide the vehicles. Other applications are in robotic vision. An interesting application is as part of a crude teleportation system consisting of a Depth Perception Camera and a three dimensional printer at a remote location.

The range measurement is performed by a short p - n junction lightguide section at each pixel. The device uses broad band ambient light. Each frequency component arriving at a pixel has a phase proportional to the distance from object point to image point. Light arriving at a pixel trough the lens adds constructively only if it comes from the object point that is in focus at this pixel. Light waves from all other object points cancel. Thus, the lightguide at this pixel receives light from one object point only. The p - n junction lightguide has contacts along its length. The charge carriers in the lightguide are generated by the light intensity mode pattern of each frequency component. The light intensity mode patterns and thus the photo voltage shift in response to the phase of the input signal. Thus, the photo voltage is a function of the distance from the pixel to the object point that is in focus at the pixel.

8720-28, Session 7

Novel polyimides for optical applications

Lei Wang, Frank W. Harris, TE Circuit Protection (United States)

Optical communication systems have been extensively investigated in the past few decades due to their advantages over traditional electronic communication systems. For example, they offer larger information capacity, less interference and less transmission loss. An important component of these systems is an optical waveguide, which is used in optical interconnects to transport the light signal. Silica-based materials were first used in the waveguide industry due their low optical loss, good manufacturing reproducibility, and long term reliability. However, these materials have some problems that limit their applications, such as very high manufacturing temperatures that can damage the previously installed components, difficulties in controlling their refractive index and their inherent brittleness. Thus, polymer materials have been investigated to replace the silica based materials in optical waveguides due to their very good processability, light weight and low cost. The conventional optical polymers include polystyrene (PS), poly (methyl methacrylate) (PMMA) and polycarbonate (PC). However, the thermal stabilities of these polymers are not high enough.

Aromatic polyimides have excellent thermal stability, good chemical resistance, low dielectric constants, and good mechanical properties. However, common aromatic polyimides have many shortcomings that prevent their application in optical communication systems, such as their insolubility and their yellow color. Their films also display large birefringence and high absorption at communication wavelengths. The objective of this research work was to develop new polyimide structures with twisted biphenyl configurations so as to improve the polymer optical properties. Thus, new diamines and new dianhydrides were to be synthesized and polymerized that contained twisted biphenyl linkages. The new polymers were expected to have good solubility that would allow them to the solution cast into thin films. The non-planar, twisted-biphenyl linkages were expected to disrupt the backbone in-plane orientation and chain packing in the films. Thus, the films were expected to display low birefringence. The polymers properties were to be carefully evaluated.

8720-29, Session 7

Thermal and vibration testing of ruggedized IR-transmitting fiber cables

Lynda E. Busse, U.S. Naval Research Lab. (United States); Frederic H. Kung, Univ. Research Foundation (United States); Brandon Shaw, U.S. Naval Research Lab. (United States); Ish D. Aggarwal, Sotera Defense Solutions, Inc. (United States); Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Mid-IR transmitting glass fiber cables are needed for many applications involving laser power transmission, including directing IR energy from a centralized laser to outgoing pointers in anti-missile aircraft protection systems and chemical sensing applications. However, there is very limited commercial availability of environmentally ruggedized cables for the specialty IR-transmitting fibers. We will present successful results obtained for thermal/ vibration testing of ruggedized, IR-transmitting chalcogenide glass fiber cables using NRL's state-of-the-art equipment capable of mil-spec environmental testing. We will also present results for high infrared power transmission. We report results for a novel, direct imprinting process to create "moth eye" patterned surfaces on the IR fiber cable ends that significantly reduces endface reflection losses. The cables with these imprinted "moth eye" ends transmit much higher IR laser power without damage than was obtained for previous cables with traditional AR coatings. This work has direct impact on the practical utilization of these fiber cables for a variety of applications.

8720-30, Session 7

Fiber optic sensor for angular position measurement: application for an electrical power-assisted steering system

Nicolas Javahiraly, Ayoub Chakari, Ecole Nationale Supérieure de Physique de Strasbourg (France)

An effective automotive power steering system needs two important datas, the angular position of the wheel and the torque applied on the shaft by the driver of the car. We present a new accurate optical fiber angular position sensor connected to an automotive power steering column. In this new design, the sensor allows the measurement of the angular position of a car steering wheel over a large and adjustable range (± several turns of the wheel). The wheel rotation induces micro-bending in the transducer part of the optical fiber sensing system. This system operates as an amplitude modulation sensor based on mode coupling in the transducing fiber in the case when all the modes are equally excited. We study the sensor response both theoretically and experimentally with a multimode step index optical fiber [rf (fiber radius) = 300 μm; rc (core radius) = 50 μm; nc (core index) = 1,457; N.A. = 0, 22 and the wavelength is 632, 8 nm at the ambient Temperature (20°C)]. We show that the sensitivity can be controlled as a function of the sensor's length. We compare modeling and experimental validation and we conclude with a perspective on what could soon be an industrial sensor.

8720-31, Session 7

Developing aircraft photonic networks for airplane systems *(Invited Paper)*

Henry J. White, BAE Systems (United Kingdom); Nick Brownjohn, Airbus Deutschland (Germany); João Baptista, GMV (Portugal); Vincent Foucal, Radiall (France); Anders Clausen, Technical Univ. of Denmark (Denmark); Luis Pessoa, INESC Porto (Portugal); Thomas Pistner, EADS Astrium (Germany); Mark Farries, Gooch & Housego (Torquay) Ltd. (United Kingdom); Stéphane Gauchy, Draka (France); Ilja Kopacek, SQS Vláknová optika a.s. (Czech Republic); Andrew Lee, AVoptics Ltd. (United Kingdom); Bruce Napier, Vivid Components (Germany); Massimo Traversone, SELEX Galileo S.p.A. (Italy); James Vincent, AgustaWestland (United Kingdom); Armin Zimmermann, Technische Univ. Ilmenau (Germany)

Using high speed fiber optic communication networks for airplane systems has proved to be challenging and faces complex issues, especially in achieving affordable systems. In this paper we describe a summary of the EU Framework 7 project DAPHNE (Developing Aircraft Photonic Networks) which aimed at addressing these issues.

DAPHNE addresses the exploitation of photonic technology from terrestrial communications networks, and the development and optimization of aircraft photonic networks to take advantage of potential cost savings. The project's main areas of emphasis are on multiplexing networks; providing standard components for aircraft use; simplifying installation; and reducing through life support costs. The DAPHNE project started in September 2009 and finishes in February 2013. It has fifteen partners from seven nations and was supported by the European Commission's Seventh Framework Programme (FP7).

The main advantages of photonic networks for aircraft systems are: reduced size & weight; enormous transmission bandwidth; and excellent Electromagnetic Compatibility (EMC) without heavy and bulky shielding.

The networks that have been developed include switched Gigabit and 10 Gigabit Ethernet using multi-mode fibre, CWDM single-mode systems for switched Gigabit Ethernet and the development of a passive optical network (PON) for aircraft use. The integration of digital and analogue data via wavelength division multiplexing down the same fibre will also be reported.

The presentation will include results from the final component evaluations, system demonstrations and modeling work of the DAPHNE project.

8720-32, Session 8

Contamination effects on single-mode optical fibre connectors

Henry J. White, Geoff M. Proudley, BAE Systems (United Kingdom)

Multi-mode fibre optic networks are becoming more and more prevalent on aircraft, while the use of single-mode fibres on aircraft has been limited due to the perceived robustness of connectors and cost implications. However, single-mode fibres are required for certain functions such as wavelength division multiplexing (WDM), analogue RF over fibre and fibre Bragg grating systems for structural health monitoring. In this paper a selection of connectors using single-mode fibres have been assessed in the presence of internal contaminants, both particulate and fluid. Butt-coupled connectors and expanded beam type connectors were assessed under the same conditions.

The results showed that different types of connector behave differently in the presence of contaminants and no single design could survive the test conditions fully. The results of the tests will be shown and discussed.

8720-33, Session 8

Optical fiber-based full-spectral monitoring system for weathering testing

Yana Z. Williams, Atlas Material Testing Technology, LLC (United States); Jacob Zhang, Kurt P. Scott, Henry K. Hardcastle, Ametek - Atlas Material Testing Technology, LLC (United States)

A fiber-based full-spectral monitoring system has been developed and implemented for weathering testing. The system can provide in-situ, real-time irradiance monitoring and control inside the weathering chamber. Compared to the conventional radiometer-based monitoring systems, this represents a revolutionary step forward for the weathering industry. The FSM system consists of a receiver, optical fiber, a CCD based miniature spectrometer, and a LabVIEW control program for data collection and analysis. The optical fiber conveys the collected light by the optical receiver inside the weathering chamber to the miniature spectrometer outside the chamber. A Design of Experiment study has been carried out to characterize the measurement capability of the FSM system under various harsh weathering test conditions.

A Xenon lamp based calibration process has been developed to perform wavelength calibration as well as spectral calibration of the FSM system. This calibration process greatly simplifies the traditional Mercury plus FEL lamp based calibration process. The total uncertainty of this FSM has also been analyzed. The major uncertainty contributors such as the optical system itself, the transfer calibration process, as well as the spectrometer used to calibrate the optical system have been evaluated and the total uncertainty has been calculated. A stray light characterization method is also described.

8720-34, Session 8

Plastic optical fiber (POF) technology for transportation systems

Kazuki Nakamura, Mitsubishi Rayon Corp. (Japan)

Plastic Optical Fiber (POF) technology is utilized for wide variety of applications for its easiness of handling and robustness against environmental variation. Thanks to its large core diameter (typically 1mm) and large numerical aperture (typically 0.5) which provides wider acceptance angle, dimensional tolerance of POF can be extremely large. This benefits a simple and low cost connection technology for system intergration.

POF manufactures are primarily focusing on growing automotive and industrial data-com areas besides the traditional lighting and sensing applications. As an application in the transportation industry, automotive data-com with POF has been used in in-vehicle networks for infotainment systems and safety information bus under the well developed MOST standard.

The paper reports the evolution of POF application starts from the automotive industry to its latest possibility in an in-airplane or aerospace environment. It explains about the technology and the features of those jacketed POF for harsh environment. These environment demands POF to be durable against high temperature (100C+), mechanical movement (dynamic repeated bending), and material compatibility with machine oil, chemical substances, fungus, flammability and smoke density, and a long life time (20 years).

Through the jacketed cable development activities, POF technology will further evolve into a well adopted aerospace industrial standard, which in return will push another great opportunity to challenge the POF application limitation.

8720-48, Session 8

A new double FFT-based filter to reduce the effect of 1/f noise spectrum in a tunable diode laser spectrometer (TDLS)

Samira Mahdi, The Univ. of Arkansas at Little Rock (United States); Youhua Chen, Gary Anderson, The Univ. of Arkansas (United States)

A Tunable Diode Laser Spectrometer (TDLS) system has been designed to scan the near-surface atmosphere on the Marth for ammonia gas over a wide range of distances (10 m to 1 Km). Since the system is designed for space applications, it needs to be small, lightweight, and low power, which dictates the use of relatively low frequency measurement scans. The spectrometer uses a diode laser, which is subject to a large 1/f noise component at these low frequencies. In this work, digital signal processing techniques are used to maximize the measurement sensitivity of a low frequency TDLS system depending on Double Fast Fourier Transform (DFFT) based filter. Simulations and experiments of the 1/f noise spectrum and ammonia gas absorption peak are performed using a sinusoidal injection current waveform to drive the diode laser. A DFFT method is proposed that reduces the average of the error in the gas readings to nearly 50 percent. This method is proved to be capable of decreasing the effect of 1/f noise while keeping the measurement signal relatively constant.

8720-49, Session 8

Enabling aspects of fiber optic sensing in harsh environments

Indu F. Saxena, DynamedX (United States)

The advantages of optical fiber sensing in harsh electromagnetic as well as physical stress environments make them uniquely suited for structural health monitoring and non-destructive testing. In addition to aerospace applications they are making a strong footprint in geophysical monitoring and exploration applications for higher temperature and pressure environments. Deeper oil searches and geothermal exploration and harvesting are possible with these novel capabilities. Progress in components and technologies that are enabling these systems to be fieldworthy are reviewed and emerging techniques summarized that can leapfrog the system performance and reliability.

8720-35, Session PTues

Improved packaging of hermetic seal mini-dual inline laser diode module for harsh environments of aerospace applications

Alex A. Kazemi, Eric Y. Chan, Dennis G. Koshinz, The Boeing Co. (United States)

This paper 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. Also discussed are the critical parameters in the transmitter, channel, receiver, and link budget that are employed in successful low cost laser for high-speed inter-satellite communications system.

Building low cost laser for high speed communications network using optical links in space has proven to be an extremely complicated task and many such schemes were tried without success in the past. 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. However in the last few years, there has been impressive progress made to bring the concept to fruition in civilian and government-non classified projects. Laser Communications offer a viable alternative to established RF communications for inter-satellite links and other applications where high performance links are a necessity. 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.

8720-44, Session PTues

Propagation characteristics considering modulation and type of wavefront in free-space laser communications

Kayo Ogawa, Maiko Sakamoto, Japan Women's Univ. (Japan)

In recent years, free-space laser communication is drawing attention as one that complements radio waves, due to circumstances such as stringency of radio wave resources caused by increased demand for wireless radio communication. As free-space laser communication has such advantages as high-speed large-capacity communication, requiring no license, while having a flaw in that its communication quality is lowered by rain, fog, and atmospheric refractive index fluctuations called scintillation, it is required to provide high-quality communication that overcomes the flaw. Conventional circuit designs considered only visibility distance and transmission power. However, among circuit design variables are modulation method, carrier wave length, type of wavefront, and communication circuits should be designed appropriately depending on the installation environment. Amplitude modulation has been the mainstream modulation method in the past, but multilevel modulation has started to be considered for increased transmission quantity and enhanced noise immunity. Optical device technology to realize phase modulation is developing day by day, and phase modulation using optical waveguides, photorefractive crystals, etc., has already been adopted in optical fiber communication. Due to that, expectations for multilevel phase modulation are becoming greater in o free-space laser communication as well.

Therefore, this study has performed an evaluation of the propagation characteristics of combinations of each modulation method and carrier waves, and considered indexes for communication circuit designs that suit the installation environment. As a result, the result has been obtained that modulation method needs to be selected depending on the CNR, and the length and wavefront of carrier waves depending on the propagation distance.

8720-36, Session 9

High-power-handling linear-integrated coherent photoreceivers for RF photonics

Abhay M. Joshi, Shubhashish Datta, Jim Rue, Sruti Rajagopalan, Shaun Lemke, Discovery Semiconductors, Inc. (United States)

During the past few years, commercial digital telecommunications networks have started to deploy optical coherent technologies at data rates of 40Gb/s and 100Gb/s. In these long-distance networks, coherent reception produces linearly-recovered electrical data signals which include the linear impairments of the received electric field. Through the use of high-speed Analog-to-Digital Converters (ADC) and Digital Signal Processing (DSP), these impairments can be corrected for to a large extent. The general trend for these commercial digital coherent systems is to implement standardized opto-electronic components which are designed and optimized specifically for these 40G / 100G systems.

RF Photonics links can also benefit by implementing such coherent technologies, however optimal performance requires the use of appropriate opto-electronic devices. For example, a critical component in a typical RF Photonic link is a linear high power-handling photoreceiver. In this paper, we report integrated coherent optical receivers designed specifically for RF Photonics applications. These receivers may be implemented in either single- or dual-polarization (DP) systems which utilize I/Q (in-phase, quadrature) phase modulation. The integrated receivers incorporate a monolithic 90 degree optical hybrid followed by eight high power-handling InGaAs photodiodes. Linear operation to +27dBm of total optical input power, 20mA photocurrent per diode, output third-order intercept (OIP3) > 40dBm, third-order harmonic distortion < -100dBc, and RF bandwidths from 4GHz to >20GHz is presented. Such photoreceiver power-handling and linearity is required to optimize the photonic system spurious free dynamic range (SFDR), noise figure (NF) and link gain.

8720-37, Session 9

High-dynamic-range and high-capacity RF and microwave fiber optic links

Frank Weiss, EMCORE Corp. (United States)

Novel fiber optic transmitter control methodologies, high optical power and low RIN source lasers, high performance photodiodes and DWDM laser capability provide high dynamic range and high capacity transport for a wide range of sensing and communications applications. Measured component and system level test data demonstrates these performance improvements. Higher spur free dynamic range in excess of 110 dB·Hz2/3 over broad range of K-band frequencies is demonstrated, increasing the practical use of fiber as a transport method for high sensitivity applications. Multichannel DWDM operation provides simplified capacity expansion without compromising system performance, allowing arrayed photonic systems to be deployed. System characterization for a wide range of optical wavelengths and RF frequencies is provided to demonstrate these levels of performance in practical applications. Photonic component cost reductions combined with compact packaging further increase the ability of high performance fiber optic transport to address a wider range of applications, as the size, weight and performance barriers are eliminated.

8720-38, Session 9

Optical access system by Y-00 protocol at 2.5-Gb/s data rate for secure fiber communications

Fumio Futami, Osamu Hirota, Tamagawa Univ. (Japan)

Recently, optical fiber transmission lines have flows of huge data including confidential information. Presently, the mathematical cipher is employed to protect eavesdropping. However, the cipher break history shows such mathematical cipher is not reliable enough. Such fact demands an urgent development of more reliable cipher and drives us to focus actively on the research and development of Y-00 cipher. Y-00 cipher is an encryption scheme combined with physical phenomena and mathematical cipher, and it provides extremely high speed performance and a provable security. So far, the authors have successfully applied Y-00 cipher to the optical fiber transmission experiment over 120 km at data rate of 40 Gb/s. For practical use, a prototype of Y-00 cipher at 2.5-Gb/s data rate has been developed and its long term operation characteristic for more than a month has been verified in the installed optical fiber cable. The multiple remote point access system from a local point is practically useful. In this report, the authors demonstrate a secure multiple point access system for the homeland security using the intensity modulated Y-00 cipher. A one-to-three point secure access system using the wavelength division multiplexing (WDM) scheme is constructed where Y-00 ciphers encrypted with three different secret keys are transmitted from a local point to three users in different remote access points. For the first time to our knowledge, Y-00 cipher communications between users with the correct keys are successfully demonstrated at 2.5-Gb/s data rate while users with the different keys are out of communication.

8720-39, Session 9

Architecture of an all optical de-multiplexer for spatially multiplexed channels

Syed H. Murshid, Gregory L. Lovell, Michael F. Finch, Florida Institute of Technology (United States)

Multiple channels of light can propagate through a multimode fiber without interfering with each other and can be independently detected at the output end of the fiber using spatial domain multiplexing (SDM). Each channel forms a separate concentric ring at the output. The typical single pin-diode structure cannot simultaneously detect and de-multiplex the multiple channel propagation supported by the SDM architecture. An array of concentric circular pin-diodes can be used to simultaneously detect and de-multiplex the SDM signals; however, all optical solution is generally preferable. This paper presents simple architecture for an all optical SDM de-multiplexer.

8720-40, Session 9

Omnidirectional free-space optical receiver architecture

Syed H. Murshid, Michael F. Finch, Gregory L. Lovell, Florida Institute of Technology (United States)

Free Space Optical (FSO) communication is the fusion of wireless technology and optical fiber communications systems. It has the potential of providing fiber optic data rates without the physical restraints of optical fiber cables. This endeavor presents a novel receiver structure with potential for omnidirectional free space optical communications. Interesting approaches for accomplishing omnidirectional free space lasercomm such as direct detection and solar blind non-line of sight UV scattering have been reported over the last few years. However, these technologies have resulted in limited distances of the order of 10 to 100 meters and data rates often limited to less than 1 Mb/s. This endeavor reports the architecture of an omnidirectional receiver setup by integrating an off the shelf detector and a fiber bundle, where the fiber bundle couples omnidirectional photons within its field of view and delivers these photons to the detector. The coupling of light from all directions into a detector is regulated by the cone of the acceptance angle of the fiber. Multiple fibers with overlapping acceptance angles provide the necessary coverage that may be needed to extract the optical signal from the free space optical channel. Simulated results, showing the normalized power pattern of the system, are presented to demonstrate omni-directional potential of the structure. Theoretical power level versus distance plot for an FSO System employing On-Off Keying (OOK) is also presented.

8720-41, Session 10

Miniature, compact laser system for ultracold atom sensors

Juan M. Pino, Mike A. Anderson, Benjamin Luey, Vescent Photonics, Inc. (United States)

As ultracold atom sensors begin to see their way to the field, there is a growing need for small, accurate, and robust laser systems to cool and manipulate atoms for sensing applications such as magnetometers, gravimeters, atomic clocks and inertial sensing. In this paper we present an absolutely referenced, frequency-agile laser source. The laser source is in a butterfly package roughly the size of a stack of business cards, and includes two copackaged lasers, one referenced to an atomic transition (780 nm), and the other a frequency agile laser, offset phase locked up to 10 GHz to the first laser.

We will also present the entire laser system. The laser system features a liquid crystal (LC) shutter/demux stage, to both shutter laser beams and divert power to different optical paths as needed. The system also includes a fiber-coupled semiconductor optical amplifier (SOA), allowing for higher powers, fast pulsing, and additional shuttering. The laser source, LC shutter, and SOA represent enabling technology for field deployable cold atom sensors, replacing a laboratory table's worth of optics with a system the size of a paperback novel.

8720-42, Session 10

Infrared light emitting quantum dots for defense applications

Matthew Stevenson, Zhaoqun Zhou, James Perkins, Melanie Bunda, Justin Kamplain, Peter Kazlas, QD Vision, Inc. (United States)

We report on infrared quantum dot light emitting diodes (QLEDs) whose emission spans the wavelength range from 900 nm to 1.35 µm. QLEDs are a printable, large-area, thin film electroluminescent technology based on colloidal quantum dots that delivers precise wavelength control and power efficiency at a low cost of manufacture. Today, these devices emit sufficient power for short-range lighting applications and long-range sensing. Infrared QLEDs run at very low drive voltages, and function as diffuse large area emitters that are very thin and light weight.

In this paper, we demonstrate narrow band infrared QLEDs that emit in the wavelength range of 900 to 1350 nm.. The devices discussed are characterized with respect to their efficiency, power output, and lifetime, and these data are used to evaluate their suitability for use in a variety of defense-related applications. We discuss devices with active areas up to 4 cm2. Experimental results are presented that demonstrate a low turn-on voltage of 1.4 V, a maximum efficiency of 0.58 %, a power efficiency of 2 mW/W, and a peak power output of 5 mW for these large area devices with no heat sinking. Operational lifetimes of up to 1000 hours at operating drive levels are also shown. We also present a radiometry model that accurately predicts the performance of infrared QLEDs in illumination applications.

8720-43, Session 10

Fiber optic-based laser systems for terahertz frequency-comb spectroscopy

Yevhen Rutovytskyy, Kimberly Kaltenecker, Fahad A. Althowibi, Eric Donkor, The Univ. of Connecticut (United States)

We present a dual channel THz frequency comb spectroscopy technique for the detection and classification of trace agents. Our approach is based on measuring the rotational, vibrational and polarization state of the line spectra. Simultaneous measurement of the polarization and the frequency of the lines greatly enhance the sensitivity of the spectrometer. The continuous THz waves are generated through spectral filtering of the broadband spectrum (1450nm-1650nm) of the spontaneous amplified emission of the semiconductor optical amplifier. The comb has orthogonal polarizations in each channel, which are used in a tandem as a probe for spectral characteristics of gas species. Such set up allows us to characterize both the wavelength and a polarization of the rotational and vibrational spectral signatures of a trace agent, thus increasing the sensitivity of a sensing system. We shall present results for common atmospheric trace agents.

8720-45, Session 10

Experimental demonstration of all-optical memory based on wave mixing in a semiconductor optical amplifier

Kimberly Kaltenecker, Yevhen Rutovytskyy, Fahad A. Althowibi, Eric Donkor, The Univ. of Connecticut (United States)

We present an experimental demonstration of an all optical memory consisting of a single semiconductor optical amplifier as the active medium based on wave mixing. The circuit is designed as a fiber ring consisting of the semiconductor amplifier, a bi-directional 2x2 fiber coupler, an isolator, a polarization controller, and a Faraday mirror. The output is observed on the spectrum analyzer, which consists of the peak wavelength of the SOA plus an additional signal generated through wave mixing, which is tunable within the band gap of the SOA. We shall demonstrate two modes of operation of the device, which will consist of a flip flop switch between three states, as well as a single data storage memory. The stable states consists of two modes, where the mode amplitude represents the state. Mode 1 corresponds to 1574 nanometers and mode 2 corresponds to 1580 nanometers. A contrast ratio between an “on” and “off” state is measured for each mode and the mode of operation is based on the polarization. We shall present the state diagram for the circuit, the effect of power on the system, the effect of the SOA structure, wave mixing effects, and how to operate the device for both logic operation and data storage.

8720-46, Session 10

Phase-shifted fiber-Bragg-grating-based humidity sensor

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A humidity sensor based on the phase-shifted fiber Bragg grating (PS-FBG) is presented. The sensor is fabricated by coating the PS-FBG surface with a thin polyimide layer. Exposure to moisture swells this thin polyimide coating and induces a tensile stress on the PS-FBG, thus PS-FBG sensor Bragg wavelength. Experimental results illustrate that Bragg wavelength of the sensor increased linearly with increase in relative humidity. It was also found that the humidity sensitivity of the sensor decreased with the temperature. Temperature compensated relative humidity approach is proposed.

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8721-1, Session 1

Development of a Raman chemical image detection algorithm for authenticating dry milk

Jianwei Qin, Kuanglin Chao, Moon S. Kim, Agricultural Research Service (United States)

Various adulterants have been found to be deliberately added to milk powder to produce increased contents of particular compositions as perceived by conventional testing methods. The adulterants can cause illnesses and deaths for consumers, and thus there is a need to develop a rapid and accurate method for authentication of milk powder. This research aims to investigate the potential of macro-scale Raman chemical imaging for rapid detection of multiple adulterants in milk powder. Potential chemical adulterants, including ammonium sulfate, dicyandiamide, melamine, and urea, were mixed together into skim dry milk in the concentration range of 0.1–5.0% for each adulterant. Using a 785-nm laser, a benchtop point-scan Raman chemical imaging system acquired hyperspectral images from the mixed powder samples. The Raman images were obtained in the wavenumber range of 102–2538 cm–1 for a 25x25 mm2 area of each mixture sample, with a spatial resolution of 0.25 mm. Important Raman shift positions for adulterant detection were determined based on the reference Raman spectra of the pure chemicals and the milk powder. An image classification method was developed using the selected wavenumbers to differentiate the adulterant particles from the milk powder background. The detection method developed in this study has the potential to be adopted by a future high-throughput inspection system for rapid and accurate authentication of dry milk powder and other food ingredients.

8721-2, Session 1

Rapid identification and quantitative detection of pesticides and pathogens using surface-enhanced Raman scattering (SERS) spectroscopy

Qiuming Yu, Univ. of Washington (United States); Yan Deng, Univ. of Washington (United States) and Tsinghua Univ. (China)

Rapid identification and quantitative detection of food contaminants from small molecules to large pathogens is highly desired. Currently, there is a lack of detection techniques capable of simultaneous detection of all types of food contaminants. Surface-enhanced Raman scattering (SERS) spectroscopy enabled by the advance of nanotechnology has immerged as a powerful analytical tool. We developed novel quasi-3D plasmonic nanostructure arrays (Q3D-PNAs) that can be rationally designed to make the SERS "hot spots" either at the top of gold nanohole arrays or at the bottom of gold nanodisk arrays for sensitive detection of large pathogens or small pesticides molecules, respectively. Unlike the SERS substrates made out of nanoparticles, Q3D-PNAs provide not only high sensitivity but also reproducibility. The finite-difference time-domain (FDTD) electromagnetic simulations were conducted to design the Q3D-PNAs that were made on silicon or ITO coated glass substrates or in PDMS. The nanostructures were designed to exhibit a surface plasmon wavelength around 785 nm, the laser excitation wavelength and the estimated enhancement factor from the relationship of the fourth power of the ratio of the maximum local electric field to the incident light electric field (|Emax/E0|4) to be ~106 (electromagnetic enhancement only). Electron beam lithography and soft lithography were applied to fabricate the optimized Q3D-PNAs. Insecticides (malathion) and herbicides (atrazine and simazine) were detected and quantified. The limit of detection in the ppb level was demonstrated. Gram negative (A. calcoaceticus, E. coli K12, P. aeruginosa) and gram positive (S. epidermidis) bacteria were detected and identified using principle component analysis (PCA). We further integrated the Q3D-PNAs SERS-active substrates in microfluidic systems for in-situ real time analysis and detection.

8721-3, Session 1

Detection of pesticide residues at paprika surface based on Raman spectroscopy

Namkyoung Choi, Korea Research Institute of Standards and Science (Korea, Republic of); Changyeun Mo, National Academy of Agricultural Sciences (Korea, Republic of); Hyun Geun Oh, Korea Research Institute of Standards and Science (Korea, Republic of); Sukwon Kang, National Academy of Agricultural Sciences (Korea, Republic of); Kangjin Lee, National Academy of Agricultural Sciences (Korea, Republic of); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Ki-Bok Kim, Yong-Il Kim, Korea Research Institute of Standards and Science (Korea, Republic of)

In this paper, the pesticide residue measurement of the agricultural products based on the diffuse reflectance Raman spectroscopy (DRRS) is described. The Raman spectroscopic system consists of diode laser generating continuous wave with wavelength of 785 nm, multimode optical fibers, focusing probe with two prism to detect the Stokes radiation, multi-channel detectors with charge couple device, sample holder, personal computer and so on. The DRRS spectra of 10 kinds of pesticides for paprika sample were measured and analyzed. The differences in intensities and absorptions Raman shift at Raman spectra among pesticides were found. The principal component analysis was used to recognize the kinds of pesticides. By using DDRS, it is possible to detect the multi-elements of pesticide residues on the paprika sample. As a conclusion, a rapid inspection of food safety will be possible based on diffuse reflectance Raman spectroscopy.

8721-5, Session 2

Development of a multi-spectral imaging system for the detection of bruises on apples

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Detection of bruises on apples is important for an automatic apple sorting system. Two effective wavelengths of 850 and 960nm for the detection of bruises on apples was selected based on a 400-1000nm hyperspectral imaging system and segmented principal component analysis (PCA) in our previous study. In this study, a multi-spectral imaging system with two bands 850 and 960nm in the near-infrared range was developed for detecting bruises on 'Fuji' apples. The system was consisted of two dichroic mirror/beamsplitters at 805 and 900nm, two bandpass filters at 850 and 960nm, and two 2-channel CCD cameras. Two LED line light sources at 850 and 960 nm provided uniform illumination on apples. Multi-spectral images of 50 intact and 50 bruised apples were acquired. The bruises on the apples were manually made on the equator region using a steel ball dropping from a 40 cm height. The principal component analysis (PCA) was conducted on the two-band images to determine the weighted coefficients for a PC image, which improved the intensity contrast between the bruised region and the sound peel. A bruise detection algorithm based on the PC images and a global threshold method was developed. Results show that 100% of the intact apples are correctly classified, 96% of the bruised apples are correctly recognized.

8721-6, Session 2

Rapid non-destructive assessment of pork edible quality by using VIS/NIR spectroscopic technique

Leilei Zhang, Yankun Peng, China Agricultural Univ. (China); Sagar Dhakal, China Agricultural University (China) and China Agricultural Univ (China); Yulin Song, Juan Zhao, Songwei Zhao, China Agricultural University (China)

This research was to develop a rapid nondestructive method to evaluate the edible quality of chilled pork. Forty-two samples were packed in seal plastic bags and then stored at 4°C. Vis/NIR reflectance spectra in the range of 380 nm to1100 nm were collected from 2 samples on each day across 21 days. Microbiological, physicochemical and organoleptic characteristics such as the total viable counts (TVC), total volatile basic-nitrogen (TVB-N), pH value and color parameters (L*, a*, b*) were determined to appraise pork edible quality. Savitzky-Golay (SG) based on five and eleven smoothing points pre-processing methods were employed to eliminate the spectra noise. The least-square support vector machines (LS-SVM) regression was applied to establish the prediction models with the de-noised spectra. A single model was developed to predict the quality of the pork meat based on TVC, TVB-N, pH and color parameter L* indexes with the prediction accuracy of 90%. The results demonstrated that Vis/NIR spectroscopic technique combined with LS-SVM algorithm is a feasible assessment tool. It can provide a potential rapid and nondestructive tool to detect pork edible quality.

8721-7, Session 2

Development and evaluation of a vision based poultry debone line monitoring system

Colin T. Usher, Wayne D. Daley, Georgia Tech Research Institute (United States)

Efficient deboning is the key to optimizing production yield (maximizing the amount of meat removed from a chicken frame while reducing the presence of bones). Many processors evaluate the efficiency of their deboning lines through manual yield measurements, which involves using a special knife to scrape the chicken frame for any remaining meat after it has been deboned. Researchers with the Georgia Tech Research Institute (GTRI) have developed an automated vision system for estimating this yield loss by correlating image characteristics with the amount of meat left on a frame. This same system is also able to determine the probability of bone chips remaining in the output product. The yield loss estimation is accomplished by the system's image processing algorithms, which correlates image intensity with meat thickness and calculates the total volume of meat remaining. The team has established a correlation between transmitted light intensity and meat thickness with an R2 of .92. Employing a special illuminated cone and sophisticated software algorithms, the system can make measurements in a few seconds and has at least a 90-percent correlation with yield measurements performed manually. The system is able to determine the presence/absence of clavicle bones with an accuracy of ~95% and fan bones with an accuracy of ~80%. This paper describes in detail the approach and design of this system, results from field testing, and potential benefits that such a system can provide to the poultry processing industry.

8721-22, Session PTues

Optical instrument development for detection of pesticide residue in apple surface

Sagar Dhakal, Yongyu Li, Yankun Peng, China Agricultural Univ. (China); Kuanglin Chao, Jianwei Qin, Agricultural Research Service (United States)

Apple is the world largest produced and consumed fruit item. At the same time, apple ranks number one among the fruit item contaminated with pesticide. This research focuses on development of laboratory based self-developed software and hardware for detection of commercially available organophosphorous pesticide in apple surface. A laser light source of 785nm was used to excite the sample, and Raman spectroscopy assembled with CCD camera was used for optical data acquisition. A hardware system was designed and fabricated to clamp and rotate apple sample of varying size maintaining constant working distance between optical probe and sample surface. Graphical Users Interface (GUI) based on LabView platform was developed to control the hardware system. The GUI was used to control the Raman system including CCD temperature, exposure time, track height and track centre, data acquisition, data processing and result prediction. Raman fingerprint of pure chlorpyrifos placed in aluminum foil and pesticide free wholesome apple were acquired first. Different concentrations of commercially available 48% chlorpyrifos pesticide solutions were prepared and gently placed in apple surface and dried. Raman spectral data at different points from same apple along the equatorial region were then acquired. The results show that prominent peaks at 341cm-1 and 632cm-1 represent the pesticide residue. The laboratory based experiment was able to detect pesticide solution of 1% (by volume) within 1 second. The result of the research is promising and thus is a milestone for developing industrially desired real time, non-invasive pesticide residue detection technology in future.

8721-23, Session PTues

Development of VIS/NIR spectroscopic system for real-time prediction of fresh pork quality

Haiyun Zhang, Yankun Peng, China Agricultural Univ. (China); Songwei Zhao, China Agricultural Univ (China); Akira Sasao, Tokyo Univ. of Agriculture & Technology (Japan)

Water content of fresh meat is one of the most important parameters in meat classification, which influences nutritional value and consumers' purchasing power. The research was aim to develop a prototype for real-time detection of water content in meat. A VIS/NIR spectrograph in the range of 350 to 1100 nm was used to collect the spectral data. In order to acquire more potential information of the sample, optical fiber multiplexer was used. A cylindrical device was designed and fabricated to hold optical fibers from multiplexer. Light unit consisted of four tungsten halogens each with power of 10w. A conveyor belt was designed to transport the samples at a prescribed speed, and a photosensor was used to detect the position of the sample. The spectral data were obtained with the exposure time of 30ms from the samples moving at the speed of 0.4m/s in the conveyor belt. A total of 70 fresh pork samples were used to develop prediction model for real time detection. The spectral data were pretreated with standard normalized variant (SNV) and partial least squares regression (PLSR) was used to develop prediction model. The correlation coefficient and root mean square error of the validation set was 0.893 and 0.546 respectively. 26 independent samples were tested to verify the accuracy of the module, with the correlation coefficient of 0.871 and root mean square error of 0.637. The research shows that the real-time detection system based on VIS/NIR spectroscopy can be efficient to predict the water content of fresh meat.

8721-24, Session PTues

A noninvasive technique for real-time detection of bruises in apple surface based on machine vision

Juan Zhao, Yankun Peng, China Agricultural Univ. (China); Sagar Dhakal, Leilei Zhang, China Agricultural Univ (China); Akira Sasao, Tokyo Univ. of Agriculture & Technology (Japan)

Apple is one of the highly consumed fruit item in daily life. However, due to its high damage potential and massive influence on taste and export, the quality of apple has to be detected before it reaches the consumer's hand. This study was aimed to develop a hardware and software unit for real-time detection of apple bruises based on machine vision technology. The hardware unit consisted of a light shield installed two monochrome cameras at different angles, LED light source to illuminate the sample, and sensors at the entrance of box to signal the positioning of sample. Graphical Users Interface (GUI) was developed in VS2010 platform to control the overall hardware and display the image processing result. The hardware-software system was developed to acquire the images of 3 samples from each camera and display the image processing result in real time basis. An image processing algorithm was developed in Opencv and C++ platform. The software is able to control the hardware system to classify the apple into two grades based on presence/absence of surface bruises with the size of 5mm. The experimental result is promising and the system with further modification can be applicable for industrial production in near future.

8721-25, Session PTues

Hyserspectral imaging for different geographical origin of red pepper powder

Sukwon Kang, Kangjin Lee, Changyeun Mo, Jongguk Lim, Jongryul Park, National Academy of Agricultural Sciences (Korea, Republic of)

The red pepper (Capsicum annuum L.) powder is one of the most important seasonings and widely utilized in processed foods at Korea. Because of unique pungency and sweet taste compared to those from other geographical origins, the most Korean consumers want to buy red pepper powder grown and produced in Korea, and then price of Korean red pepper power is higher than imported one. Thus the violation of geographical origin for red pepper powder happens frequently every year. Trace elements (strontium and barium) in red pepper powder were analyzed to determine the geographical origins. However, to analyze the trace elements, this method was not easy to use. The simple and nod-destructive analytical method has been required to determine the geographical origins of red pepper powder. It is known that the near infrared spectroscopic analysis can distinguish between the Korean and Chinese red pepper powder. However, if those are mixed, the accuracy is decreased. Hyperspectral image has been used as quantity and quality analysis for agricultural products. In this study, the hyperspectral image processing method was investigated whether it can discriminate the geographical origin of red pepper powder. The objective of this study is to evaluate if near infrared spectra from the hyperspectral imaging could be used to discriminate between the red pepper powder produced in Korea and imported red pepper powder.

8721-26, Session PTues

Hyperspectral fluorescence imaging for measuring responses of drought and salt stresses in rice crop

Park Eunsoo, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States); Jin-Won Kim, Do-Sun Kim, Seoul National Univ. (Korea, Republic of)

Spectral imaging technique has been used as a useful phenotyping tool for high throughput screening in plant breeding. In this study, the responses of drought and salt stresses in rice crop were investigated using hyperspectral fluorescence imaging. Fluorescence spectral images were acquired for the rice crops with and without drought and salt stresses. Optimal spectral wavebandsof the fluorescence imagewere investigated for the measurements of the stress responses of the rice crops. The results showed that fluorescence images of the wavebands of 688 nm and 630 nm were the most effective images for the measurements of the stress responses in rice crops exposed to the drought and salt, respectively.

8721-27, Session PTues

Cross-correlation of temperature-dependent Raman and NIR data for glycine

Julie Nguyen, Walter F. Schmidt, Agricultural Research Service (United States)

Frequencies in Raman data are discrete, sharp, and large in number and mostly independent of each other. Frequencies in NIR data are broad, non-discrete, often overlapping, few in number, and routinely co-vary. Spectral interpretation in both regions therefore can prove to be complicated. Glycine (Gly) chemical structural features are discrete and limited: thus cross correlation of spectral interpretation with temperature is possible. Raman peaks can verify NIR interpretation and correspondingly, NIR peaks can confirm Raman structural interpretation. Spectral analysis of Gly allows access to interpretation of structurally more complicated amino acids and potentially also peptides, i.e. more complicated structural analogs of amino acids.

8721-28, Session PTues

Raman spectroscopy and imaging to detect contaminants for food safety applications

Kuanglin Chao, Jianwei Qin, Moon S. Kim, Agricultural Research Service (United States); Yankun Peng, China Agricultural Univ. (China); Diane E. Chan, Yuche Cheng, Agricultural Research Service (United States)

Pesticides are used in agricultural production to control pests, diseases, weeds and other plant pathogens to minimize yield losses and maintain high product quality. Since residues from those chemical compounds can be present on the surfaces of vegetables and fruits which may cause major health problems. However, the chronic effects of pesticides from food intake on human health are not well defined, but there is increasing evidence of carcinogenicity and genotoxicity, as well as disruption of hormonal functions. (It is not easy to establish how much of a pesticide is "safe" for people.) It is thus essential that pesticide exposure be minimized and the presence of pesticide residues in food be regulated and monitored. This study established a rapid method using a laboratory-based point-scanning Raman chemical imaging system to quantify the presence of selected pesticide compounds. Pesticide chemicals (thiabenazole, acetamiprid, Diphenylamine, azinphos-methyl, and Pyrimethanil) were mixed with organic solvents at various concentrations, to investigate spectral detection and quantification. Relationships between ingredient concentration and the height and area of Raman spectral peaks were determined. Models were developed for quantitative analysis of these pesticides.

8721-29, Session PTues

PLSR model development for prediction of melamine concentration in milk powder by NIR hyperspectral reflectance imaging

Jongguk Lim, National Academy of Agricultural Sciences (Korea, Republic of); In-Suck Baek, Chungnam National Univ. (Korea, Republic of); Moon S. Kim, Hoyoung Lee, Agricultural Research Service (United States); Sang Ha Noh, Seoul National Univ. (Korea, Republic of); Xiaping Fu, Zhejiang Univ. (China)

Hyperspectral imaging technology is the latest spectroscopic techniques for measuring the quality and safety evaluation for agricultural products and food quickly and non-destructively. In this study, near-infrared

(NIR) hyperspectral imaging system (1000 ~ 1700 nm) combined with partial least square regression (PLSR) analysis was used to predict the melamine concentration contained in milk powder. Mixture concentration levels of melamine and milk powder was set to weight ratio (g/g) at 0%, 0.02%, 0.04%, 0.06%, 0.08%, 0.1%, 0.2%, 0.4%, 0.6%, 0.8% and 1%. The PLSR model was developed to correlate the hyperspectral reflectance spectrum data (independent variables) with melamine concentration (dependent variables) in milk powder. Several pretreatment methods were adapted for removing of spectrum distribution according to the scattering of light and irregular surface of mixture samples. The determination coefficient for the calibration (RC2) and standard error of prediction for calibration (SEC) of developed PLSR model for non-pretreatment (raw spectrum) were 0.9619 and ±0.0657% for calibration, respectively. The determination coefficient for the validation (RV2), standard error of prediction for validation (SEP) and number of factors (F) were 0.9432, ±0.0809%, and 10, respectively. The optimal result acquired for predicting melamine in milk powder was a PLSR model using a 1st Derivative pretreatment with RV2= 0.9562, SEP=±0.0711%, and F=8, respectively.

8721-30, Session PTues

Detection of liquid hazardous molecules using linearly focused Raman spectroscopy

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It is an important issue to identify and analyze hazardeous materials in the water in a nondestructure manner and very short time. Particularly, prompt nondestructive checking at the gate of crowded malls, stadiums, or airports is of particuar importance. We have used linearly focused Raman spectroscopy to analyze liquid materials in transparent or semi-transparent bottles without opening their caps. Continuous laser with 532 nm wavelength and 54 mW/130 mW beam energies were used for Raman spectroscopy. Various hazardous materials including flammable liquids and explosive materials in the water have successfully been distinguished and identified within a couple of seconds. We believe that our technique will be one of suitable methods for fast screening of liquid materials in bottles.

8721-31, Session PTues

Rapid and sensitive determination of benzo[a] pyrene in black ginseng using fluorescence detector and high-performance liquid chromatography-tandem mass spectrometry

Hyun-jeong Cho, Hye-jin Kim, Byeong-cheol Son, Dong-geun Cho, National Agricultural Products Quality Management Service (Korea, Republic of)

A black ginseng is produced by steaming a ginseng root followed by drying repeatedly 9 times during the process and it is changed to be black color, so it is known that a black ginseng has more contents of saponins than a red ginseng. However a fake black ginseng which is produced to be black color at high temperature in a short period of time generate carcinogenic benzo[a]pyrene(BaP) through the process. In South Korea this year, maximum residue level (MRL) for BaP was established to 2 ?g/kg in black ginseng and more sensitive method was developed to quantitatively analyze the BaP by high performance liquid chromatography (HPLC) coupling with tandem mass spectrometry (MS/MS). Chromatographic separation was performed on a SupelcosilTM LC-PAH column (3 ?m, 3 mm x 50 mm). Mobile phase A was acetonitrile and mobile phase B was water. Bap was separated other 15 polycyclic aromatic hydrocarbons (PAHs) which have been selected as priority pollutants by the US Environmental Protection Agency (EPA). Linearity of detection was in the range of 0.2–20 ng/mL and limit of detection (LOD) for BaP was lower than 0.1 ?g/kg, limit of quantification (LOQ) was 0.2 ng/kg. The recovery of Bap was 92.54%±6.3% in black ginseng.

8721-37, Session PTues

A multifrequency, self-calibrating, in-situ soil sensor with energy-efficient wireless interface

Gunjan Pandey, Ratnesh Kumar, Robert J Weber, Iowa State Univ. (United States)

Real time and accurate measurement of sub-surface soil moisture and nutrients is critical for agricultural and environmental studies. This paper presents a novel on-board solution for a robust, accurate and self-calibrating soil moisture and nutrient sensor with inbuilt wireless transmission and reception capability that makes it ideally suited to act as a node in a network spread over a large area. The sensor works on the principle of soil impedance measurement by comparing the amplitude and phase of signals incident on and reflected from the soil in proximity of the sensor. Accuracy of measurements is enhanced by considering a distributed transmission line model for the on-board connections. Presence of an inbuilt self-calibrating mechanism which operates on the standard short-open-load (SOL) technique makes the sensor independent of inaccuracies that may occur due to variations in temperature and surroundings. Moreover, to minimize errors, the parasitic impedances of the board are taken into account in the measurements. Measurements of both real and imaginary parts of soil impedance at multiple frequencies gives the sensor an ability to detect variations in ionic concentrations other than soil moisture content. A switch-controlled multiple power mode transmission and reception is provided to support highly energy efficient medium access control as introduced by Sahota et al.

8721-8, Session 3

Determination of optimal excitation and emission wavebands for detection of defect cherry tomato by using fluorescence emission and excitation matrix

In-Suck Baek, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States); Young-Sik Kim, SangMyung Univ. (Korea, Republic of)

Fluorescence imaging technique has been widely used for quality and safety measurements of agro-food materials. Fluorescence intensity of the target materials is influenced by spectral wavebands of excitation sources. Hence, selection of the proper wavelength of the excitation source is important to differentiate target materials effectively. In this study, optimal fluorescence excitation wavelength was determined on the basis of fluorescence emission intensity of defect and sound areas of cherry tomatoes. The result showed that fluorescence responses of defect and sound surfaces were most distinctively separated with the excitation of the spectral range between 400 and 410 nm. Fluorescence images of defect cherry tomatoes were acquired with the LEDs of the central wavelength of 400 nm to verify the detecting performance of the defect cherry tomatoes. The resultant fluorescence images showed that the defects were discriminated from sound areas on cherry tomatoes with above 95% accuracy. It was indicated that the excitation of 400 nm LEDs is suitable for fluorescence imaging for defect detection of cherry tomatoes.

8721-9, Session 3

Development of fluorescence-based handheld imaging devices for food safety inspection

Hoyoung Lee, Moon S. Kim, Kuanglin Chao, Diane E. Chan, Agricultural Research Service (United States)

For sanitation inspection in food processing environments, we recently designed and developed inexpensive handheld imaging devices. The aim is to use the devices as assistive tools for human inspectors performing visual sanitation inspection of food processing/handling equipment surfaces. Many organic materials emit fluorescence. The devices use fluorescence techniques to detect the presence of fecal contaminants, organic residues, and bacterial biofilms at multispectral emission bands. The inexpensive visual aid devices utilize miniature cameras, multispectral (interference) filters, and high power LED illumination with wi-fi capabilities to display live inspection images on smart phone or tablet devices. The devices can provide objective means to assess the effectiveness of sanitation procedures and can help processors minimize food safety risks or determine potential problem areas. This paper presents the design and development including evaluation and optimization of the hardware components of the imaging devices.

8721-10, Session 3

Time efficient methods for scanning a fluorescent membrane with a fluorescent microscopic imager for the quality assurance of food

Steffen Lerm, Silvio Holder, Mathias Schellhorn, Peter Brückner, Gerhard Linss, Technische Univ. Ilmenau (Germany)

One part of the quality assurance of meat is the estimation of germs in the meat exudes. The kind and the number of the germs in the meat configure the medical risk for the consumer of the meat. State-of-the-art analyses of meat are incubator test procedures. The main disadvantages of such incubator tests are the time consumption, the necessary equipment and special skilled employees. These facts cause a high inspection cost. For this reason a new method for the quality assurance is necessary which combines low detection limits and less time consumption. One approach for such a new method is fluorescence microscopic imaging. The germs in the meat exude are caught in special membranes by body-antibody reactions. The germ typical signature could be enhanced with fluorescent chemical markers instead of reproduction of the germs. Each fluorescent marker connects with a free germ or run off the membrane. An image processing system is used to detect the number of fluorescent particles. Each fluorescent spot should be a marker which is connected with a germ. Caused by the small object sizes of germs, the image processing system needs a high optical magnification of the camera. A high optical magnification causes a small field of view and a small depth of focus. For this reasons the whole area of the membrane has to be scanned in three dimensions. To minimize the time consumption, the optimal path has to be found. This optimization problem is influenced by features of the hardware and is presented in this paper. The traversing range in each direction, the step width, the velocity, the shape of the inspection volume and the field of view have influence on the optimal path to scan the membrane.

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8721-11, Session 4

A new wireless detection device for the in-situ identification of Salmonella Typhimurium on food surfaces

Yating Chai, Suiqiong Li, Shin Horikawa, Bryan A. Chin, Auburn Univ. (United States)

This paper presents a new device and method for the direct and real-time detection of Salmonella Typhimurium on tomato surfaces. This real-time in-situ detection was accomplished with phage-based magnetoelastic (ME) biosensors on fresh food surfaces. The E2 phage from a landscape phage library serves as the bio-recognition element that has the capability of binding specifically with S. Typhimurium. This mass-sensitive ME biosensor is wirelessly actuated into mechanical resonance by an externally applied time-varying magnetic field. When the biosensor binds with S. Typhimurium, the mass of the sensor increases, resulting in a decrease in the sensor's resonant frequency. Until now, ME sensors had to be collected from the tomato surface where they are exposed to S. Typhimurium and inserted into a measurement coil for the detection of the bacterium. In contrast, the newly designed test device allows the whole detection process to take place directly on the tomato. Changes in resonant frequency over time due to the accumulation of S. Typhimurium on the sensor were measured and are presented. Real-time in-situ detection of 20 minutes was achieved. In addition, this new methodology effectively decreases the measurement error and enables the simultaneous detection of multiple sensors.

8721-12, Session 4

Novel approach for Salmonella detection in soil using phage-based magnetoelastic biosensors

Mi-Kyung Park, Suiqiong Li, Kanchana Weerakoon, Shin Horikawa, Yating Chai, Nitil Hirematha, Bryan A. Chin, Auburn Univ. (United States)

Fresh produce can become contaminated by direct contact with irrigation water, animal waste, insects, and soil that carry pathogens. The identification of the original source of a contamination is necessary to better control and prevent foodborne illnesses caused by consumption of fresh produce. Hence, a previously developed phage-based magnetoelastic (ME) biosensor was applied to detect Salmonella in soil. The ME biosensors are composed of a magnetostrictive strip (1-mm size) and filamentous E2 phages as a biorecognition element. The principle advantage of ME biosensors is that they can be applied and read directly in the field providing a near real time detection of bacterial contamination. Initial results from the direct application of the ME biosensors to soil did not provide reliable results. It was found that the sensor bound nonspecifically with numerous components (organic matter, humic acid, and minerals) of the soil. Therefore, multiple filtration procedures were introduced in order to isolate target bacteria from the soil while minimizing the extraction of other soil components. A procedure involving simple soil preparations that can be conducted in the field was developed. Using this preparation, it was demonstrated that Salmonella in the soil can be successfully detected with reliable and reproducible results. This study demonstrates that the ME biosensor method may serve as a simple, inexpensive, sensitive, and practical detection method for on-site detection of Salmonella in soil, and this approach enhance safety of fresh produce.

8721-13, Session 4

Automatic colony detection and counting using hyperspectral imaging for pathogen detection

Seung-Chul Yoon, William R. Windham, Scott Ladely, Bosoon Park, Kurt C. Lawrence, Agricultural Research Service (United States)

This paper reports the development of a technique for detecting and counting bacterial colonies on an agar plate using hyperspectral imaging for pathogen detection. Colony counting is widely used for enumerating microbial counts within food products, such as ground beef and chicken carcass rinses. Colony detection and segmentation to locate colonies on Petri dishes is fundamental to many image-based automatic colony counting systems with RGB color cameras. Image segmentation algorithms adopted in automatic colony counters often utilize a high contrast and a color difference between agar and colonies. However, phenotypic difference in genetically similar microorganisms

and presence of background microflora often make a color-based colony-detection technique difficult in determining and counting specific bacterial types. Separation of touching colony objects is also difficult because the information about how many colonies are present in a clump is not available a priori. We propose to use hyperspectral imaging for detecting and counting specific types of bacterial colonies on an agar plate. Multivariate data analysis based absorbance data was used to find optimal wavelengths that maximize the contrast between colonies and agar and the accuracy of determining bacterial types, and that provide colony-object sizes to reduce mixed spectral effects from background agar. The developed image segmentation technique consisted of a local maxima search, an automatic intensity threshold algorithm, and a touching-object separation technique with the Delaunay triangulation that was constructed from the estimated number of colonies in a clump. Experimental results with spread plates of non-O157 E. coli are provided. When combined with a type-identification method, the fully developed system provides a rapid and accurate tool to enumerate and identify pathogens in food products.

8721-14, Session 4

Development of hyperspectral imaging technique for detecting Salmonella on agar media

Youngwook Seo, Seung-Chul Yoon, Bosoon Park, Arthur Hinton Jr., Willian R. Windham, Kurt C. Lawrence, Agricultural Research Service (United States)

Salmonella bacteria are the second leading cause of foodborne disease outbreaks resulting from the consumption of contaminated foods (commonly poultry products) in the United States. This paper reports the development of hyperspectral imaging technique for detecting and differentiating two most common Salmonella serotypes, Salmonella Enteritidis (SE) and Salmonella Typhimurium (ST), from background microflora that are often found in poultry carcass rinse. Presumptive positive screening of colonies with a traditional direct plating method is labor intensive and prone to human subjective errors. Thus, this paper is concerned with the detection of differences in spectral characteristics among pure SE, ST, and background microflora grown on Brilliant Green Sulfa (BGS) and Xylose Lysine Tergitol 4 (XLT4) agar media with a spread plating technique. Visible near-infrared hyperspectral imaging providing the spectral and spatial information unique to each microorganism was utilized to differentiate SE and ST from the background microflora. Various classification algorithms using some of classical machine learning techniques and multivariate data analysis methods such as PCA-DA, PLS-DA, kNN, LDA, QDA, and SVM were tested and compared to find the best method in classification accuracy. The classification accuracy for determining the presence of SE and/or ST on BGA agar was over 99% although it was difficult to differentiate between SE and ST. The classification accuracy for ST detection on XLT4 agar was over 99%. Thus, an automatic decision making algorithm with over 99% classification accuracy was developed to determine the presence of Salmonella regardless of serotypes. Once fully developed, this hyperspectral imaging technique is expected to become a rapid and accurate technique for positive-presumptive screening of Salmonella on agar plates.

8721-15, Session 5

Investigation of NIR hyperspectral imaging for discriminating melamine in milk powders

Xiaping Fu, Zhejiang Univ. (China); Moon S. Kim, Agricultural Research Service (United States)

Identification of food ingredients rapidly and accurately is an important issue in food safety analysis. In the past five years, melamine (2,4,6-triamino-1,3,5-triazine) contamination of food has become an urgent and broadly recognized topic as a result of several food safety scares. In this study, the feasibility and effectiveness of near infrared (NIR) hyperspectral imaging (from 990 to 1700 nm, 144 spectral bands) techniques that combine the advantages of spectroscopy and imaging was investigated for discriminating low levels (<=1%) of melamine particles in milk powders. Pure and mixture samples were put in Petri dishes and the top layer was smoothed for imaging. Following image preprocessing, bands with the most significant difference between pure milk and pure melamine were selected. Then, band math method was applied to the spectrum of each pixel in the sample images to identify melamine particles in milk powders. The result images allowed visualization of the distribution of melamine particles within images of milk powder mixture samples that were prepared with various melamine concentrations. The classification results were verified by spectral feature comparison between separated mean spectra of melamine pixels and milk pixels. The study demonstrated that NIR hyperspectral imaging technique was an effective way to detect melamine adulteration in milk powders. It may be feasible to detect melamine at very lower concentrations in milk powders by spreading the sample mixtures in a thin layer in large containers to increase the surface area presented for NIR hyperspectral imaging.

8721-16, Session 5

The development of a line-scan imaging algorithm for the detection of fecal contamination on leafy geens

Chun-Chieh Yang, Moon S. Kim, Agricultural Research Service (United States); Yung-Kun Chuang, National Taiwan Univ. (Taiwan)

The paper reported the development of a line-scan imaging algorithm to detect fecal contamination on leafy greens. The fresh cow feces were applied to the front and back surfaces of baby spinach and romaine lettuce leaves. The contaminated leaves were line-scanned under fluorescence light to obtain hyperspectral images. The main components of the line-scan hyperspectral imaging system included an EMCCD camera, a spectrograph, and a pair of fluorescence line lights. The multispectral algorithm was developed from hyperspectral image analysis to quickly and precisely detect feces on leafy greens. The algorithm can be applied to the machine vision system for food safety in the fresh produce processing lines.

8721-17, Session 5

Hyperspectral imaging system for whole corn ear surface inspection

Haibo Yao, Russell Kincaid, Zuzana Hruska, Mississippi State Univ. (United States); Robert Brown, Deepak Bhatnagar, Thomas Cleveland, Agricultural Research Service (United States)

Aflatoxin is a mycotoxin produced by Aspergillus flavus (A.flavus) and Aspergillus parasiticus fungi that grow naturally in corn. Ingestion of the toxin is associated with serious health problems including liver damage and lung cancer if the level of the toxin is high. Consequently, many countries have established strict guidelines for permissible levels in consumables. There has been a continuing effort within the research community to find a way to rapidly and non-destructively detect and possibly quantify aflatoxin contamination in corn. One of the more recent developments in this area is the use of spectral technology. The current hyperspectral imaging system is designed for scanning flat surfaces, which makes it suitable for imaging a single kernel or a group of corn kernels. In the case of a whole corn ear, it is preferable to be able to scan the circumference of the corn cob for whole ear inspection. This study describes a hyperspectral imaging system for whole corn ear imaging. The new instrument is based on a hyperspectral line scanner incorporated with a rotational stage for turning the corn cob. Lab and field corn ears inoculated with A. flavus were used to test the instrument.

8721-18, Session 5

Wavelength-configurable hyperspectral imaging system and image-guided robot for detecting foreign material in food products

Seung-Chul Yoon, Agricultural Research Service (United States); Richard Driver, Blair Simon, Sam Hill, Headwall Photonics Inc. (United States); Gerald W. Heitschmidt, Kurt C. Lawrence, Bosoon Park, William R. Windham, Agricultural Research Service (United States)

This paper reports the development of a real-time machine vision system utilizing a wavelength-configurable hyperspectral camera and integration of the vision sensor with a robot for detecting and rejecting foreign material (FM) on high-speed food processing lines. FM either naturally or unintentionally introduced into food products is a physical hazard that causes a thread to the consumer. Most machine vision systems to detect FM in food products predominantly rely on an area sensor capturing a small number of broad wavelength bands, such as a RGB color camera. Recently, researchers at the USDA and Headwall Photonics developed a VNIR line-scan hyperspectral imaging system being capable of producing over 1000 of narrow wavelength bands and wavelength-configurable for high-speed multispectral imaging that requires a few non-contiguous narrow wavelength bands, such as online poultry carcass inspection for disease and fecal contamination detection. To further expand the previous research, we investigate the feasibility of the real-time line-scan hyperspectral imaging system integrated with an image-guided robot for FM detection and rejection. The system consists of a wavelength-configurable line-scan VNIR hyperspectral camera, two line lights, a conveyor system, a robotic picker, and application software. Real-time multispectral image processing algorithms for detecting small color blocks moving on a blue conveyor system at about 0.46 m/s (about 400 Hz) were also developed to demonstrate the system performance in detecting and picking FM with different and/or similar spectral responses. The fully developed, commercially-available, in-line hyperspectral imaging system provides the food industry with flexibility, speed and accuracy necessary for FM detection.

8721-19, Session 6

Geographical classification of apple based on hyperspectral imaging

Zhiming Guo, Wenqian Huang, Liping Chen, National Engineering Research Ctr. for Information Technology in Agriculture (China); Chunjiang Zhao, National Engineering Research Center of Intelligen Equipment for Agriculture (China); Yankun Peng, China Agricultural Univ. (China)

Attribute of apple according to geographical origin is often recognized and appreciated by the consumers. It is usually an important factor to determine the price of a commercial product. Hyperspectral imaging technology and supervised pattern recognition was attempted to discriminate apple according to geographical origins in this work. Hyperspectral images of 208 Fuji apple samples were collected by hyperspectral camera (400-1000nm). Principal component analysis (PCA) was performed on hyperspectral imaging data to determine main efficient wavelength images, and then characteristic variables were extracted by texture analysis based on gray level co-occurrence matrix (GLCM) from each image. All characteristic variables were obtained by fusing the data of images in efficient spectra. Support vector machine (SVM) was used to construct the classification model. The classification rates were 95% and 92% in the training and prediction sets, respectively. The SVM algorithm shows excellent performance in classification results in contrast with other pattern recognitions classifiers. The overall results demonstrated that the hyperspectral imaging technique coupled with SVM classifier can be efficiently utilized to discriminate Fuji apple according to geographical origins.

8721-20, Session 6

A study on germination characteristics of pumpkin seed using hyperspectral reflectance imaging

Kangjin Lee, Changyeun Mo, Sukwon Kang, Jongguk Lim, Jongryul Park, National Academy of Agricultural Sciences (Korea, Republic of)

This study investigated the potential of hyperspectral reflectance imaging for selecting the high quality pumpkin seed by classifying into viable or non-viable one. A hyperspectral imaging system with the range 400 nm to 1000 nm was used to examine reflectance images of pumpkin seeds. The partial least squares–discriminant analysis (PLS-DA) to predict viable seeds was developed with spectra extracted from reflectance images and results from germination test. Various pretreatments for spectra were applied to find the proper classification models. The results of developed PLS-DA models using the spectra with 1st order derivatives showed 96% discrimination accuracy. These results showed that hyperspectral reflectance imaging technology can be used to select the high quality pumpkin seeds.

8721-21, Session 6

Whole-surface produce inspection using hyperspectral line-scan imaging

Moon S. Kim, Agricultural Research Service (United States); Hyun Jeong Cho, Univ. of Michigan (United States); In-Suck Baek, Chungnam National Univ. (Korea, Republic of); Hoyoung Lee, Agricultural Research Service (United States); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Kuanglin Chao, Diane E. Chan, Agricultural Research Service (United States)

Researchers have made significant progress in the development of hyperspectral imaging-based detection for contaminants and defects on fruits and vegetables. From hyperspectral imaging and analysis, multispectral imaging algorithms using visible/near-infrared reflectance and fluorescence, respectively, have been developed to detect defects and fecal residues. These multispectral image-based methods can be implemented into online inspection in processing lines. However, the complete surfaces of produce must be fully inspected for defects or contamination in order to assure safety of products for human consumption. We recently developed prototype device/conveyor systems for whole-surface inspection of round fruits and of relatively flat leafy-greens; currently, no such whole-surface online imaging inspection technologies exist for industry use. We present mechanical designs and methods for wholes-surface inspection of produce using a hyperspectral/multispectral line-scan imaging system.

SPIE Defense, Security+Sensing

8722-1, Session 1

A personal review of 25 years of fiber grating sensor development *(Invited Paper)*

Eric Udd, Columbia Gorge Research (United States)

Early efforts developing smart structures started with strain sensors based on interferometeric techniques. It immediately became apparent that structural engineers were used to dealing with conventional electrical strain gages and thermocouples with much shorter gage lengths. The fiber grating offered a competitive solution for the measurement of strain and temperature with the advantages of electrical isolation and improved ruggedness. The principal draw back was cost. So early applications involved high value projects where the unique capabilities of the technology offered superior performance. One area of particular interest involved the usage of fiber gratings to sensor more than one parameter simultaneously. Multi-dimensional strain and the measurement of pressure and temperature were two key examples of multi-parameter sensing. In parallel efforts were conducted to operate at high speed. Early examples in aerospace and civil structures were at speeds in the range of 10 kHz. Ballistic work later dictated increasing speeds to 5 MHz. Much more recent work with burn, deflagration and detonation has involved measurements from more than 100 MHz to multiple GHz. This paper provides a personal history of some of these developments and how fiber grating sensor technology is moving into the future.

8722-2, Session 1

The use of fiber Bragg gratings in acoustic sensing applications *(Invited Paper)*

Anthony Dandridge, Clay Kirkendall, Geoff A. Cranch, U.S. Naval Research Lab. (United States)

No abstract available.

8722-3, Session 1

Fiber Bragg grating sensing of detonation and shock experiments at Los Alamos National Laboratory *(Invited Paper)*

George Rodriguez, Richard L. Sandberg, Scott I. Jackson, Dana M. Dattelbaum, Quinn McCulloch, Samuel W. Vincent, Los Alamos National Lab. (United States); Eric Udd, Columbia Gorge Research (United States)

An all optical-fiber-based approach to measuring high explosive detonation front position and velocity is described. By measuring total light return using an incoherent light source reflected from a fiber Bragg grating sensor in contact with the explosive, dynamic mapping of the detonation front position and velocity versus time is obtained. We demonstrate two calibration procedures and provide several examples of detonation front measurements: PBX 9502 cylindrical rate stick, radial detonation front in PBX 9501, and PBX 9501 detonation along curved meridian line. In the cylindrical rate stick measurement, excellent agreement with complementary diagnostics (electrical pins and streak camera imaging) is achieved, demonstrating accuracy in the detonation front velocity to below the 0.3% level when compared to the results from the pin data. In a similar approach, we use embedded fiber grating sensors for dynamic pressure measurements to test the feasibility of these sensors for high pressure shock wave research in gas gun driven flyer plate impact experiments. By applying well-controlled steady shock wave pressure profiles to soft materials such as high density polyethylene, PMMA, and explosives, we study the dynamic pressure response of embedded fiber Bragg gratings to extract pressure amplitude of the shock wave. Comparison of the fiber sensor results is then made with traditional methods (velocimetry and electro-magnetic particle velocity gauges) to gauge the accuracy of the approach.

8722-4, Session 1

Development of high-speed fiber grating sensor solutions for measuring velocity, position, pressure and temperature during burn, deflagration, and detonation of highly energetic material *(Invited Paper)*

Eric Udd, Columbia Gorge Research (United States); Jerry J. Benterou, Lawrence Livermore National Lab. (United States)

In order to fully characterize highly energetic material it is necessary to measure velocity, position, pressure and temperature during burn, deflagration and detonation. This paper summarizes a series of fiber grating sensor system approaches to this important problem and overviews selected results that have been obtained over the past five years.

8722-5, Session 2

Analysis, compensation, and correction of temperature effects on FBG strain sensors *(Invited Paper)*

Todd C. Haber, Steve Ferguson, Dan Guthrie, Tom W. Graver, Micron Optics, Inc. (United States); Alexis Mendez, MCH Engineering LLC (United States)

Over the last few years, optical fiber sensors have seen an increased acceptance as well as widespread use in structural sensing and monitoring in civil engineering, aerospace, marine, oil & gas, composites and smart structure applications. One of the most common fiber optic sensor (FOS) types used are fiber Bragg gratings (FBG, and the most frequently measured parameter is strain. Hence, FBG strain sensors are one of the most prevalent FOS devices in use today. However, since FBGs are simultaneously sensitive to both temperature and strain, it becomes essential to utilize sensors that are either fully temperature insensitive or, alternatively, properly temperature compensated to avoid erroneous measurements.

In this paper, we review and analyze the temperature and strain sensitivities of FBG strain sensors and decompose the total measured strain into thermal and non-thermal components. We also present specific guidelines to achieve proper temperature-insensitive strain measurements by combining adequate installation, sensor packaging and data correction techniques. Additionally, we present details of a novel, dual-grating, temperature-compensating FBG strain sensor design.

8722-6, Session 2

Nondestructive inspection of CFRP adhesively bonded joints using embedded FBG sensors

Sean C. Webb, Peter H. Shin, Kara J. Peters, North Carolina State Univ. (United States); Stephen Schultz, Richard Selfridge, Brigham Young Univ. (United States)

One challenging need for inspection capabilities is in adhesively bonded joints between composite components, a common location of premature failure in aerospace structures. In this work we demonstrate

that dynamic, full-spectral scanning of FBG sensors embedded in the adhesive bond can identify changes in bond quality through the measurement of non-linear dynamics of the joint. Eighteen lap joint specimens were fabricated with varying manufacturing quality. Ten samples also included fiber Bragg grating (FBG) sensors embedded in the adhesive bond for real-time inspection during a simulated flight condition of these single-lap joints. Prior to testing, pulse phase thermography imaging of the pristine specimens revealed defects such as air bubbles, adhesive thickness variations, and weak bonding surface between the laminate and adhesive. The lap joint specimens were then subjected to fatigue loading, with regular interrogation of the FBG sensors at selected load cycle intervals. The FBG data was collected during vibration loading of the lap joint to represent an in-flight environment. Changes in the lap joint dynamic response, including the transition to non-linear responses, were measured from both the full-spectral and peak wavelength FBG data. These change were correlated to initial manufacturing defects and the progression of fatigue-induced damage independently measured with pulse phase imaging and visual inspections of the failure surfaces.

8722-7, Session 2

Distributed fiber optic laser ultrasound generation

Ming Han, Jiajun Tian, Qi Zhang, Univ. of Nebraska-Lincoln (United States)

We propose and experimentally demonstrate a distributed fiber-optic laser ultrasound generation technology that can generate ultrasound in a controllable way along a single span of fiber at selected multiple locations. The proposed technology is based on a smart light tapping method enabled by titled fiber Bragg gratings and a highly absorptive coating material made from a mixture of graphite powder and an epoxy resin. We demonstrate that laser pulses are coupled out of the fiber at a location determined by the laser wavelength and are absorbed by the graphite/epoxy coating for ultrasonic generation. Key performances of the proposed laser ultrasound generation system, such as the number of ultrasound generation nodes, the effect of the laser pulse width and laser energy on the ultrasound generation efficiency is studied.

8722-8, Session 2

Engine test for wavelength-multiplexed fiber Bragg grating temperature sensor

Li Yu, Dorothy Y. Wang, Yunmiao K. Wang, Christopher M. Collins, William C. Schneck III, Justin M. Bailey, Walter F. O'Brien Jr., Anbo Wang, Virginia Polytechnic Institute and State Univ. (United States)

A temperature sensor based on wavelength-multiplexed fiber Bragg grating (FBG) was designed and fabricated for distributed temperature measurement in a jet engine nozzle under field condition. The Bragg wavelength shift of the FBG structure induced by elevated temperature enables accurate measurement of temperature change. Eight FBGs with different Bragg wavelengths ranging from 1520 nm to 1560 nm were fabricated along one single-mode fiber protected inside a stainless steel tube with 0.5 mm ID. The reflected signal from the sensor was collected by an optical sensing interrogator and interrogated into temperature data simultaneously. After sensor fabrication, the fiber was coated by silver, and annealed before the insertion into the tube. No adhesion between the fiber and the tube was observed during the test so the sensor was strain-free. The steel tube was embedded in a steel flange assembly attached to a jet engine. Three engine cycles were performed from 55% (idle) to 80% of the engine's full power to test the sensor response under high temperature, vibration and strong exhaust flow. Test results show good survivability of the sensor, and the temperature around the nozzle was measured up to 290 °C. The system has temperature measurement range from 20 °C to 600 ° and the response time is less than 1 second. The advantages of this sensor over traditional thermocouples are light weight, multiplexing capability, no electromagnetic interference and shorter response time, all of which show great potential of distributed fiber-optic sensors for engine health monitoring.

8722-9, Session 3

Draw tower fiber Bragg gratings in polarization-maintaining fibers for the independent measurement of strain and temperature *(Invited Paper)*

Eric Lindner, Julia Mörbitz, Christoph Chojetzki, FBGS Technologies GmbH (Germany); Alexander Hartung, Manfred Rothhardt, Kay Schuster, Institut für Photonische Technologien e.V. (Germany)

The development of the draw tower grating technology in the last 5 years enabled a great variety of use for different sensing applications due to the flexible fiber and grating specification. It is now a cost effective industrial production of draw tower fiber Bragg gratings (DTG®). In this paper we want to report about the new possibility of writing FBGs in polarization maintaining (PM) fibers during the fiber drawing process. For that purpose a photosensitive PM preform based on stack and draw technology was designed and fabricated to enable a high stress birefringence in the resulting fiber. During the fiber drawing process of the PM fiber we were able to generate arrays of UV single pulse fiber Bragg gratings. By using a Talbot interferometer configuration for the grating writing we are able to generate multiple Bragg wavelengths in the telecommunication C band within one fiber. The reached grating reflectivity is around 10%. The polarization separated peak splitting is in the range of 0.4 nm which leads to a refractive index difference between the slow and the fast axes of approximately 3.8x10-4. By interrogating both polarization peaks of the PM DTG it is possible to measure strain and temperature simultaneously but independent.

8722-10, Session 3

Distributed vibration and temperature sensing using fiber optics, a technology whose time has come with the automation of the Femto second laser grating writing process

Peter Kung, QPS Photronics Inc. (Canada)

Two Novel technologies will be discussed in this paper, First a Femto second laser with 800 nm wavelength will be used to write an array of up to 600 fiber Bragg gratings onto the same fiber without any splice. These low reflectivity gratings have the same center wavelength are resulted from mechanical damage. Writing will be performed through the coating material. Fiber does not need stripping nor recoating thus maintains close to its original strength. Further more, they will not get erased at higher temperatures because they are not index gratings. They would work up 600 degrees C limited only by the coating material. This technology is ideally suited to be applied to another novel technology platform: The FDM technology. The technology is targeted at distributed sensing of temperature and vibration in the most hostile environment.

It involves chirping of the transmitter to give a band of continuously changing frequency labels. The laser light will get reflected at each FBG element with distinct frequency label, allowing one to locate their origin on this long stretch of fiber. Automation of this process makes the FBG array affordable. Writing time for each element is kept below 10 seconds, aided by specially developed high speed testing equipment. This platform technology will open up many important applications in distributed sensing of vibration, temperature or strain. The presence of FBG improves the sensitivity of the system by 10 fold when compared with simple fiber based distributed temperature (DTS) or distributed acoustic sensing (DAS)

8722-12, Session 3

Isolation of thermal and strain responses in composites using embedded fiber Bragg grating temperature sensors

Kyle Elam, Brian Jenkins, Peter Joyce, Deborah Mechtel, U.S. Naval Academy (United States)

In this research, fiber Bragg grating (FBG) optical temperature sensors are used for structural health monitoring of composite materials. Specifically, the goal is to detect the thermal response that results when high energy radiation is incident on the surface of a composite. The unique optical characteristics of FBG sensors make them well-suited for such an application because they can detect highly localized temperature gradients.

To accomplish this, the FBG temperature sensors are embedded in the composite in a multidimensional array. However, FBG sensors also respond to any axial strain in the optical fiber. When an optical fiber containing an FBG is embedded in a composite matrix, the epoxy bonding serves to couple structural strain experienced by the composite into the optical fiber. As a result, embedded FBG sensors respond to the strain of the host structure. Recent research has focused on distinguishing differences between the temperature and strain responses to ensure that mechanical strain does not drown out any potential temperature response.

Similarities and differences between FBG responses due to structural strain and localized temperature gradients will be discussed. The effectiveness of in-plane and through-plane sensor arrays in composite materials will be presented as a means to isolate the temperature response. Furthermore, a signal processing scheme will be presented as a software technique that interprets the combined strain-temperature responses. The degree to which these advances increase the functionality of FBG sensors in composites will be assessed. Finally, further research regarding alternative composite architectures and other FBG technologies will be discussed.

8722-13, Session 4

High-resolution, high-sensitivity, dynamic distributed structural monitoring using optical frequency domain reflectometry *(Invited Paper)*

Stephen T. Kreger, Alex K. Sang, Dawn K. Gifford, Mark E. Froggatt, Luna Innovations Inc. (United States)

Optical Frequency Domain Reflectometry is used to measure distributed strain and temperature change with very high sensitivity and precision by measuring the phase change of an optical fiber sensor as a function of distance with high spatial resolution and accuracy. Semi-continuous Bragg gratings or Rayleigh Scatter can be used as the sensor. The higher reflection amplitude of gratings favors high acquisition rate environments, but at a higher sensor cost. Continuously tracking the phase change along the length of the fiber sensor enables high resolution distributed measurements that can be used to detect very small displacements, temperature changes, or strains. The distributed, high spatial resolution nature of the measurement makes the technique well-suited for detecting structural defects as well as deducing subtle structural shape changes. Measurement examples depicting sub-cm spatial resolution and > 100 Hz acquisition rates will be described.

8722-14, Session 4

Fully-distributed fiber optic high-temperature sensing based on stimulated Brillouin scattering

Jing Wang, Di Hu, Dorothy Y. Wang, Anbo Wang, Virginia Polytechnic Institute and State Univ. (United States)

We proposed a Brillouin optical fiber time domain analysis (BOTDA)-based fully-distributed temperature sensing system in which one pulse and one continuous-wave (CW) light counter propagate in a fiber. Temperature induced Brillouin Frequency shift of single mode fiber shows good linearity with temperature in relatively low temperature(<100 c), we captured the Brillouin Frequency Shift for high temperature from 100 c to 1000 c with a 100 c step by sweeping the frequency difference of the two light beams. In the experiment, 200 ns pulse was implemented to increase signal to noise ratio (SNR). Our experiment showed that for single mode fiber, temperature induced Brillouin Frequency shift shows good linearity in high temperature as well. Then we heated up an arbitrary 10 meter portion of a single mode fiber (500 meter total length) to 1000 c while the other portions were still kept in room temperature. We could achieve 5 meter spatial resolution, locate position of heated portion, and estimate heated length by means of the increase of CW light power, as a function of time. Same experiment was repeated at 980 c and 990 c respectively. They both showed coherency with previous results. Our system can be applied to even higher temperature and stress sensing; therefore it is expected to be capable of other fully-distributed sensing application.

8722-15, Session 4

Novel optical fibers for Brillouin-based distributed sensing

Peter D. Dragic, Univ. of Illinois at Urbana-Champaign (United States); John Ballato, Stephanie Morris, Alex Evert, Clemson Univ. (United States); Robert R. Rice, Dreamcatchers Consulting (United States); Thomas Hawkins, Clemson Univ. (United States)

Optical fiber sensors utilizing Brillouin scattering rely on the principle that the Brillouin frequency shift is a function of the local temperature or strain. Conventional optical fibers, such as standard telecommunications single-mode fibers, have been successfully used in these applications, and most typically in the time domain, such as with BOTDR. Such conventional fibers however are susceptible simultaneously to both temperature and strain, requiring either at least two fibers or specialized cabling to distinguish the effects of a local stress from those of a local change in temperature. Recently, methods utilizing fibers possessing at least two Brillouin frequency shifts, each with different temperature or strain coefficients have been proposed. However, realizing such fibers is challenging, requiring fibers with regions of very different compositions, all of which must have substantial overlap with the optical field, posing significant manufacturing challenges. We present several new specialty optical fibers based on novel and unconventional fabrication techniques with significant potential for use in distributed fiber sensor systems. First, we describe a class of fibers fabricated from materials whose Brillouin frequency shifts are immune to either temperature or strain, with a demonstration of the former using fiber derived from sapphire crystal, and modeling and measurements predicting the latter. The 'Brillouin-athermal' fiber enables the measurement of a local strain, independent of the local temperature. Second, we describe and demonstrate a novel group of longitudinally-graded (chirped) fibers enabling easily-implemented frequency-domain systems; affording the potential to simplify and reduce the cost of Brillouin-based distributed sensors.

8722-16, Session 4

Improved distributed fiber optic sensing system based on single-ended double-pulse input Brillouin scattering

Tianying Chang, Ruijuan Yang, Jilin Univ. (China); Yongliang Wang, Beijing Pegasus, Ltd (China); David Y. Li, L.C. Pegasus Corp. (United States); Lei Jia, Shandong Univ. (China); Hong-Liang Cui, Jilin Univ. (China)

For traditional single-end input distributed fiber optic sensing system based on spontaneous Brillouin back-scattered light, input light intensity should be less than the threshold value which is much smaller than that of Raman scattering. If the intensity of the input light is higher than the threshold value, stimulated Brillouin back-scattered light will be generated in the fiber. Stimulated Brillouin back-scattered light is unstable, and as a result it is not generally used as a sensing medium for single-end input distributed system.

In this paper, we propose a new method of using stimulated Brillouin back-scattered light to measure strain accurately in distributed fiber optic sensing system with single-end input. In this system, we make use of the frequency-demodulation method based on Fast Fourier Transform (FFT) to determine the Brillouin frequency shift accurately. For given input light and sensing fiber, the same acoustic phonons are responsible for both spontaneous and stimulated Brillouin back-scattering of photons, leading to the same frequency shift. Thus the frequency-demodulation method can ignore the intensity instability of stimulated Brillouin back-scattered light, while still obtains accurately the frequency shift due to Brillouin scattering.

Compared to the system based on the spontaneous Brillouin back-scattered light, spatial resolution in the new system could potentially be higher since the duration of the input light pulse is unconstrained by the life time of the acoustic phonons, while accurate frequency shift can be obtained by the frequency-demodulation method. Therefore, in this system, we can easily obtain high strain resolution and spatial resolution. Moreover, the distributed strain sensing system requires single-ended input, and its sensing distance can be very long since stimulated Brillouin back-scattered light is used. We have estimated the performance characteristics for this system as follows: strain resolution < 10με, spatial resolution < 1 m, and sensing distance > 30 km.

8722-11, Session PThur

Development of polymer Bragg grating based strain, temperature, and chemical sensors

Sebastiampillai G. Raymond, Adam J. Swanson, Mohamed D. H. Bhuiyan, Andrew J. Kay, Industrial Research Ltd. (New Zealand)

Advances in photosensitivity lead to the development of fibre Bragg grating (FBG) sensors that have a wide variety of applications. These applications include the monitoring of civil structures, smart manufacturing and non-destructive testing, remote sensing, as well as traditional strain, pressure and temperature sensing. This type of sensor has many benefits over conventional sensors such as a small size, totally passive, extremely low sensitivity to electromagnetic interference, good resistance to corrosion, large capacity for multiplexing, high temperature capacity, long working lifetime and excellent sensitivity to strain and temperature.

Conventional fibre Bragg gratings are ideally designed for the measurement of the strain magnitude. However, There are applications that require the ability to determine two dimensional strain fields. Bragg grating sensors arranged in a rosette configuration is generally used in experimental stress analysis to measure the state of strain at a point on the surface. Furthermore, strain sensors are also needed for strain measurements at high temperatures. For these reasons we have been researching new materials and methods for strain tensor and temperature compensated strain measurements.

In this report we discuss our optics-based strain/temperature sensing system as well as development of new polymer sensors for the measurement of the strain tensor and temperature. Simulations predict that a Bragg reflection of more than 90% can be achieved for Bragg Gratings in polymer thin films containing chromophores for grating lengths as small as 200 μm. A small Bragg grating length means that it should be possible to create waveguides and four Bragg gratings for strain tensor and temperature measurements within an area as small as 5x5 mm2. We present the results performed to validate the above prediction. We will also describe our work towards the development of fibre Bragg grating based chemical sensor.

8722-21, Session PThur

The semi-explicit formulation of U-shape optical fiber for sensing applications

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The U-shape optical fibers have been used in optical fiber sensing for the enhancement of sensitivity due to the increase of evanescent wave interaction with analyte around fiber cladding region. However, the effects of increase of loss due to the U-shape bending and NA of optical fiber is rarely exploited.

In this paper, the potential of developing a semi-explicit function of absorption/loss increases and refractive index difference between core and cladding in U-shape optical fiber on sensitivity of sensing applications is discussed. The emphases of study are:

(1) Sensitivity enhancement: The magnitudes of sensitivity enhancement for various U-shape fiber designs are presented.

(2) Detection limit/Accuracy: On the other hand, the effect of U-shape design on detection limit and accuracy is also studied, which are rarely discussed in literatures.

(3) Optimization design of fiber: An optical fiber with optimal U-shape design toward high detection sensitivity is proposed in terms of optical fiber design and U-shape bending parameters.

8722-33, Session PThur

Large-area, vertically-aligned GaN n-core/p-shell arrays for UV photodetectors

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Significant advances have been made in the fabrication methods of GaN nanostructures, including large-area growth of vertically aligned core-shell structures. Despite successes of bottom-up growth methods, there are significant challenges in terms of controlled scalable growth of these nanoscale structures suitable for device applications. By combining standard top-down micro- and nano-fabrication methods with selective epitaxial overgrowth, we can address these challenges. As the dimensions and orientations are defined by mature technologies such as lithography and etching, and dopant profiles are established during the growth of thin films, these methods promise reproducible large-area fabrication of arrays of nanostructures with precisely controlled geometry.

We have demonstrated dense arrays of vertically-oriented, individual GaN core-shell structures realized with a combination of top-down etching of the n-type pillars and subsequent p-shell growth using selective epitaxy. Silicon-doped GaN epitaxial thin film grown on silicon substrates were patterned using lithography and metal liftoff. The patterned samples were then etched in an inductively coupled plasma system using a Cl2/N2 /Ar gas mixture to form n-GaN pillars. Mg-doped GaN shells were epitaxially grown over the etched GaN pillars in a custom-built horizontal hot-wall halide vapor phase epitaxy (HVPE) reactor. Room-temperature photoluminescence and Raman scattering measurements indicate strain-relaxation in the etched pillars and shells compared to the as-grown GaN on Si. Complete devices have been fabricated using three-layer dielectric planarization. The top p-contact was made using conductive indium-tin-oxide and the n-contact was made by backside metallization of the Si substrate. Detailed device characterization was correlated with cross-sectional TEM microstructural correlation observations.

8722-34, Session PThur

A process for co-molding a visible-wavelength photonic crystal and microfluidic channel for biosensing applications

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Rapid DNA analysis systems show promise for reduced DNA analysis times, and can be used by untrained operators in point-of-use applications. Throughput improvements can be gained by reducing the polymerase chain reaction (PCR) cycle count, which is used in conventional DNA processing to amplify the DNA to an easily measurable amount. A Photonic Crystal (PhC) can be integrated within a microfluidic channel to enhance fluorescence emission, enabling a reduction in PCR cycling. Most PhCs are fabricated using serial top-down fabrication techniques, resulting in a structure that is challenging to integrate with microfluidic system components. Here, we present a process for fabricating a silicon master mold consisting of a visible range PhC lattice and a microfluidic channel. This process can be used to co-fabricate microscale channel and nanoscale lattice structures in polymer or thermoplastic materials. Two-dimensional visible range PhCs with a photonic bandgap centered at 520nm fluorescein (FAM) emission are fabricated by patterning electron beam resist via E-Beam Lithography. The patterned features (~100nm features with ~200nm pitch) are cured to a glass-like material that is used as a direct-etch mask for Reactive Ion Etching. A 200μm wide and 25μm high ridge “strip” is fabricated around the PhC region using Photolithography and KOH wet etching to form the completed channel & lattice mold. Results indicating the quality of features resulting from the molding process and repeatability across multiple molding iterations will be discussed as well.

8722-35, Session PThur

Quantum dot photoemission optic sensors

Subhamoy Singha Roy, JIS College of Engineering (India)

I study theoretically the external photoelectric effect from quantum dots of non-linear optical and optoelectronic nanostructure materials on the basis of a newly formulated electron dispersion law considering the anisotropies of the the spin-orbiting constants, effective mass electrons, and control of crystal field splitting within the framework of k.p formalism. The external photoelectric effect has also been calculated for quantum confined optoelectronic II-VI materials . It has been found taking quantum confined Hg1-xCdxTe, CdGaAs2 and In1-xGaxAsyP1-y lattice matched to CdS, InP as examples that the external photoelectric effect exhibits plateaus as function of incident photon energy, which is vital from experimental point of view. The numerical results of quantum confined optoelectronic III-V degenerate semiconductors form the special case of our generalized analysis. The external photoelectric effect also exhibits oscillatory variation with changing for all types of quantum confinement and the photo emitted power is the greatest for quantum dots and the least for quantum dots.

8722-36, Session PThur

Effect of extrinsic perturbation by transverse pressure, bending, and tension birefringence

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Birefringence and polarization dispersion caused by elliptical core, twist, pure bending, transverse pressure and axial tension are studied by treating these deformations as perturbations to step-index single-mode fiber with a round core. These effects are formulated in terms of fiber structure and perturbation parameters and are compared comprehensively. The results show that as the transverse pressure is increased, the birefringence also increases and the transverse pressure is more dominated to polarization and remains steady but birefringence varies to the wavelength. The results also shows that as the bending radius increased the delta and DGD decreased and polarization is steady for the corresponding bending and wavelength but the delta beta is varying with wavelength for the corresponding bending radius and spooled tension is increased the delta beta and DGD increases and also these increases as bending radius decreased.

8722-37, Session PThur

Strain response of metal-encapsulated regenerated grating strain sensors for structural health monitoring under high-temperature environments

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Regenerated gratings (RG) with titanium (Ti) - silver (Ag) - nickel (Ni) coatings have been embedded in flexible metal substrates for encapsulation as strain sensors by electroplating Ni process. After bonded to a plate tensile specimen by spot welding, a metal-encapsulated RG strain sensor has been evaluated by a tensile test at a constant temperature range from room temperature to 400°C. For comparison, the tensile test has also been performed on a bare RG sensor. Experimental results show that the shifts in the wavelengths of the metal-encapsulated RG strain sensor and RG sensor are both linear function of applied tensile strains at a constant temperature. It is also shown that the metal-encapsulated RG strain sensor presents a higher sensitivity of strain, compared with the bare RG sensor. It is found that the sensitivity of stain is enhanced up with the increase of temperature with respect to the metal-encapsulated RG strain sensor, whereas it is almost temperature-independent with respect to the bare RG sensor. The metal-encapsulated RG strain sensor also exhibits a satisfactory repeatability and provides a great potential for the measurement of strain for structural health monitoring under high-temperature environments.

8722-39, Session PThur

Position determination of disturbance along a modified saganac interferometer

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An interferometric technique is described to detect and locate disturbance along two different optical fibers at the same time. This system is based on the sagnac interferometer and modified by a faraday rotator mirror, changing the traditional sagnac loop into a linear structure. With the technique of the frequency-division-multiplexing, disturbances from different areas can be detected and located at the same time. The result of the experiment shows that the error of the location is less than 500 m.

8722-17, Session 5

Long-period gratings in photonic crystal fiber for layer-by-layer assembly of pH responsive polyelectrolytes

Fei Tian, Stevens Institute of Technology (United States); Jiri Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); Svetlana A. Sukhishvili, Henry H. Du, Stevens Institute of Technology (United States)

The accessible cladding air channels of photonic crystal fiber (PCF) and the high-index sensitivity of its long-period gratings (LPG) inscribed by CO_2 laser have been exploited to deposit poly(vinyl pyrrolidone) (PVPON)/poly(methacrylic acid) (PMAA) polyelectrolyte thin films via

layer-by-layer assembly (LbL). We show that LbL can be controllably carried out within the air channels with diameters ranging from a fraction of a micron to tens of microns. PCF-LPG is highly sensitive to monolayer deposition for in-situ monitoring of the LbL process and the release of PVPON from crosslinked polyelectrolytes. The latter step results in the formation of pH-responsive PMAA hydrogel. PCF-LPG containing the hydrogel exhibits well-behaved response to changes in solution pH over 2 to 7.5. We demonstrate that PCF-LPG is two orders of magnitude more sensitive than its traditional all-solid counterpart through parallel investigation. Numerical simulations are used to correlate the response of PCF-LPG with the behavior of pH-responsive hydrogel.

8722-18, Session 5

Mode coupling and mode-field distribution in long period gratings tri-directionally and uni-directionally inscribed in photonic crystal fiber

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We report the inscription and measurements of long period gratings (LPG) in photonic crystal fiber (PCF) by unidirectional as well as tri-directional CO_2 laser irradiation with the aid of a pair of 120° angled, Au-coated reflective mirrors. We show that tri-directional inscription results in symmetric mode coupling, while uni-directional inscription leads to asymmetric mode coupling in PCF-LPG. We reveal that mode coupling is facilitated by reflective index modulation resulting from residual stress relaxation in the outer solid cladding for LPG inscribed in the low load range (1-5 g). In contrast, mode coupling stems from refractive index modulation due to combined residue stress relaxation and structural deformation for LPG inscribed in the high load range (10-30 g). We attempt to arrive at a unified understanding of the mode coupling and mode-field distributions in the various PCF-LPG structures with further investigation involving near-field imaging and numerical simulations.

8722-19, Session 5

Compact, fiber-based, fast-light enhanced optical gyroscope

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It has been proposed that fast-light optical phenomena can increase the sensitivity of a Ring Laser Gyroscope (RLG) of a given size by several orders of magnitude. MagiQ is developing a compact fully-fibered fast light RLG using Stimulated Brillouin Scattering (SBS) in commercial optical fiber. We will discuss our experimental results on SBS pumped lasing in commercial fibers and analyze their implications to the fast light generation. Based on these results, we envision a fast light enhanced Ring Laser Gyroscope (RLG) that will use only a few meters of fiber and require reasonable pump power (only a few 100's of mW). We will present the design that is based on proven, commercially available technologies. By using photonic integrated circuits and telecom-grade fiber components, we created a design that is appropriate for mass production in the near term. We eliminated all free-space optical elements (such as atomic vapor cells), in order to enable a compact, high sensitivity RLG stable against environmental disturbances. Results of this effort will have benefits in existing applications of RLGs (such as inertial navigation units, gyrocompasses, and stabilization techniques), and will allow wider use of RLGs in spacecraft, unmanned aerial vehicles or sensors, where the current size and weight of optical gyros are prohibitive.

8722-20, Session 5

Impact time measurement by using the fiber optic sensor in the pendulum ball collision

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In case of two pendulum balls collision, detected signal contains steel plate of the shaft vibration after collision. It cannot identify the impact force because of the shaft vibration. Because of soft shaft it comes out inconsistent responses. So collision system was changed to the fixed ball case. To measure impact force and other physical quantities when two balls collide fiber optic sensor with Sagnac interferometer was fabricated. To compare detected signal accelerometer also attached near the fixed ball. Colliding ball was determined by increasing the hit angle, i.e. 20, 30, and 50 degrees. Voltage response of the collide in time domain and frequency spectrum were analyzed. The response was consistent. Impact duration time is about 0.14ms for FOS and 0.12ms for accelerometer. FOS also detect free vibration of the optical fiber which passing through the fixed ball. But this unwanted signal can not avoid using Sagnac interferometer.Using fiber optic sensors to measure the impulsive force, this experiment is useful.

8722-22, Session 5

An integrated theoretical and experimental study of SERS nanotags on competitive Raman gain and signal attenuation in PCF

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The complexity of designing a PCF platform for SERS detecting arises from the competitive Raman gain and scattering/absorption-induced signal attenuation over the length of a waveguide decorated with SERS-active Ag or Au nanoparticles, which critically depends on the particle size and coverage density. We have carried out a combined theoretical and experimental investigation of this complex interplay to ascertain optimal nanoparticle parameters for SERS-active photonic crystal fiber sensors. In particular, discrete dipole approximation (DDA) and finite difference time domain (FDTD) simulation methods have been used to evaluate the interaction of the evanescent field of the guided core with immobilized nanoparticles. Favorable nanoparticle parameters have been experimentally assessed using well-behaved, individually SERS-active Au shell-Ag core nanotags that are immobilized on the cladding air channels of a suspended core PCF. The theoretical calculations and experimental findings will be compared and contrasted, using the optical path length (i.e., fiber length) as a means of further increasing the detection sensitivity of the SERS-active PCF.

8722-23, Session 5

Fabry-Perot microstructured polymer optical fiber sensors for ultrasonic and optoacoustic endoscopic biomedical applications

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Recently, it has been presented the images of internal organs in vivo using a 2.5-mm diameter optoacoustic and ultrasonic dual-mode

endoscope. In order to extend the use of this kind of dual mode endoscopes to complement the intravascular ultrasound (IVUS), adding to the morphological information the specifity of the optoacoustic imaging, is necessary to miniaturize the probe to be fitted in less than 1mm to pass through thin vasculature. Moreover, for a practical IVUS/IVPA catheter is mandatory to have a wideband ultrasonic detector up to 50MHz with enough sensitivity despite the necessary miniaturization. The optical detection of ultrasound provides the compactness, sensitivity and bandwidth required for this application

Our group, previously, has demonstrated that ultrasonic sensitivity of an interferometric single mode polymer optical fiber sensor (SMPOF) is one order of magnitude higher than a silica counterpart. However, these SMPOF are not easily commercially available and its performance in terms of loss and coupling light into is very poor what makes them impractical for real implementation. In contrast, microstructured polymer optical fiber (mPOF), exhibiting the same acoustic sensitivity, presents moderate low loss at visible wavelength regime and can be made endlessly single-mode. These ultrasonic characterizations have been carried out over mPOF based on PMMA and TOPAS. Most of the POFs are based on PMMA. However, TOPAS presents the fundamental advantage over PMMA of the humidity insensitive. This is important for ultrasonic measurements due to the sensor must be in an inherently wet medium.

In this contribution, we present an ultrasonic characterization it the MHz regime of FBG in PMMA and TOPAS mPOFs. Besides this, the response of a Fabry-Perot interferometer sensor made from two FBG is investigated. The results are compared with a straightforward fiber optic Mach-Zehnder interferometric sensor based on the same mPOFs.

8722-24, Session 6

Temperature sensing in high-voltage transmission lines using fiber Bragg grating and free-space-optics

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A major problem in the electricity transmission is the heating of the conductor due Joule effect caused by the circulating electric current. The temperature sets the limit for safe operation of the conductors. Thus it is very important to monitor the temperature manly in power cables and substation bus bars.

Fiber Bragg grating (FBG) sensor is one of the best technologies to monitor temperature in high voltage systems. The main problem is to connect the fiber and the sensors in the high voltage lines. The traditional solution is change the ordinary isolator by one containing the optical fiber embedded inside the isolator. A solution that is expensive.

In this work we proposed the use of free-space-optics (FSO) to transmit and receive the optical signals from optical fiber placed in ground potential to the FBG fiber optics at high voltage potential, using a pair of optical collimators. The use of collimators fixing kits avoids the change of an ordinary isolator to one with embedded fiber optic.

The evaluation of this technique was performed in a laboratory prototype for the study of sensitivity to optical alignment and in an external environment using a chain of insulators. For misalignment sensitivity studies several types of collimators and optical fibers were used. It has been shown that the FSO system allows collimators operate at distances of 500 mm to 2.000 mm. This range of distances is similar to the length of insulator's chain up to 230 kV.

8722-25, Session 6

Single fiber Bragg grating for the measurement of liquid level and temperature

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The present work proposes a simple sensor head design making use of single FBG, for simultaneous measurement of Liquid level and Temperature eliminating usage of two separate FBGs. To implement this, exactly half the portion of a long FBG was glued to the sensor head and embedded on a cantilever with suitable adhesive while the other half which is chemically etched was left free. As a result of chemical etching, the reflection peak of the FBG will split into two at normal room temperature, corresponding to the two halves of the grating. The two peaks responded differently, when the grating was stretched due to deflection of the cantilever and change in temperature. The sensitivity coefficient of these peaks obtained from the graph for the change in liquid level and temperature allows the simultaneous measurement of liquid level and temperature. From the knowledge of the temperature in the tank containing liquid, a correction can be made from the specific gravity and temperature characteristic curve equation of the liquid for accurate determination of liquid level.

8722-26, Session 6

Design and sensing research of the stepped metal film on optical fiber

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Optical fiber corrosion sensor with metal film was usually made by metal film replacing cladding, and monitored corrosion proceeding through the optical signal change caused by metal film corrosion. Now optical fiber corrosion sensor with metal film had much more studied, but the optical signal influenced with film thickness and structure was complicated, so the further research was needed. In this paper, an optical fiber corrosion sensor with stepped metal film was designed and fabricated. The principle of the optical fiber sensor for corrosion monitoring was analyzed. The stepped metal film was prepared by magnetron sputtering and electroplating on the core of multimode optical fiber with cladding removed. The optical performance of the sensor with different steps was investigated by optical power measuring. The result showed that a stepped metal film on optical fiber could enhance the properties of sensor, and the detective range was enlarged.

8722-27, Session 6

Escherichia coli biosensors for environmental, food industry and biological warfare agent detection

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This work has the objective to research and develop a plastic optical fiber biosensor based taper and mPOF LPG techniques to detect Escherichia coli by measurements of index of refraction.

Generally, cell detection is crucial in microbiological analysis of clinical, food, water or environmental samples. However, methods current employed are time consuming, taking at least 72 hours in order to produce reliable responses as they depend on sample collection and cell culture in controlled conditions. The delay in obtaining the results of the analysis can result in contamination of a great number of consumers.

Plastic Optical Fiber (POF) biosensors consist in a viable alternative for rapid and inexpensive scheme for cells detection. A study the sensitivity of these sensors for microbiological detection, fiber Tapers and Long Period Grating (LPG) both in poly-methyl-methacrylate (PMMA) were realized as possible candidates to take part of a biosensor system to detect Escherichia coli in water samples.

In this work we adopted the immunocapture technique, which consists of quantifying bacteria in a liquid sample, attracting and fixing the bacteria on the surface of the polymer optical fiber, by the antigen-antibody reaction.

The results showed the possibility of the POF in biosensor application capable to detect E. coli for envi-ronmental and food industry and for detecting and identifying biological-warfare agents using a very rapid re-sponse sensor, applicable to field detection prototypes.

8722-28, Session 7

Fiber optic refractive index sensors based on etched pi-phase-shifted fiber Bragg gratings

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We present a highly sensitive refractive index sensor based on etched pi-phase shifted fiber Bragg gratings (piFBG). Due to the pi-phase shift at the center of the grating structure, the transmission spectrum features an extremely narrow peak. When the fiber is etched into the fiber core, the narrow transmission peak of the piFBG can be used for highly sensitive refractive index sensing. A 7 mm-long strong piFBG at ~1550 nm with an ultra-high Q factor of 5x10^6 is fabricated using a UV laser and a phasemask. The fiber diameter is then etched to be < 10 microns to demonstrate highly-sensitive refractive index sensing of NaCl solutions in water. The effect of the absorption from water solution on the Q-factor and the sensitivity of the piFBG sensor is analyzed.

8722-29, Session 7

Integration of thin films with fiber microstructures for sensing applications

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The combination of fiber optics with micro-structure technologies and sensitive thin films offers great potential for the realization of novel sensor concepts. Minitured optical fiber sensors with thin films as sensitive elements could open new fields for optical fiber sensor applications. Thin films work as sensitive elements and transducer to get response and feedback from environments, optical fiber here are employed to signal carrier. Micro-structured Farby-Perot (F-P) sensors on single mode fiber (SMF) could be realized with femtosecond (fs) laser, and could be integrated with sensitive thin films for new sensing applications. In this paper, an optical fiber hydrogen sensor based on Fabry-Perot Interferometer near the tip of a single-mode fiber fabricated by femtosecond laser micromachining, is proposed and demonstrated. Pd film is deposited on the interferometer micro-cavity as the sensing material for hydrogen detection. The micro-cavity of 20 m in length and coated with 50 nm Pd film has been investigated in the hydrogen volume ratio rang of 0%–16%, and experimental results show that the sensor exhibits a hydrogen sensitivity of ~0.3846 nm/%. The compact optical fiber hydrogen sensor developed in this work is easy to fabricate and has high potentials in hydrogen sensing.

8722-30, Session 7

A hybrid plasmonic whispering gallery mode sensor for single bionanoparticle detection

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Biological warfare agents pose a real threat to national security. Exposure to harmful pathogenic material through contaminated media such as food and water supplies can result in severe outbreaks, and lead to mass hysteria in the civilian sector and impairment of resources in the military sector. Rapid detection of pathogenic material in vital resources and infected, or potentially infected individuals requires high sensitivity and responsivity. Resonant systems have long been known to be highly responsive and highly sensitive to changes in the local environment, but the ability to perform single bionanoparticle detection has proven difficult. Though not impossible, optical resonator systems exhibit detection limits for biological particles to be >100 nm. We have recently demonstrated detection and characterization of the smallest known RNA virus (13.5 nm radius) using a plasmonically enhanced hybrid whispering gallery mode biosensor. By affixing gold nanoparticles to the surface of a whispering gallery mode resonator, one locally enhances the electric field of the circulating light. When a target analyte binds with this nanoscopic antenna the result is an enhanced response (spectral shift) of the resonator system to the binding event. We have observed shift enhancements ~70x over the response of the bare resonator, thereby permitting the detection and characterization of all known viral particles and even some large protein molecules. Further enhancements are expected to push the detection limits into a range that would allow detection of toxins from pathogens such as Bacillus anthracis.

8722-31, Session 7

Novel compact architecture for high-resolution sensing with plasmonic gratings in conical mounting

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Recent research concerning the excitation of Surface Plasmon Polaritons (SPPs) on metallic gratings in conical mounting revealed new phenomena unexpectedly promising for sensing applications. More SPPs can be excited by the same wavelength with a refractive index sensitivity one order greater than conventional mountings[1]. In addition, the critical role of incident polarization on SPPs excitation[2] provides a new degree of freedom with high impact on sensing performance and architecture[3]. Here we provide the results of a first compact prototype implementing a Grating-Coupled Surface Plasmon Resonance (GCSPR) technique based on polarization modulation in conical mounting[4]. A metallic grating is azimuthally rotated in order to support a double excitation of high-sensitivity SPPs. At resonance, a polarization scan of the incident light is performed and reflectivity is collected before and after the sensing procedure. Output signal exhibits a harmonic dependence and the phase term is exploited as sensing parameter. The mechanical complexity of the SPR system is significantly reduced and benefits in sensitivity and resolution are assured, with values down to 10-7 Refractive Index Units (RIU). The system has been tested with saline solutions flowing through an integrated microfluidic setup and for the multiplexed detection of binding events (avidin/biotin, DNA/PNA probes) on the properly-functionalized gold pattern (Cysteine-thiolated polyethyleneoxide antifouling layer).

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[2]F. Romanato, et al., Appl. Phys. Lett. 96, 111103 (2010).

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8722-32, Session 7

Multiplexed detection of aquaculture fungicides using a pump-free optofluidic SERS microsystem

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We report the development of an optofluidic surface enhanced Raman spectroscopy (SERS) microsystem that is optimized for on-site food and water quality and safety control. The microdevice consists of a porous matrix of packed silica microspheres inside a microchannel that passively concentrates silver nanoparticles (AgNPs) and adsorbs analyte molecules, resulting in a significant increase in SERS signal intensity as compared to conventional open channel microfluidic SERS systems. The signal boost is due to molecule accumulation and SERS “hot spot” formation within the detection zone. Moreover, two multimode fiber optic cables are integrated into the detection zone for optical excitation and collection. This improves the detection automation since no traditional microscope alignment/focusing is necessary. In addition, the optofluidic SERS microsystem does not require a bulky syringe pump for sample loading. Instead, the sample is introduced into the device simply by applying negative pressure at the outlet using a pipette. Utilizing our optofluidic SERS device, multiplexed detection of three highly regulated fungicides in aquaculture is demonstrated. Malachite green, thiram, and methyl parathion were simultaneously detected in concentrations as low as 0.1 ppb, 5 ppb, and 5 ppm respectively. Integration of the optofluidic microsystem with state-of-the-art portable spectrometers and laser diodes may lead to improved portability and practicality of SERS for on-site detection of environmental contaminants. The device has the potential to integrate with other microfluidic functions (e.g. on-chip chromatographic separation), which makes it suitable for contaminants detection in complex real world samples.

8723-1, Session 1

The oral-systemic connection: role of salivary diagnostics *(Invited Paper)*

Daniel Malamud, New York Univ. (United States)

Salivary diagnostics is a rapidly advancing area of research, applying microfluidic technology to address major biomedical challenges. Surprisingly, most of the publications that utilize saliva for diagnostics are related to systemic rather than oral diseases. The field has blossomed into a range of applications involving diverse areas of basic and translational research and most recently has generated corporate interest and investments. The connections between the oral cavity and systemic diseases have fueled the progress in oral-based diagnostic technologies. In this presentation we will look at the origins of oral diagnostics and the oral-systemic connection, and then present recent results from our own group in developing point-of-care diagnostics for HIV, TB, and Malaria. This constellation of these three infectious diseases occurs in the same geographic regions, and typically infected individuals succumb to TB and Malaria which flourish due to HIV-induced immunosuppression.

8723-6, Session 1

Detection of congenital cytomegalovirus infection using real-time polymerase chain reaction of saliva

Shannon A. Ross, Masako Shimamura, The Univ. of Alabama at Birmingham (United States); April Palmer, The Univ. of Mississippi Medical Ctr. (United States); Amina Ahmed, Levine Childrens Hospital (United States); Marian Michaels, Univ. of Pittsburgh School of Medicine (United States); Pablo Sanchez, Univ. de Cantabria (Spain); David Bernstein, Cincinnati Children's Hospital Medical Ctr. (United States); Robert Tolan, Saint Peter's Healthcare System (United States); Novak Zdenek, Nazma Chowdhury, William Britt, Karen Fowler, Suresh Boppana, The Univ. of Alabama at Birmingham (United States)

Congenital cytomegalovirus (cCMV) infection is the most common congenital infection and a leading cause of hearing loss in children. As most infants with cCMV have no clinical abnormalities at birth, screening all infants for CMV will permit early identification of those at risk for hearing deficit. The gold standard for the diagnosis of cCMV infection in newborns has traditionally been viral culture of urine or saliva, however, culture based methods are labor and time intensive. PCR based detection of CMV in blood has been used in immunocompromised patients to detect and monitor CMV disease, However, PCR of dried blood spots was shown to be insensitive for the identification of newborns with cCMV. Since infants with cCMV shed large amounts of virus in saliva and urine, we developed a real-time PCR assay of saliva for newborn CMV screening. This assay was highly sensitive and specific for detecting CMV when compared with the gold standard, saliva viral culture, in over 34,000 newborns. Saliva PCR was also found to be equivalent to urine PCR for diagnosis. Therefore, saliva PCR appears to be the ideal assay for newborn CMV screening and diagnosis due to high sensitivity and specificity, as well as ease of sample collection, transport, and storage.

8723-7, Session 1

Computing Tutte polynomials of contact networks in classrooms

Doracelly Hincapie-Palacio, Univ. de Antioquia (Colombia); Juan Ospina, Univ. EAFIT (Colombia)

Objective: The topological complexity of contact networks in classrooms and the potential transmission of an infectious disease were analyzed by sex and age.

Methods: The Tutte polynomials, some topological properties and the number of spanning trees were used to algebraically compute the topological complexity. Computations were made with the Maple package GraphTheory. Published data of mutually reported social contacts within a classroom taken from primary school, consisting of children in the age ranges of 4–5, 7–8 and 10–11, were used.

Results: The algebraic complexity of the Tutte polynomial and the probability of disease transmission increases with age. The contact networks are not bipartite graphs, gender segregation was observed especially in younger children.

Conclusion: Tutte polynomials are tools to understand the topology of the contact networks and to derive numerical indexes of such topologies. It is possible to establish relationships between the Tutte polynomial of a given contact network and the potential transmission of an infectious disease within such network.

8723-8, Session 1

Detection of herpesviruses and papillomaviruses in saliva

Jennifer Webster-Cyriaque, The Univ. of North Carolina at Chapel Hill (United States)

No Abstract Available.

8723-11, Session 1

Therapeutic monitoring of HIV/AIDS using saliva biomarkers

Sárka Southern, Gaia Medical Institute (United States)

We have developed a large panel of saliva-based biomarkers (n=100) using new methods for saliva proteomics. The methods provide quantitative measures of distinct biomarkers with high sensitivity and specificity. The new saliva biomarkers can be translated into a rapid point-of-care (POC) test and have clinical applications in disease diagnostics and therapeutic monitoring. Current applications of the technology include monitoring the outcome of anti-retroviral therapy (ART) in HIV/AIDS patients. Saliva biomarkers for this application were validated using a clinical study of HIV/AIDS patients at AIDS Healthcare Foundation in Los Angeles. The biomarkers are clinically specific for HIV and correlate with standard blood tests for therapeutic monitoring of HIV/AIDS: the CD4 T cell count and the HIV-RNA viral load. The saliva biomarkers provide a new approach to HIV/AIDS monitoring, and offer new insights into the molecular mechanism of HIV persistence and AIDS progression. The new saliva ART test will significantly improve clinical HIV/AIDS care by allowing real-time, cost-effective assessment of ART efficacy during routine patient visits in community clinics.

8723-13, Session 1

Diagnostic microRNA profiling distinguishes infection types

Dirk P. Dittmer, Pauline E. Chugh, Sang-Hoon Sin, Seonjoo Lee, Haiping Shen, Lineberger Comprehensive Cancer Ctr., The Univ. of North Carolina at Chapel Hill (United States)

Micro RNAs are a new class of transcripts, which function to modulate gene expression. They themselves are regulated by host gene signaling pathways and thus can be used as a read-out of the host cell state. MicroRNA profiling is gaining increasing popularity as a means of expression profiling owing in part to the extraordinarily stability of these small RNAs within the cell and within body fluids. We initially used miRNA profiles to differentiate among viral cancers (PLoS Pathog. 2009 Apr;5(4):e1000389) using custom real-time qPCR arrays. Here, we will present data using TaqMan qPCR as well as NextGen sequencing (Virology. 2012 Nov 10;433(1):220-5.) to distinguish among viral infections (herpes B virus vs. HSV1) and to delineate disease progression in Kaposi sarcoma associated herpesvirus (KSHV or HHV8) infections. We will present a new concept for the classification of data based on NextGen sequencing.

8723-57, Session 1

Oral microbiome in health and disease: lessons from HIV

Mahmoud Ghannoum, Case Western Reserve Univ. (United States)

No Abstract Available.

8723-58, Session 1

NIDCR overview on salivary biology and oral fluid-based diagnostics for diseases *(Invited Paper)*

Isaac Rodriguez-Chavez, Penny Wung Burgoon, National Institute of Dental and Craniofacial Research (United States)

The principle of using novel technologies for clinical diagnosis of non-infectious and infectious comorbidities that affect millions of people globally relies on biomedical advances and the development and implementation of cost effective, rapid and minimally invasive procedures for biospecimen collection and testing in robust assays. The latter incorporates analytes' detection with high sensitivity, specificity and reproducibility in diverse settings including clinical diagnostic laboratories and field conditions. Based on this principle and the readily accessibility of the oral cavity with its constituting oral fluids, which represent an ideal milieu of plentiful biomarkers –the analytes- for the identification of oral and systemic diseases, the clinical diagnostics field has embraced salivary biology and the use of oral-fluid-based assays as a novel and powerful alternative to the more traditional blood and plasma biospecimens collected and tested in routine, time-consuming clinical diagnostic assays. This presentation will provide an overview of the field of salivary biology and oral fluid-based diagnostics for diseases, discussing emerging trends and future directions.

8723-2, Session 2

Salivary analytes for interdisciplinary biomedical research and diagnostics *(Invited Paper)*

Douglas A. Granger, Johns Hopkins Univ. (United States)

No Abstract Available.

8723-4, Session 2

Update on a lab-on-a-chip system for saliva diagnostics: link to oral cancer

Pierre N. Floriano, Rice Univ. (United States); A. Ross Kerr, Brian L. Schmidt, Patricia Corby, Ismael El Khouly Castilla, New York Univ. College of Dentistry (United States); Martin H. Thornhill, Katy D'Apice, Craig Murdoch, Paul Speight, The Univ. of Sheffield (United Kingdom); Spencer Redding, Stan McGuff, Chih-Ko Yeh, Steve Westbrook, Mark Diburro, Stephanie Rowan, The Univ. of Texas Health Science Ctr. at San Antonio (United States); Nadarajah Vigneswaran, Etan Y. Weinstock, Nagi Demian, Tammy Tran, Maga Sanchez, The Univ. of Texas Dental Branch at Houston (United States); Nicolaos Christodoulides, Surabhi Gaur, Kailash Karthikeyan, Humberto Talavera, Michael Nguyen, Cathy Le, Leander Taylor, John McDevitt, Rice Univ. (United States)

A large multi-site international clinical was conducted to develop and validate a lab-on-a-chip (LOC) method to analyze exfoliated oral cells. Three groups of subjects: PMOD (potentially malignant oral disorders), OSCC (oral squamous cell carcinoma) and normal controls were enrolled at three sites. Three-color immunofluorescence analysis of cellular samples for up to 25 cytomorphometric parameters and biomarker expression (of 7 candidate biomarkers) were generated in an automated manner with image analysis algorithms based on pattern recognition techniques and advanced statistical methods. Based on preliminary results, we expect the outcome of this study to produce a tool based on LOC analysis of exfoliated cells collected noninvasively and capable of discriminating between benign and dysplastic or OSCC lesions with high sensitivity and high specificity with multivariate panels of molecular and cytomorphometric parameters.

8723-5, Session 2

Saliva diagnostics for respiratory diseases using an automated integrated device

Shuai Nie, Huaibin Zhang, David R. Walt, Tufts Univ. (United States)

Multiplexed antibody microarrays have been used for a variety of clinical diagnostics applications. Saliva has been considered as a preferred diagnostic fluid as its collection is safe, noninvasive, and requires minimal personnel training. We have developed an automated integrated device based on sensitive, multiplexed protein microarrays for the quantification of biomarkers in human saliva samples. Monoclonal antibodies are covalently bonded to fluorescent-encoded cross-linked polymer microspheres. Different types of antibody-modified microspheres are mixed and then loaded in microwells integrated into a microfluidic chip. The protein biomarkers are quantified via fluorescence sandwich immunoassays. A saliva sample is introduced into the microfluidic chip, and automatically analyzed by the integrated analyzer. This multiplexed platform enables fast, accurate, and reproducible analysis of different proteins over a wide concentration range. The test requires only 10 ?L of saliva and the results are reported within 75 minutes. The performance of the integrated device has been verified using standard solutions

constituted with recombinant proteins. Saliva samples collected from patients with different respiratory diseases as well as healthy controls have also been tested. Statistical analysis on six protein biomarkers for asthma and cystic fibrosis demonstrates the possibility of using human saliva samples for point-of-care diagnostics of respiratory diseases.

8723-9, Session 2

The proteome of human saliva *(Invited Paper)*

Timothy J. Griffin, Pratik Jagtap, Univ. of Minnesota (United States); Sricharan Bandhakavi, Bio-Rad Labs., Inc. (United States); Susan K. Van Riper, Univ. of Minnesota, Rochester (United States); Ebbing de Jong, Nelson L. Rhodus, John V. Carlis, Univ. of Minnesota (United States); Joel D. Rudney, Univ. of Minnesota School of Dentistry (United States)

Human saliva holds tremendous potential for transforming disease and health diagnostics given its richness of molecular information and non-invasive collection. Enumerating its molecular constituents is an important first step towards reaching this potential. Among the molecules in saliva, proteins and peptides arguably have the most value: they can directly indicate biochemical functions linked to a health condition/disease state, and they are attractive targets for biomarker assay development. However, cataloging and defining the human salivary proteome is challenging given the dynamic, chemically heterogeneous and complex nature of the system. Presented here will be a summary of communal efforts to meet this challenge, focusing on the current snapshot of the human salivary protein catalog, and including efforts to characterize the chemical heterogeneity of the proteome (e.g. post-translational modifications). A summary of work aimed at identifying the contribution from the oral microbiome to the human saliva proteome will also be presented. Implications of these efforts to characterize the salivary proteome in the context of disease diagnostics will be discussed.

8723-10, Session 2

Emerging technologies for salivary diagnostics: lessons from chronic graft-versus-host disease *(Invited Paper)*

Jacqueline W. Mays, National Institute of Dental and Craniofacial Research, National Institutes of Health (United States)

Saliva is a protein-rich oral fluid that contains information about systemic and oral-specific disease pathogenesis and for their diagnosis. Technologies are emerging to improve detection of protein components of saliva for use not only in biomarker discovery, but also for the illumination of pathways involved in oral disease. These include the optimization of liquid chromatography tandem mass spectrometry analysis of saliva in health and disease. Downstream of saliva component identification and validation comes the complex task of connecting salivary proteomic data to biological function, disease state, and other clinical patient information in a meaningful way. Augmentation of database information with biological expertise is crucial for effective analysis of potential biomarkers and disease pathways in order to improve diagnosis and identify putative therapeutic targets. This presentation will use LC-MS/MS analysis of saliva from chronic Graft-versus-Host disease patients and from Sjogren's syndrome patients to illustrate these principles.

8723-12, Session 2

Salivary proteome as an in vivo model to study breast cancer progression *(Invited Paper)*

Charles F. Streckfus, The Univ. of Texas Dental Branch at Houston (United States)

The objective of this study was to compare the salivary protein profiles of saliva specimens from individuals diagnosed with breast cancer with and without HER2/neu overexpression.Pooled (n=10 pooled) stimulated whole saliva specimens from women were analyzed. One pooled specimen was from healthy women, another was from women diagnosed with Stage IIa ($T_2/N_0/M_0$) invasive ductal carcinoma (IDC) without positive HER2/neu receptor status. A third pooled specimen was from women diagnosed with Stage IIa ($T_2/N_0/M_0$) IDC with a positive HER2/neu receptor status. Isotopically tagging proteins in the tumor groups and comparing them to the healthy control group measured differential expression of proteins. Experimentally, saliva from each of the pooled samples was trypsinized and the peptide digests labeled with the appropriate iTRAQ reagent. Labeled peptides from each of the digests were combined and analyzed by reverse phase (C18) capillary chromatography on an LC-MS/MS mass spectrometer equipped with an LC-Packings HPLC. The results of this study yielded 20 proteins unique to HER2/neu positive receptor status and 28 proteins that were unique to HER2/neu negative status. In conclusion, results of this study provide support to the novel idea of using salivary biomarkers to study breast cancer progression.

8723-14, Session 2

Nanosensor for saliva-based glucose monitoring

Jonathan C. Claussen, U.S. Naval Research Lab. (United States)

No Abstract Available.

8723-15, Session 2

Cell phone-based imaging and sensing architectures *(Invited Paper)*

Aydogan Ozcan, Univ. of California, Los Angeles (United States)

Today there are more than 6 billion cell-phone users in the world, and the majority of these cellphones are being used in developing parts of the world. This massive volume of wireless phone communication brings an enormous cost-reduction to cellphones despite their sophisticated hardware and software capabilities. Utilizing this advanced state-of-the-art cell phone technology towards point-of-care diagnostics and/or microscopic imaging applications 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.

This talk will introduce new imaging and detection architectures that can compensate in the digital domain for the lack of complexity of optical components by use of novel theories and numerical algorithms to address the immediate needs and requirements of Telemedicine for Global Health Problems. Specifically, I will present an on-chip cytometry and microscopy platform that utilizes cost-effective and compact components to enable digital recognition and 3D microscopic imaging of cells with sub-cellular resolution over a large field of view without the need for any lenses, bulky optical components or coherent sources such as lasers. This incoherent holographic imaging and diagnostic modality has orders of magnitude improved light collection efficiency and is robust to misalignments which eliminates potential imaging artifacts or the need for realignment, making it highly suitable for field use. Applications of this lensfree on-chip microscopy platform to high-throughput imaging and automated counting of whole blood cells, monitoring of HIV+ patients (through CD4 and CD8 T cell counting) and detection of waterborne parasites towards rapid screening of water quality will also be demonstrated. I will discuss lensfree implementations of various other computational imaging modalities on the same platform such as pixel super-resolution imaging, lensfree on-chip tomography, holographic opto-fluidic microscopy/tomography. Finally, I will demonstrate lensfree on-chip imaging of fluorescently labeled cells over an ultrawide field of view of >8 cm2, which could be especially important for rare cell analysis

(e.g., detection of circulating tumor cells), as well as for high-throughput screening of DNA/protein micro-arrays.

8723-59, Session 2

Saliva-based testing for malaria

Sungano Mharakurwa, Johns Hopkins Univ. (United States)

No Abstract Available.

8723-18, Session 3

The military's approach to TBI and PTSD *(Invited Paper)*

Geoffrey S. F. Ling M.D., Uniformed Services Univ. of the Health Sciences (United States); Jason S. Hawley, Walter Reed National Military Medical Ctr. (United States)

No Abstract Available.

8723-20, Session 3

Prevention and reduction of injuries in soldiers: current and future challenges *(Invited Paper)*

Richard Shoge, U.S. Army Medical Research and Material Command (United States)

The mission of the Military Operational Medicine Research Program (MOMRP) and USAMRMC is to develop effective countermeasures against stressors and to maximize Soldier health, performance, and fitness. Soldiers are susceptible to debilitating injuries. Head and neck injuries, including severe traumatic brain injury (TBI), have been reported in 25% of evacuated service members. In FY10, over 700,000 veterans experienced a hearing disorder (tinnitus) and over 600,000 suffered hearing loss. Chronic musculoskeletal injuries are the leading cause (78%) of discharge for male and female Soldiers. To address injury rates, the medical research community is tasked to develop injury criteria that will lead to better preventive standards and strategies to protect against current and future threats which include blast overpressure, blunt and penetrating trauma, musculoskeletal and training injuries, and acoustic trauma. Addressing future challenges will require maturation of the science in areas such as mild traumatic brain injury (mTBI), injury prediction and reduction models, injury criteria for equipment design specifications and guidelines, health hazard injury assessment criteria, and validated standards to assess return to duty following physical and neurosensory injury. In the end this will help the overall military challenge of optimizing the soldiers' survivability, protection, and mobility to enhance mission success.

8723-23, Session 3

Clinical detection of brain damage in military and civilian TBI

Ava M. Puccio, UPMC Presbyterian (United States)

No Abstract Available.

8723-24, Session 3

Systems biomarkers as acute diagnostics and chronic monitoring tools for traumatic brain injury *(Invited Paper)*

Kevin K.W. Wang, Univ. of Florida (United States)

Traumatic brain injury (TBI) is a significant biomedical problem among military personnel and civilians. There exists an urgent need to develop and refine biological measures of acute brain injury and chronic recovery after brain injury. Such measures, "biomarkers," can assist clinicians in helping to define and refine the recovery process and developing treatment paradigms for the acutely injured to reduce secondary injury processes. Recent biomarker studies in the acute phase of TBI have highlighted the importance and feasibilities of identifying clinically useful biomarkers. However, much less is known about the subacute and chronic phases of TBI. We propose here that for a complex biological problem such as TBI, multiple biomarker types might be needed to harness the wide range of pathological and systemic perturbations following TBI, including acute neuronal death, neuroinflammation, neurodegeneration and neuroregeneration to systemic responses. In terms of biomarker types, they range from brain-specific proteins, microRNA, genetic polymorphism, inflammatory cytokines, autoimmmune markers and neuro-endocrine hormones. Furthermore, systems biology-driven biomarkers integration can help present a holistic approach to understand scenarios and complexity pathways involved in brain injury.

8723-50, Session 3

Blast-induced TBI: recovery and rehabilitation

Yelena Bogdanova, Boston Univ. (United States)

No Abstract Available.

8723-53, Session 3

A review of glutamates role in traumatic brain injury mechanisms

Cameron Good, U.S. Army Research Lab. (United States)

Glutamate is the primary excitatory neurotransmitter used by the central nervous system for synaptic communication, and its extracellular concentration is tightly regulated by glutamate transporters located on nearby astrocytes. Both animal models and human clinical studies have demonstrated elevated glutamate levels immediately following a traumatic brain event, with the duration and severity of the rise corresponding to prognosis. This rise in extracellular glutamate likely results from a combination of excessive neurotransmitter release from damaged neurons and down regulation of uptake mechanisms in local astrocytes. The immediate results of a traumatic event can lead to necrotic tissue death in severely injured neurons, while prolonged increases in excitatory transmission can cause secondary excitotoxic injury through activation of delayed apoptotic pathways. Initial TBI animal studies utilized a variety of broad glutamate receptor antagonists to successfully combat secondary injury mechanisms, but unfortunately this same strategy has proven inconclusive in subsequent human trials due to deleterious side effects and heterogeneity of injuries. More recent treatment strategies have utilized specific glutamate receptor subunit antagonists in an effort to minimize side effects and have shown promising results. Future challenges will be detecting the concentration and kinetics of the glutamate rise following injury, determining which patient populations could benefit from antagonist treatment based on their extracellular glutamate concentrations and when drugs should be administered to maximize efficacy. This talk will review our current thinking of glutamates role in the pathophysiology of TBI and highlight potential avenues for future research in injury mechanism and detection.

8723-60, Session 3

Mechanisms of traumatic and degenerative brain injury and repair

Vassilis Koliatsos, Johns Hopkins Univ. (United States)

No Abstract Available.

8723-61, Session 3

Intelligent mouthguard: new technology to measure head impact in soldiers and athletes

Adam Bartsch, Cleveland Clinic (United States)

Nearly 2 million Traumatic Brain Injuries (TBI) occur in the U.S. each year, with societal costs approaching $60 billion. Including mild TBI and concussion, TBI's are prevalent in soldiers returning from Iraq and Afghanistan as well as in domestic athletes. Long-term risks of single and cumulative head impact dosage may present in the form of post traumatic stress disorder (PTSD), depression, suicide, Chronic Traumatic Encephalopathy (CTE), dementia, Alzheimer's and Parkinson's diseases. Quantifying head impact dosage and understanding associated risk factors for the development of long-term sequelae is critical toward developing guidelines for TBI exposure and postexposure management. This fundamental gap limits the understanding of underlying TBI mechanisms, including effective treatment protocols and prevention methods for soldiers and athletes.

To address this fundamental gap, Cleveland Clinic is developing the Intelligent Mouthguard (IMG) to measure head impact dosage in soldiers and athletes. Dynamic benchtop IMG testing under real-world impact conditions have shown a 3% under prediction in linear acceleration (R2 = 0.99) up to 200g, a 3% under prediction in angular velocity (R2 = 0.99) up to 40rad/s and a 19% under prediction in angular acceleration (R2 = 0.97) up to 10,000rad/s2. In vitro impact tests are ongoing and have demonstrated the need to co-localize IMG sensor positions and orientations with respect to each user's head center of gravity as well as identify impact frequency content. In vivo testing has been completed on hockey players (n=4) and continues on amateur boxers (n=10). The IMG will assist in developing injury assessment reference values (IARV) for head impact dosage related to clinical neurocognitive functional deficit data for TBI, mTBI and concussion.

8723-65, Session 3

Circulating exosomes as new biomarkers for brain disease and injury

Michael W. Graner, Univ. of Colorado Denver (United States); Laura M. Epple, Univ. of Colorado Denver (United States) and Colorado State Univ. (United States); Nathaniel L. Dusto, Alex M. Lencioni, Univ. of Colorado Denver (United States)

Brain diseases such as cancers, neurodegenerative disorders, or trauma are frequently diagnosed with imaging modalities and sometimes with intracranial biopsies. Treatment response is similarly monitored, along with clinical indications. While these technologies provide important windows into the disease state, they fail to provide us a detailed molecular portrait of the disease and of the changes taking place during therapy. Exosomes are virus-sized nanovesicles derived from the endosomal system and are released extracellularly from essentially all cell types. Exosomes contain intracellular entities (proteins, nucleic acids, metabolites), membrane proteins and lipids, and even extracellular proteins bound to them. Exosomes may be considered as mini-surrogates of their cells of origin, with some content common to all cells/exosomes, but some of the content would be cell-specific. These vesicles are found in all biofluids in humans, and are thus accessible to "liquid biopsy" with harvest of vesicles from such fluids. Current challenges are to identify disease-related markers or panels of markers to distinguish the disease state. Here we will show examples of brain tumor markers found in/on exosomes from cell culture and patient sera, and we will suggest that aspects of the biology of disease may have a relevant place in the search for biomarkers.

8723-28, Session 4

Monitoring astronaut health in space *(Invited Paper)*

Virginia Wotring, NASA Johnson Space Ctr. (United States)

During spaceflight missions, NASA crewmembers experience months of ordinary medical events, as well as certain syndromes associated with the extreme environment of spaceflight. It is well documented from current and past missions that many spaceflight-associated alterations are observed in human physiology, including changes in bone remodeling, muscle atrophy, immune system status, sensorimotor integration, circadian rhythms, and fluid distribution in the body. Current missions are approximately 6 months in length, but preparation for long-duration exploration missions will require additional examination of these physiological changes over longer periods of time. NASA uses microgravity-compatible aspects of remote medicine to enable better diagnosis and treatment of crewmembers, but currently the medical and physiological research systems still rely heavily on return of physiological samples (blood, urine, and saliva) from the ISS to ground laboratories for analysis. NASA is developing additional analytical instrumentation onboard the ISS to improve both diagnostic and research capabilities. To reduce risk to the crewmembers during sample collection as well as to improve crew compliance and participation, NASA is also exploring the expanded use of saliva as a physiological fluid for both clinical tests and research studies.

8723-29, Session 4

High-altitude physiology: Lessons from Tibet *(Invited Paper)*

Peter D. Wagner, T. S. Simonson, Univ. of California, San Diego (United States); G. Wei, Qinghai Univ. Medical School (China); H. Wagner, Univ. of California, San Diego (United States); T. Wuren, Qinghai Univ. School of Medicine (China); M. Yan, G. Qin, R. L. Ge, Qinghai Univ. Medical School (China)

Polycythemia is a universal lowlander response to altitude; healthy Andean high-altitude natives also have elevated hemoglobin [Hb]. While this may enhance O_2 transport to tissues, studies have shown that acute isovolumic changes in [Hb] do not affect exercise capacity. Many high-altitude Tibetans have evolved sea-level values of [Hb], providing a natural opportunity to study this issue. In 21 young healthy male Tibetans with [Hb] between 15 and 23 g/dl, we measured $V\cdot O_{2MAX}$ and O_2 transport capacity at 4200m. $V\cdot O_{2MAX}$ was higher when [Hb] was lower, enabled by both higher cardiac output and muscle O_2 diffusional conductance, but neither ventilation nor the alveolar-arterial PO2 difference ($AaPO_2$) varied with [Hb]. In contrast, Andean high altitude natives remain polycythemic with larger lungs and higher lung diffusing capacity, a smaller exercising $AaPO_2$, and lower ventilation. The challenges now are to understand the different adaptive pathways used by Andeans and Tibetans, and determine in Tibetans whether, during evolution, reduced [Hb] appeared first, causing compensatory cardiac and muscle adaptations, or if enhanced cardiac function and muscle O_2 transport capacity appeared first, permitting secondary reduction in [Hb].

8723-30, Session 4

Molecular diagnostics of osmotic stress and dehydration

Sárka O. Southern, Gaia Medical Institute (United States)

We have developed a large panel of saliva-based biomarkers (n=100) using new methods for saliva proteomics. The methods provide quantitative measures of distinct biomarkers with high sensitivity and specificity. The new saliva biomarkers can be translated into a rapid hand-held test for point-of-care settings. Clinical applications include noninvasive disease diagnostics, monitoring systemic health and treatment outcomes. Saliva biomarkers for noninvasive monitoring of hydration status were validated in two DoD-sponsored clinical studies of hypertonic and isotonic dehydration. The biomarkers provide a new approach to dehydration diagnostics, and offer insights into the molecular mechanism of osmotic stress and dehydration. Dehydration is a significant public health issue. Over 90 million people are expected to become dehydrated in the U.S. each year. Most of them are children, the elderly, sports participants, and patients with trauma, diabetes, kidney dialysis, cancer or Alzheimer's disease. Proper fluid balance is critical for Warfighter performance and health during training and deployment. Dehydration is one of the fundamental physiological mechanisms of illness and injury in extreme environments such as Afghanistan. The new dehydration test will allow improved hydration management and return-to-duty metrics during training and combat for Warfighters, and will provide early detection of dehydration in pediatrics, geriatrics and sports medicine.

8723-31, Session 4

Thermal physiology: research approaches and clinical applications

Thad Wilson, Ohio Univ. (United States)

Exposure to acute cold and heat stress elicits robust physiological responses aimed at maintaining body temperature in humans. Cold ambient temperatures cause cutaneous vasoconstriction in an effort to increase the thermal insulation properties of the skin. If cooling is of significant magnitude, whole body metabolic rate increases via shivering and non-shivering thermogenesis. The precise response to a cold stress is highly dependent on the type, duration, severity, and pain involvement during the stress, but these stresses have the potential to model aspects of hypertension and myocardial ischemia in humans.

Hot ambient temperatures induce cutaneous vasodilation to offload heat. To increase skin perfusion, heart rate and cardiac output increase and conductance to renal and splanchnic vascular beds decreases. Sweat glands are engaged to increase evaporative heat loss, but this can decrease plasma and interstitial fluid volumes. These cardiovascular and fluid changes decrease cardiac preload and central blood volume. The precise cardiovascular and autonomic responses to heat stress are highly dependent on the type (passive or active), duration, and severity of the stress, but these stresses have the potential to model aspects of shock and orthostatic intolerance in humans.

8723-32, Session 4

Exercise science: research to sustain and enhance performance

Jonathan Wingo, The Univ. of Alabama System (United States)

Cardiovascular adjustments accompanying exercise in high ambient temperatures are likely responsible for diminished aerobic capacity and performance in such conditions. These adjustments include a phenomenon known as cardiovascular drift in which heart rate rises and stroke volume declines progressively over time during constant-rate exercise. A variety of factors modulate the magnitude of cardiovascular drift, e.g., elevated core and skin temperatures, dehydration, and exercise intensity. Regardless of the mode of manipulation, decreases in stroke volume associated with cardiovascular drift result in directionally and proportionally similar decreases in maximal aerobic capacity. Maximal aerobic capacity is determined by maximal heart rate, maximal tissue oxygen extraction, and maximal stroke volume. Because maximal heart rate and maximal tissue oxygen extraction are unaffected during exercise in the heat, decreased stroke volume associated with cardiovascular drift likely persists during maximal efforts and explains the decrease in maximal aerobic capacity. Decreased maximal aerobic capacity results in a greater perceptual and physiological strain accompanying any given level of work. Therefore, sustaining and enhancing performance involves sophisticated monitoring of physiological strain combined with development of countermeasures that mitigate the magnitude of deleterious phenomena like cardiovascular drift.

8723-33, Session 4

Energy-aware Activity Classification using Wearable Sensor Networks

Bo Dong, Alexander Montoye, Rebecca Moore, Karin Pfeiffer, Subir Biswas, Michigan State Univ. (United States)

This paper presents a wearable sensor network for human activity analysis and energy expenditure estimation for telemedicine based remote health monitoring applications. The primary military application of the proposed system can be real-time soldier monitoring in battleground settings. We characterize the energy and processing constraints of on-body sensors. Machine learning mechanisms are implemented for recognizing 14 activities with both out-of-body and on-body processing arrangements. Impacts of energy consumption and processing limitation of the on-body sensors and the number of sensors are analyzed in terms of activity detection accuracy. Conclusively, it is shown that an efficient human activity analytics system can be designed under energy and processing constraints of on-body sensors.

8723-62, Session 4

How cells detect and survive osmotic stress caused by dehydration *(Invited Paper)*

Maurice Burg, National Heart, Lung, and Blood Institute (United States)

Hypertonicity, such as caused by high NaCl, shrinks cells by osmosis, acutely reducing cell water and increasing both intracellular ionic strength and macromolecular crowding. Those intracellular alterations perturb proteins, but also serve to sense the dehydration. In cell culture, high levels of hypertonicity kill cells by apoptosis, but cells adapt to lesser hypertonicity after cell cycle delay. Damage from high NaCl includes increased DNA double strand breaks and increased reactive oxygen species resulting in oxidation of proteins. Remarkably, those damages persist in otherwise normal seeming cells adapted in culture and in the hypertonic renal medulla in vivo. Within minutes of hypertonicity cells restore their volume by importing extracellular electrolytes, followed by osmotic uptake of water. This reduces macromolecular crowding, but not the high intracellular ionic strength. The latter becomes normalized over hours by accumulation of nonperturbing organic osmolytes that replace the elevated electrolytes. The organic osmolytes accumulate because of increased transcription of transporters that that take them up into the cells and of enzymes that catalyze their synthesis. The responsible transcription factor is NFAT5. Activation of NFAT5 is signaled by a complex system, including numerous protein kinases and phosphatases that cause widespread phosphorylation of proteins, including NFAT5, itself.

8723-63, Session 4

Integrative environmental physiology and fluid regulation

Nina S. Stachenfeld, Yale Univ. (United States)

Sweating during exercise in the heat causes sodium and water losses. The extent of these losses depends upon the intensity and duration of the activity, the individual's genetic predisposition and acclimation, and environmental factors. Integrated neural and hormonal systems have evolved to control thirst and fluid regulation. These systems respond to stimuli that arise from a deficit of fluid arising in both the intracellular and extracellular fluid compartments or to systemic hypertonicity. During or after dehydrating exercise, sodium ingestion helps to restore plasma volume and osmolality by continuing thirst sensation (thus drinking) and by increasing body fluid retention. This talk provides a discussion of acute sodium exposure on the sodium and fluid regulation systems, and describes how sodium is an intrinsic part of the thirst response at rest, during and after exercise. Intravascular hypertonic saline infusion may cause transient osmotically mediated blood pressure increases in sensitive people. Moreover, these fluid regulatory systems are sensitive to aging and sex. In young women, estradiol lowers the operating point for osmoregulation of arginine vasopressin and thirst and increases plasma volume. This talk will briefly address aging effects on sodium and water regulation.

8723-40, Session PTues

Assessing satellite AOD based and WRF/ CMAQ output PM2.5 estimators

Lina Cordero, Chowdhury Nazmi, Barry M. Gross, Fred Moshary, The City College of New York (United States); Yonghua Wi, City College of New York (United States)

Fine particulate matter with particle diameters < 2.5 microns (PM2.5) has been linked to respiratory and pulmonary difficulties and for this reason, strong concentration guidelines have been developed by the EPA to limit exposure. While the EPA utilizes an extensive network of ground stations to monitor PM2.5 concentrations on an hourly basis, the instruments and procedures are expensive and time consuming. Efforts to connect surface PM2.5 to satellite retrieval of Aerosol Optical Depth (AOD) have been made and real time spatial maps of PM2.5 based on this methodology have been made operational . In this methodology, regression analysis is applied to provide coefficients for different seasons and geographic regions.

However, since these estimates are based on satellite AOD retrievals, systemic biases in these retrievals will result in PM2.5 biases. However, in urban areas such as NYC, significant overestimates of AOD from MODIS is observed leading to PM2.5 hotspots being predicted. These overestimates can be traced to underestimates of the urban surface reflection and can be compensated using regional land classification information .

In this presentation, PM2.5 estimator regression coefficients used in the IDEA operational algorithm are applied to both MODIS operational C005 AOD and regional model estimates for PM2.5 averaged over both urban and non urban AQS stations. In particular, we see significant overbias in the operational PM2.5 estimates which are significantly reduced when the regional model is used . More details of the satellite algorithm and a better understanding of the urban surface model for satellite retrieval will be presented.

8723-44, Session PTues

Generalized Mathematical-computational-electronic model of MPTP- induced Parkinsonism

Daniela Jaramillo Raquejo, Univ. EAFIT (Colombia)

The substance has been studied is 1-methyl-4-phenyl-1 ,2,3,6-tetrahydropyridine (MPTP), which has been studied as a major cause of neurodegeneration dopaminica, which is specifically related to Parkinson's disease, the analysis is in terms of the diffusion of the substance to the mammalian brain, by evaluating the diffusion equation in a spherical coordinate system, although the progress of the disease with respect to time has not been established with certainty, below are trying to find a stable pattern of the concentration of MPTP and its effects.

8723-45, Session PTues

Processing of medical images using Maple

Veronica Toro, Univ. EAFIT (Colombia)

Maple's Image Tools package was used to process medical images. The results showed clearer images and records of its intensities and entropy. The medical images of a rhinocerebral mucormycosis patient, who was not early diagnosed, were processed and analyzed using Maple's tools, which showed, in a clearer way, the affected parts in the perinasal cavities.

8723-46, Session PTues

Application of the diffusion-convection equation to modeling the infection by histoplasmacapsulatum

Sergio A. Jaime, Univ. EAFIT (Colombia)

Using computer algebra, the respiratory infection of the histoplasma capsulatum humus was modeled and analyzed; the effects of the infection could also be described as a change in the lungs elastic modulus. A further analysis to the immune system was also done in order to describe and model the way the body can handle those kinds of infections once they get to the body. Using those models we can describe the behavior of the respiratory infection and then how to reduce or control its effects. As an investigation in the medical field, we need to test the models obtained and compare the results with the real infection behavior. The models where made based on the diffusive-convective equation; giving some initial and boundary conditions, we can get to the results obtained, which can describe how the infections spreading and with a previous study of the immune system, the infection control done by the body can also be modeled.

8723-47, Session PTues

Refining environmental satellite data using a statistical approach

Md. Z. Rahman, LaGuardia Community College (United States); Leonid Roytman, The City College of New York (United States); Abdel Hamid Kadik, LaGuardia Community College (United States)

The proposed approach in this article applies an efficient and novel statistical technique to accurately describe radiometric data measured by Advanced Very High Resolution Radiometers (AVHRR) onboard the National Oceanic and Atmospheric Administration's (NOAA) Polar

Orbiting Environmental Satellites (POES). The corrected data set will then be applied to improve the strength of NOAA Global Vegetation Index (GVI) data set for the 1989-2010 period produced from AVHRR. The GVI is used extensively for studying and monitoring land surface, atmosphere and recently for analyzing climate and environmental changes. The POES AVHRR data, though useful, cannot be directly used in climate change studies because of the orbital drift in the NOAA satellites over the lifetime of the satellites. This orbital drift causes inaccuracies in AVHRR data sets for some satellites. The main goal is achieved by implementing a statistical technique that uses an Empirical Distribution Function (EDF) to produce error free long-term time-series for GVI data sets. This technique permits the representation of any global ecosystem from desert to tropical forest and to correct deviations in satellite data that are due to orbital drifts and AVHRR sensor degradations. The primary focus of this research is to generate error free satellite data by applying the EDF technique for climatological research.

8723-48, Session PTues

Health hazards of cell phone radiation and the zebrafish as a model in this study

Mary C. Vagula, Ryan V. Harkless, Gannon Univ. (United States)

Radio wave frequency (RF) radiation emitted from cellular telephones has become increasingly ubiquitous as a result of the popularity of these phones. With the increasing and unavoidable exposure to RF radiation a reality, it is imperative that the effects of such radiation on living tissue be well understood. In particular, it is critical to understand any effects that RF radiation may have as a carcinogen and on embryonic development, as pregnant women are not exempt from such exposure. As a model organism, zebrafish (Danio rerio) have been studied extensively, and their value in studies of gene expression cannot be overstated. This study is to understand the effects of RF radiation on the embryonic development of zebrafish. The expression of several genes that are the key to the early development of the fish will be presented, and all such genes have homologs in humans as well as in other model organisms; in particular, the gli1 gene (and its human homolog) has been implicated as a possible carcinogen. The goal of this study is twofold: firstly, to provide data on the effects of RF radiation on zebrafish development, very little of which exists; and secondly, to elucidate the effects of RF radiation on zebrafish genes which have homologs in humans and other model organisms.

8723-49, Session PTues

The toxic effects of flame retardants: The gene expression study in elucidating their carcinogenicity

Mary C. Vagula, Ali Al-Dhumani, Sajaad Al-Dhumani, Alexandra Mastro, Gannon Univ. (United States)

Polybrominated Diphenyl Ethers (PBDEs) are flame retardants widely used in many commercial products, including building materials, electronics, furnishings, motor vehicles, airplanes, plastics, polyurethane foams, and textiles. Although the specific toxic action of these chemicals is not clear, it is proven that they can cause serious damage to the nervous, reproductive, and endocrine systems. In addition, the Environmental Protection Agency (EPA) has placed PBDEs as a class of possible carcinogens. Out of 209 possible congeners in this class of flame retardants, two are selected for this study namely BDE-209 and BDE-85. BDE- 209 is one of the most abundantly used flame retardant worldwide and BDE-85 is one of the most toxic congeners of this class. Few reports have shown an increased tumor formation in animals exposed to PBDE's in large amounts, however very little information is available on the effects of these compounds on cell division, apoptosis, and their link to cancer. Therefore this study is taken up to investigate the expression of genes involved in apoptosis, DNA repair and cell cycle regulation. The gene expression study is employed in this investigation to examine their role in cancer. The study has targeted human umbilical vein endothelial cells in this study and this not only reveals the toxic effects of PBDEs and their role in cancer but also give new insights into how fetuses might be exposed to higher levels through mother's circulations via damaged umbilical vein endothelial cells.

8723-54, Session PTues

Integrative paradigms bridging defense and bioscience

George C. Giakos, Suman Shrestha, Yinan Li, Chaya Narayan, Aditi Deshpande, Tannaz Farrahi, Chris Mela, Ryan Koglin, The Univ. of Akron (United States)

Active polarimetric sensors using laser sources offer predictable illumination levels, polarimetric filtering to minimize specular reflections, and the ability to operate independent of sunlight illumination and temperature, have been applied successfully for an array of defense applications.

Polarimetric sensing and imaging offer unique advantages for a wide range of detection and classification problems due to the intrinsic potential for high contrast in different polarization components of the backscattered light. Indeed, polarized imaging can yield high-specificity images under high-dynamic range and extreme condition scenarios, in scattering media, or cluttered environments, offering at the same instance information related to the object material composition and its surface characteristics.

In this study, a new imaging approach based on polarimetric detection principles will be introduced and the Mueller matrix formalism will be defined, aimed at enhancing the detection, identification, characterization, and angular discrimination of different early-stage lung cancer carcinomas, under backscattered geometry. The design principles of the liquid crystal polarimetric imaging system will be introduced and related to operating conditions and system performance metrics. The depolarization, diattenuation, and retardance of the materials will be estimated using Mueller matrix decomposition for different aspect angles.

8723-55, Session PTues

Polymer nanostructure materials for space defense applications

George C. Giakos, Tannaz Farrahi, Diya Bandopadhayay, Alamgir Karim, Suman Shrestha, Yinan Li, Chaya Narayan, Aditi Deshpande, Mohit Kumar Agarwal, The Univ. of Akron (United States)

The unique functional characteristics of nanostructured material stemming mainly from a large surface-to-volume-ratio and on quantum effects; can yield numerous potential space applications.

Space-based electronic systems such as communications satellites, interplanetary space probes, are some of the examples that have become increasingly important during the last few years. Similarly, unmanned aerial vehicles (UAV) and micro UAV, and missile defense systems are of extremely significance for the national defense. As these systems become smaller, and more sophisticated, the design constraints regarding their ability to carry to optical instrumentation, guidance and avionics systems, and radiation shielding to protect against the cosmic radiation becomes more stringent and challenging. Therefore, new lightweight, miniaturized radiation resilient electronics, and high strength materials, as well as materials with with high agility, tunability, scalability, reconfigurability, programmable intrinsic sensing and compensating properties are needed to meet the demands of new space systems designs.

The objective of this study is to explore the polarimetric characterization of polymer nanomaterials, using Mueller matrix and Stokes parameters analysis. Specifically, gold nanoparticles were dispersed within a matrix of two-different polymer domains and their polarimetric response to infrared light was studied. The outcome of this study indicates that this

polymer nanomaterial yields to enhanced properties of the backscattered light.

8723-56, Session PTues

Bio-inspired polarization navigation sensor for autonomous munitions systems

George C. Giakos, The Univ. of Akron (United States)

By utilizing the polarimetric-spectral capabilities of insects enhanced munition guidance, navigation, and control capabilities, may result in terms of robustness, performance, and agility.

While the human eye can practically cope only with two aspects of light, brightness and colour, many animals use polarization as a further source of visual information.

Development of future highly efficient, low cost munition systems, small UAVs (SUAVs) and micro air vehicles (MAVs) for more challenging engagement environments is limited by the capabilities of current guidance system technologies as well as by their competing design requirements.

Therefore looking to biology for inspiration for MAV designs, enhanced guidance, navigation and control capabilities (GNC) of the munition systems, in terms of agility and robustness, can result.

The purpose of this study is to explore the optical polarimetric, spectral and structural characteristics of insects, for enhanced guidance, control, and navigation. Key-paradigm experimental results will be presented.

8723-34, Session 5

Aptamer functionalized metal oxide nanostructures for optical microbe sensing *(Invited Paper)*

Shayla Sawyer, Irina Barash, Kethia Matieu, Sydney Halperin, Dali Shao, Rensselaer Polytechnic Institute (United States); Stephan Weeks, Kevin Kyle, National Security Technologies, LLC (United States)

DNA aptamers are immobilized on metal oxide nanostructures to become a hybrid inorganic/organic layer on a sensitive, wavelength selective photodetector. Low-dimensional, metal oxide semiconductor nanomaterials are of great interest for their biocompatibility and novel electronic and optical properties. Specifically, the surfaces of indium oxide (In2O3) and zinc oxide (ZnO) nanostructures are modified using a chemical protocol that facilitates thiol/silica binding. The intended sensor will detect intrinsic fluorescence of captured microbes for signal transduction in UV-blue wavelength range allowing for visible blind operation in ambient light. Previous work demonstrated nanostructure-based photodetectors with wavelength selectivity and high responsivity. Wavelength selectivity was created by nanostructure deposition on an independent substrate that blocks unwanted light. High responsivities are due to a high internal photoconductive gain as a result of the oxygen desorption/adsorption process, nanomaterial quality, and the high resolution of interdigitated electrodes. In2O3 and ZnO materials were chosen for band gap properties that correspond with the detection of NADH and tryptophan intrinsic fluorescence within biohazards respectively. These materials fill a significant niche where traditionally used photomultiplier tubes (PMTs) and silicon (Si)-based photodetectors show a marked reduction in responsivity. This work presents the target capture layers of a compact, low power sensor using an E-coli DNA aptamer as a biorecognition layer on metal oxide nanoparticles and nanowires. The ability of the aptamer to immobilize are determined with variations of temperature, buffer solutions, and surface area. Progress is made toward a rugged, lower power, compact, multipurpose microbe sensor array through optical transduction.

8723-35, Session 5

Continuous, real-time bioimaging of chemical bioavailability and toxicology using autonomously bioluminescent human cell lines

Tingting Xu, The Univ. of Tennessee (United States); Dan Close, The Univ. of Tennessee (United States) and 490 BioTech Inc. (United States); James Webb, The Univ. of Tennessee (United States); Sarah Price, The Univ. of Tennessee Knoxville (United States); Steven Ripp, Gary Sayler, The Univ. of Tennessee (United States)

Bioluminescent imaging is an emerging biomedical surveillance strategy that uses external cameras to detect in vivo light generated in small animal models of human physiology or in vitro light generated in tissue culture or tissue scaffold mimics of human anatomy. At the core of this technology are cells expressing light emitting reporter genes that reveal the activation dynamics of cellular and molecular functions. The most widely utilized of these reporters is the firefly luciferase gene; however, it carries a disadvantage in that it generates light only upon the addition of a chemical substrate. This limits its informational output to only intermittent single time point data snapshots. To overcome this disadvantage, we have demonstrated substrate independent bioluminescent imaging in human cells using a synthetically optimized bacterial luciferase (lux) reporter system. Unlike firefly luciferase, bacterial luciferase produces bioluminescence autonomously using components found naturally within the cell, thereby allowing imaging to occur continuously and in real-time over the lifetime of the host. We have validated this technology in human cells with demonstrated chemical toxicological profiling against antibiotic and exotoxin exposures at photon emission strengths comparable to existing firefly luciferase reporter systems (~1.33x10^7 photons/second). As a proof-in-principle demonstration of its utility, we have engineered breast carcinoma cells to express bacterial luciferase for the real-time screening of chemicals displaying endocrine disrupting activity and validated detection of 17β-estradiol at low 1 picomolar concentrations (EC50≈10 pM). These and other applications of this new reporter technology will be discussed as potential new pathways towards improved models of target chemical bioavailability, toxicology, efficacy, and human safety.

8723-36, Session 5

Biosensing with semiconductor quantum dots *(Invited Paper)*

Kelly B. Gemmill, James B. Delehanty III, Kimihiro Susumu, Michael Stewart, Eunkeu Oh, Igor Medintz, Alan Huston, U.S. Naval Research Lab. (United States)

CdSe/ZnS semiconductor quantum dots (QDs) are ideal materials for biological sensing applications due to their superior photophysical properties in comparison to fluorescent proteins or dyes, and their ease of conjugation to biological materials. We have previously developed numerous Fœrster resonance energy transfer (FRET) based in vitro sensors for a variety of proteases. The quantum dots are conjugated to a dye labeled peptide substrate specific for each protease allowing FRET to occur between the QD and the acceptor dye. In the presence of the protease of interest, the peptide is cleaved resulting in a loss of FRET signal. While we are continuing our work to create improved in vitro sensors for biological and chemical agents, we concurrently would like to expand this capability to sense biological processes inside of living cells in real-time. This would improve our ability to observe and understand biological processes, and could also impact the development of targeted diagnostics and therapeutics. We will present some of our current successes and challenges in translating our in vitro protease sensor systems to intracellular use and discuss future implications of this research.

8723-37, Session 5

Development of a field-deployable prototype device for the rapid point-of-care detection of cyanide in whole blood *(Invited Paper)*

Hans Boehringer, Winnie Tong, Roy Chung, Diagnostic Consulting Network (United States); Gerry Boss, Univ. of California, San Diego (United States); Sari Mahon, Beckman Laser Institute and Medical Clinic (United States); Matthew Brenner, Univ. of California, Irvine (United States); Brendan O'Farrell, Diagnostic Consulting Network (United States)

Cyanide is an extremely potent and rapid acting poison with as little as 50 mg being fatal to humans. Cyanide poisoning has been recognized as a threat from smoke inhalation and potentially through weapons of mass destruction. There are currently no commercially available portable rapid tests for the detection of cyanide in whole blood.

We have now demonstrated the feasibility of a prototype field-deployable device for the rapid and early diagnosis of cyanide poisoning in whole blood based on the spectral shift of the vitamin B12 precursor Cobinamide upon binding with cyanide as an indicator. Cobinamide has an extremely high affinity for cyanide and rapidly binds hemoglobin associated cyanide in whole blood. Upon binding cyanide, Cobinamide undergoes a spectral shift that can be measured with a spectrophotometer.

For our prototype device, Cobinamide is first conjugated to a polymer while retaining its spectral properties. The cobinamide conjugate is then attached to and immobilized on solid surfaces as the sensor. The lysed whole blood sample is passed over and through the immobilized sensor in a prototype rapid flow-through test. The spectral shifts in cyanide-spiked buffer, plasma and whole blood have been detected within 5 minutes using a handheld, off-the-shelf reader. In addition, whole blood samples from rabbits that have been exposed to cyanide were tested. Our prototype rapid test was able to detect cyanide in those samples at levels of 10-30uM, well within the critical clinical range of the levels found in potential victims of cyanide poisoning.

8723-38, Session 5

SdAb heterodimer formation using leucine zippers *(Invited Paper)*

Ellen Goldman, George Anderson, Dan Zabetakis, U.S. Naval Research Lab. (United States); Audrey Lee, Nova Research, Inc. (United States)

Single domain antibodies (sdAb) derived from the heavy-chain antibodies found in camelids have a number of properties that make them attractive reagents for use in bioassays. Although they bind antigen through the use of only three complementarity determining regions, many sdAb have excellent affinity for their cognate antigens with binding constants as good as conventional antibodies. In addition to their affinity and specificity, most camelid sdAb are able to refold and bind antigen after heat denaturation, in contrast conventional antibodies aggregate irreversibly after heating. We have developed sdAb specific towards a variety of potential biothreat targets including ricin, abrin, staphylococcal enterotoxin B , Botulinum neurotoxin A complex, and Bacillus anthracis. Recently we have modified sdAb by expressing them as genetic fusions with c-terminal peptides or proteins to expand their usefulness. For example, these fusions can facilitate conjugation to nanoparticles, provide more efficient capture and/or reporter reagents, and improve protein solubility. Expressing sdAb with a triple histidine tail enabled self assembly onto DHLA coated quantum dots (QD); we incorporated the sdAb-QD conjugates into several assay formats. Expressing sdAb as fusions with a streptavidin core produced a stable, multivalent capture reagent that enabled improved limits of detection. Some sdAb are prone to aggregation when heated at high concentrations, we have demonstrated a charged peptide fusion that helps to overcome this potential limitation. The ability engineer these unique, recombinantly expressed binding elements for improved utility offers the potential to tailor make sdAb-based reagents for optimum performance in biosensors and bioassays.

8723-39, Session 5

Liquid Intake Monitoring Through Breathing Signal Using Machine Learning

Bo Dong, Subir Biswas, Michigan State Univ. (United States)

This paper presents a wireless and wearable noninvasive diet monitoring system, which provides a brand new platform for instrumented diet monitoring applications. The primary application is diet and drinking habit monitoring of soldiers and military personnel in the battleground settings. Food and drink intake can be detected by the way of detecting a person's swallow events. The system works based on the key observation that a person's otherwise continuous breathing process is interrupted by a short apnea during swallowing. We detect the swallows through the difference between normal breathing cycle and breathing cycle with swallows using a wearable piezoelectric chest-belt. Popular machine learning algorithms have been applied. It is shown that the proposed system provides a reliable and easy-to-use solution for diet monitoring.

8723-41, Session 6

Discrimination of airborne material particles from light scattering (TAOS) patterns *(Invited Paper)*

Giovanni F. Crosta, Univ. degli Studi di Milano-Bicocca (Italy); Yong-Le Pan, Gorden Videen, U.S. Army Research Lab. (United States); Kevin B. Aptowicz, West Chester Univ. of Pennsylvania (United States); Richard K. Chang, Yale Univ. (United States)

TAOS is an experimental technique which collects the intensity pattern of LASER light scattered by a single, air-borne material particle, ≈ 1 μm in size. Since phase-less data make reconstruction of the scatterer very difficult, the interpretation of TAOS patterns has been restated in statistical terms. An algorithm based on feature extraction (Fourier analysis and non-linear filtering) and linear classification (principal components analysis) has been developed and implemented in two stages. In stage one the classifier is repeatedly trained and validated on different sets formed by TAOS patterns from reference materials. In stage two the trained classifier is applied to patterns from bacterial spores and environmental sampling: pattern recognition occurs by information fusion. A large data set (> 3, 000 patterns) has been analysed. Bacillus subtilis patterns (Bq class) are discriminated from those of other, airborne materials (from outdoor sampling) and from confounders (Diesel engine soot).

By assuming all training and recognition patterns to come from the respective reference materials only, the most satisfactory discrimination result corresponds to ≈ 17% false negative Bq's and ≈ 22% false positives from all other materials.

8723-42, Session 6

Optical remote sensing a potential tool for forecasting malaria in Orissa, India

Mohammad Nizamuddin, The City College of New York (United States); Kawsar A. Akhand, The City Univ. of New York (United States); Leonid Roytman, The City College of New York (United States); Felix Kogan, National Environmental Satellite, Data, and Information Service (United States); Mitch Goldberg, National Oceanic and Atmospheric Administration (United States)

Information on current and anticipate moisture and thermal condition from satellite data represents a source of affordable yet careful information for Malaria forecasters to prevent and to control of epidemic. During the last decades Orissa state in India suffered from highest level of malaria incidence. This situation requires frequent monitoring of environmental conditions and dynamics of malaria occurrence. During 1985 to 2004 the NOAA AVHRR global vegetation index (GVI) dataset and its vegetation health (VH) have been studied and used as proxy for malaria fluctuation. This paper discusses applications of VH for early detection and monitoring malaria incidence in Orissa. A significant relationship between satellite data and annual malaria incidences is found at least three months before the major malaria transmission period. Principal component regression (PCR) method was used to develop a model to predict malaria as a function of the TCI. The simulated results were compared with observed malaria statistics showing that the error of malaria estimation is small.

8723-51, Session 6

A multifrequency, self-calibrating, in-situ soil sensor with energy-efficient wireless interface *(Invited Paper)*

Ratnesh Kumar, Gunjan Pandey, Robert J. Weber, Iowa State Univ. (United States)

Real time and accurate measurement of sub-surface soil moisture and nutrients is critical for agricultural and environmental studies. This paper presents a novel on-board solution for a robust, accurate and self-calibrating soil moisture and nutrient sensor with inbuilt wireless transmission and reception capability that makes it ideally suited to act as a node in a network spread over a large area. The sensor works on the principle of soil impedance measurement by comparing the amplitude and phase of signals incident on and reflected from the soil in proximity of the sensor. Accuracy of measurements is enhanced by considering =a distributed transmission line model for the on-board connections. Presence of an inbuilt self-calibrating mechanism which operates on the standard short-open-load (SOL) technique makes the sensor independent of inaccuracies that may occur due to variations in temperature and surroundings. Moreover, to minimize errors, the parasitic impedances of the board are taken into account in the measurements. Measurements of both real and imaginary parts of soil impedance at multiple frequencies gives the sensor an ability to detect variations in ionic concentrations other than soil moisture content. A switch-controlled multiple power mode transmission and reception is provided to support highly energy efficient medium access control as introduced by Sahota et al.

8723-52, Session 6

Determination of soil ionic concentration using impedance spectroscopy *(Invited Paper)*

Gunjan Pandey, Ratnesh Kumar, Robert J. Weber, Iowa State Univ. (United States)

This paper presents a novel approach to determine the soil ionic concentration by developing a mathematical model which takes the results of soil impedance spectroscopy as its input parameters. The model combines the dielectric mixing models with the dielectric relaxation models and forms a unified multi-frequency model to efficiently determine the individual ionic concentration in a multi-component soil mixture. To develop this model, the permittivity of different components found in a soil mixture has been measured at multiple frequencies and parameter-fitted in dielectric relaxation models (Cole-Cole, Havriliak-Negami). The permittivity values of individual components are then applied to a generalized dielectric mixing model (Shivola-Kong) at multiple frequencies to form equations which have only the concentrations of the components as the unknown variables. Using the fact that the impedance of a dielectric mixture is proportional to its impedance, the model has been validated by making multi-frequency impedance measurements of a soil mixture at different concentrations of various components. The model provides a good estimate of individual components such as soil, air, bound and bulk water and ions like nitrates and chlorides. While the paper is written with the perspective of soil content determination, the underlying principle of determining individual component concentration using multi-frequency impedance measurement is useful for many other applications, including characterizing biological systems like pathogens, quality control of pharmaceuticals etc.

8723-64, Session 6

Assessing satellite AOD based and WRF/ CMAQ output PM2.5 estimators

(Invited Paper)

Lina Cordero, Chowdhury Nazmi, Yonghua Wu, Barry M. Gross, Fred Moshary, The City College of New York (United States)

Fine particulate matter with particle diameters < 2.5 microns (PM2.5) has been linked to respiratory and pulmonary difficulties and for this reason, strong concentration guidelines have been developed by the EPA [1] to limit exposure. While the EPA utilizes an extensive network of ground stations to monitor PM2.5 concentrations on an hourly basis, the instruments and procedures are expensive and time consuming. Efforts to connect surface PM2.5 to satellite retrieval of Aerosol Optical Depth (AOD) have been made [2] and real time spatial maps of PM2.5 based on this methodology have been made operational [3]. In this methodology, regression analysis is applied to provide coefficients for different seasons and geographic regions. However, it is quite clear that even if the satellite retrievals of Aerosol Optical Depth are accurate, many factors play a role in complicating the simple regression relationships used. Such factors may include: RH modification of aerosols, inhomogeneous or plume layering above the PBL, aerosol speciation inhomogeneity and complex Planetary Boundary Layer (PBL) height dynamics . On the other hand, the WFR/CMAQ model builds on a combination of physically based meteorological factors together with emission inventories to estimate particulate concentrations and vertical distributions [4,5].

One issue that has not been studied is the statistical performance of the satellite based PM2.5 estimators in comparison to the WRF/CMAQ model outputs. In making this comparison, it is well known that strong biases in the PM2.5 model exist and manifests themselves on seasonal periods [6]. However, in making a relevant comparison with regression based satellite estimates, a suitable regression based post-analysis can be made to the CMAQ PM2.5 in comparison to EPA AQS surface network station measurements for seasonal and diurnal periods to better understand the relative merits of satellite based and model based PM2.5 estimates.

8724-1, Session 1

State-of-the-art tools for next-generation underwater optical imaging systems

Linda J. Mullen, Shawn O'Connor, Brandon Cochenour, Naval Air Systems Command (United States); Fraser R. Dalgleish, Harbor Branch Oceanographic Institute (United States)

Emerging underwater threats have increased the required range, resolution, and sensitivity of optical sensors operating in this challenging environment. The detection and identification of these threats is needed at ranges exceeding the 3-4 attenuation length limit of conventional underwater optical imaging systems. As the threats become smaller and are better camouflaged by the surrounding environment, the required resolution and sensitivity of the sensor are difficult if not impossible to achieve with existing technology. In response to these challenges, new transmitters and receivers are being developed to develop a next-generation underwater optical imaging system. This system is based on the modulated pulse concept where the pulsed laser source is encoded with a radar signal, and a range-gated, high-speed optical receiver recovers the radar signal. The advantages of this approach includes higher immunity against backscatter 'clutter', enhanced ranging accuracy, and potentially better image resolution. The challenge of implementing this concept in hardware is the lack of commercially available transmitter and receiver components that meet the requirements of the modulated pulse technique. Researchers at the Naval Air Systems Command are working closely with industry and academia to develop these needed state-of-the-art tools to advance the development of next-generation optical imaging systems. This presentation will review the progress that has been made in both transmitter and receiver hardware and the tests that have been completed to evaluate the modulated pulse concept in a controlled laboratory environment.

8724-5, Session 1

Polarimetric imaging of underwater targets

Alex Gilerson, Alberto Tonizzo, Carlos Carrizo, Ahmed El Habashi, Samir Ahmed, The City College of New York (United States)

Underwater imaging is challenging because of the significant attenuation of light due to absorption (by water and suspended/dissolved matter) and scattering (by water and suspended particulates) which results in rapid (in respect to the distance) blurring and degradation of an image. Using polarization properties of light is one of the options to improve image quality. Some of the living and manmade objects in water have partially polarized surfaces, whose properties can be advantageous for the purpose of target camouflage or, oppositely, for better detection and thus are of significant scientific and technical interest. Here we present results of imaging of a polarized target in various water conditions.

A target in the shape of a square is divided into several smaller squares, each of which is covered with a polarizing film with different polarization orientations or transmission coefficients. The target was placed on a stainless steel, first surface mirror and was imaged by a green-band full-Stokes polarimetric video camera in a custom-made underwater housing. The housing was mounted on our system which includes a multi-angular polarimeter and underwater thrusters. The system was rotated under water by thrusters, permitting imaging at different azimuth angles against the Sun and at different depths. Several other instruments measured the inherent and apparent optical properties (which were further used in the vector radiative transfer calculations) while the polarimeter measured polarization characteristics of light in water. The images taken in open ocean (Curacao), coastal (NY Bight) and turbid (Long Island Sound) waters are compared with the image of the target in the air and the impact of the water body on the polarized underwater image is evaluated.

8724-7, Session 1

An undersea free space laser communications and imaging network simulator

Fraser R. Dalgleish, Harbor Branch Oceanographic Institute (United States); David Rashkin, Univ. of Florida (United States); Bing Ouyang, Florida Atlantic Univ. (United States); Anni K. Vuorenkoski, Harbor Branch Oceanographic Institute (United States); Mihaela Cardei, Ionut Cardei, Florida Atlantic Univ. (United States)

Mobile, high throughput mid-range data communications and robust real-time data networking in the subsea environment that can accommodate high bandwidth sensors such as optical imagers have a potentially high impact as enabling technologies for a variety of future subsea operations in the areas of distributed sensing and real-time wireless feedback and control of unmanned undersea vehicles. Although much work has been done recently in the field of undersea optical free space communications and networking, to date there has yet to be an implementation of a complete multi-node undersea wireless optical data communications network. The deployment and testing of optical wireless network equipment in the undersea environment is expensive and time-consuming, and there is a clear need for a network simulation framework that will allow researchers to explore higher level networking concepts and the effects of operational and environmental factors on network performance.

This paper combines experimental laser results that were collected during littoral field exercises with prototype distributed laser serial imaging and communications channel characterization apparatus with a network simulation approach that uses an accurate physical layer time dependent Monte Carlo channel model, as well as higher network layer protocols to simulate larger scale network performance.

8724-8, Session 2

Characterization of optical communication in a leader-follower unmanned underwater vehicle formation

Firat Eren, Shachak Pe'eri, May-Win Thein, The Univ. of New Hampshire (United States)

Over the past few decades, the control design and mechanics of unmanned underwater vehicles (UUVs) has advanced to allow commercial underwater operations, such as inspection of underwater infrastructure, seafloor mapping and the installation of cables and pipes. The use of multiple UUVs for the same mission can reduce survey/operation time. However, the challenge is to be able to communicate between all UUVs in order to control the UUV fleet. A common approach is to control only one UUV (leader UUV) that the rest of the UUVs will follow. The key for this approach is a cost-efficient communication between the leader and the follower UUVs. This will also allow a larger variety of UUV formations for different tasks. This study presents an optical communication design of a leader-follower formation between UUVs, specifically remotely operated vehicles (ROVs). As an initial step in this study, the light field produced from a light source mounted on the leader UUV was empirically characterized and modeled. Based on the light field measurements, a photo-detector array for the follower UUV was designed. Evaluation of the communication algorithms to monitor the UUV's motion was conducted through underwater experiments in the Ocean Engineering Laboratory at the University of New Hampshire. Preliminary results show that the array and the communication algorithms are able to detect translation and rotational motion of the leader UUV.

8724-9, Session 2

Measurements of turbulent dissipation during the Bahamas Optical Turbulence Experiment

Silvia Matt, Weilin W. Hou, U.S. Naval Research Lab. (United States); Sarah Woods, SPEC, Inc. (United States); Ewa Jarosz, Wesley Goode, Alan Weidemann, U.S. Naval Research Lab. (United States)

The Bahamas Optical Turbulence Experiment (BOTEX) was conducted in the summer of 2011 to investigate the impact of turbulence on underwater optical imaging. Underwater optical properties can be affected by turbulence in the water, due to localized changes in the index of refraction. We discuss measurements of current velocity and temperature, made with a Nortek Vector Acoustic Doppler Velocimeter (ADV) and PME Conductivity-Temperature (CT) probe, as well as observations made with a Rockland Scientific Vertical Microstructure Profiler (VMP). The instruments were deployed in close proximity in the field and in the context of measurements of optical target clarity. Turbulent kinetic energy dissipation (TKED) and temperature dissipation (TD) rates are calculated from the ADV/CT measurements and compared to TKED and TD estimated from the data collected with the VMP. The results show reasonable agreement between the two methods; differences are attributed to turbulence patchiness and intermittence, as well as sampling challenges. The study also highlights the importance of collecting concurrent data on temperature, current velocity, and current shear to assess the turbulence impact on underwater optical properties.

8724-10, Session 2

Multiuser sonar watermarking and detection in an underwater acoustic channel

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Active sonars broadcast wideband signals that are only distinguished by physical properties such as bandwidth, frequency, duration and pulse shape. Watermarking is a method where a digital fingerprint is added to the sonar pulse in a secure, robust and transparent manner. This work expands previous results to the multiuser case. The issue with multiuser watermarking is the challenge of keeping user codes orthogonal after transmission through acoustic channel. This has been achieved by embedding the watermark the in proper time-frequency cells of the sonar. Truth tables are produced to illustrate cross classification rates.

8724-11, Session 2

Using computer vision to analyze the images obtained from ocean mapping

Irene Fernandez Florez, Univ. EAFIT (Colombia)

Nowadays there is a significant interest in the study of the ocean´s mapping. This research goal is to find a way through computer vision to automate image analysis obtained underwater, skip handwork; people may have the aptitude to do it on paper, however it might not be as precise, trustful and quick. The basis of this case study is the shades present in pictures. There are several techniques that can be used to approach this purpose. In order to develop this idea, there will be used Fourier transform, Wavelet transform and computer vision filters, among other methods. Underwater mapping is difficult because of the noise and lack of high resolution marine technologies; there is needed more than one procedure to obtain a sharp map.

8724-12, Session 3

Effect of surface roughness on lidar overlap function

James H. Churnside, National Oceanic and Atmospheric Administration (United States)

The lidar overlap function is defined as the fraction of the transmitted beam that is within the receiver field of view. It is an important part of the calculation of lidar performance for bistatic lidars at close ranges. Generally, one considers a uniform transmitted beam that illuminates a circular cross section at any range, and a receiver field of view that also has a circular cross section at that range. The overlap function is the area of the overlap of these two circles divided by the area of the transmitter circle. For the case of bistatic oceanographic lidar from the deck of a ship, the overlap function can vary from pulse to pulse under the influence of the rough sea surface. The problem arises because the transmitted beam and the receiver field of view are affected by different regions of the sea surface.

This paper considers the overlap function as a function of depth for a bistatic lidar operating from the deck of a ship. The effect is calculated using a Monte-Carlo approach, with a Pierson–Moskowitz spectrum of surface roughness and optical ray tracing through that surface. The results show that even low winds can affect the surface enough to affect the overlap function. For this not to be the case, the transmitter divergence and receiver field of view have to be much larger than the wind-generated surface slopes. At a wind speed of 5 m s-1, the standard deviation of the surface slope is almost 10 degrees.

8724-13, Session 3

CZMIL (coastal zone mapping and imaging lidar): from first flights to first mission through system validation

Viktor Feygels, Joong Yong Park, Optech International, Inc. (United States); Jennifer M. Wozencraft, U.S. Army Corps of Engineers (United States); Jennifer Aitken, Optech International, Inc. (United States); Christopher L. Macon, U.S. Army Corps of Engineers (United States); Abhinav Mathur, Andy Payment, Vinod Ramnath, Optech International, Inc. (United States)

CZMIL is an integrated lidar-imagery sensor system and software suite designed for the highly automated generation of physical and environmental information products for mapping the coastal zone in the frame of US Army Corps of Engineers (USACE) National Coastal Mapping Program.

This paper presents the results of CZMIL system validation in turbid water conditions in the Gulf Coast of Mississippi and in relatively clear water conditions in Florida in late spring 2012 and results of May-October 2012 mission in Green Bay, WI and Lake Erie. The system performance test shows that CZMIL successfully achieved 7-8m depth in Kd =0.46m-1 (Kd is the diffuse attenuation coefficient) in Mississippi and up to 41m when Kd=0.11m-1 in Florida.

CZMIL measured depths were compared with multi-beam sonar data over Cat Island, MS and off the coast of Ft. Lauderdale, FL. Validation demonstrated that CZMIL meets USACE specifications (two standard deviation, 2σ, ~32 cm).

To measure topographic accuracy we made direct comparisons of CZMIL elevations to GPS surveyed ground control points and vehicle-based lidar scans of topographic surfaces. Results confirmed that CZMIL meets the USACE topographic requirements (2σ, ~15 cm). Upon completion of the Lake Erie mission we had 89 flights with 2231 flightlines. The general hours of aircraft engine time (which doesn't include all transit/ferry flights) was 441 hours with 173 hours of flightlines. We generated 4.8 billions (!) laser shots and recorded 38.6 billion digitized waveforms. 1025 miles of shoreline were surveyed.

8724-14, Session 3

Sea floor classification with satellite data and airborne lidar bathymetry

H. Michael Tulldahl, Swedish Defence Research Agency (Sweden); Petra Philipson, Brockmann Geomatics Sweden AB (Sweden); Hans Kautsky, Stockholm Univ. (Sweden); Sofia A. Wikström, AquaBiota Water Research (Sweden)

Classification of the sea floor and its vegetation is of great interest for characterizing, mapping, and monitoring coastal environments. While land maps of vegetation cover and substrate types exist, similar underwater maps are rare or almost non-existing. We developed the use of airborne bathymetric lidar mapping and high-resolution satellite data to a combined method for shallow sea floor classification of seabed substrate type and vegetation. A classification accuracy exceeding 80% is possible, when validated against field data taken from underwater video recordings. The method utilizes lidar data directly (topography, slopes) and as means for correction of image data for water depth and turbidity. The lidar data and corrected satellite image data are used as classification variables. In this paper we present results using WorldView-2 imagery and data from the HawkEye II lidar system in a Swedish archipelago area. The classification was performed using a model-based maximum likelihood approach. In situ documentation of the bottom substrate and vegetation was made using a towed underwater video recorder equipped with an integrated GPS positioning system. The classification models were created with lidar and satellite data taken from locations documented with underwater video. A separate set of underwater video data was used for evaluation of the classification accuracy. Apart from the mapping capabilities, our results also indicate that a method using high resolution depth data together with remote imagery data distributed either over short periods of time or over several years can be applied for monitoring changes in shallow benthic environments.

8724-15, Session 3

Active laser sensing of mixed layer turbulence

Fraser R. Dalgleish, Anni K. Vuorenkoski, Harbor Branch Oceanographic Institute (United States); Bing Ouyang, Florida Atlantic Univ. (United States); Gero Nootz, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Weilin W. Hou, U.S. Naval Research Lab. (United States)

This talk will discuss and compare some recent ocean and laboratory test results that were conducted over path lengths of many meters in both the backward and forward directions using both tightly collimated short laser pulses and multiple beam illumination patterns to examine the effect of refractive index microstructures existing within the turbulent thermocline mixing layer.

8724-16, Session 3

Circulation on the continental shelf within the Mississippi Bight

Stephan D. Howden, The Univ. of Southern Mississippi (United States); Amy Kern, Univ. of Southern Mississippi (United States)

The University of Southern Mississippi's Central Gulf of Mexico Ocean Observing System (CenGOOS) operates three long-range (~200 km) 5 MHz CODAR high frequency radar (HFR) stations at Singing River Island in Pascagoula, Mississippi, Gulf State Park in Orange Beach, Alabama, and Henderson Beach State Park in Destin, Florida. Each station broadcasts electromagnetic (EM) waves that follow the conducting sea surface and are Bragg-scattered preferentially by surface gravity waves with a wavelength of one half the wavelength of the EM waves moving towards or away from the antenna. The back-scattered waves are Doppler shifted by the sum of the speed of the waves through the water and the component of the surface velocity in the radial direction to the receive antenna. If the water depth is sufficient for the deep-water approximation to hold (in this case deeper than 20 m), the wave speed is a function of only the wavelength, so it is known from the Bragg-scattering condition. Thus, the component of the surface velocity radial to the receive antenna can be computed from the amount of Doppler shift, and these components are known as "radials". Where there is overlapping coverage of radials, the total surface current vectors are estimated. The HFR stations cover much of the Mississippi Bight (MSB) seaward of the 20 m isobath. The surface current fields have been analyzed for annual and seasonal climatology, as well as for tides. The tidal analysis allows for tidal predictions of surface currents to be made for most of the MSB.

8724-17, Session 3

Assimilation of bio-optical properties into coupled physical, bio-optical coastal model

Igor Shulman, Sergey Frolov, Stephanie Anderson, Bradley Penta, Richard W. Gould Jr., Peter Sakalaukus, Sherwin Ladner, U.S. Naval Research Lab. (United States)

Data assimilation experiments with the coupled physical, bio-optical model of Monterey Bay are presented. The objective of this study is to investigate whether the assimilation of satellite-derived bio-optical properties can improve the model predictions (phytoplankton population, chlorophyll) in a coastal ocean on time scales of 1-5 days. The Monterey Bay model consists of a physical model based on the Navy Coastal Ocean Model (NCOM) and a biochemical model which includes three nutrients, two phytoplankton groups (diatoms and small phytoplankton), two groups of zooplankton grazers, and two detrital pools. The Navy Coupled Ocean Data Assimilation (NCODA) system is used for the assimilation of physical observations. For the assimilation of bio-optical observations, we used a stationary Kalman filter. The approach is based on the representation of the error covariances in the subspace of the multivariate (bio-optical, physical) empirical orthogonal functions (EOFs) estimated from a month-long model run. With the assimilation of satellite-derived bio-optical properties (chlorophyll-a and absorption due to phytoplankton), the model was able to reproduce intensity and tendencies in subsurface chlorophyll distributions observed at water samples locations in the Monterey Bay, CA. Data assimilation also improved agreement between the observed and model-predicted ratios between diatoms and small phytoplankton populations. Model runs with or without assimilation of satellite-derived bio-optical observations show underestimated values of nitrate distributions in comparison to the water samples observations. We found that an instantaneous update of nitrate based on statistical relations between temperature and nitrate corrected the model underestimation of the nitrate fields during the multivariate update.

8724-19, Session 4

Optical backscattering in water: measurements and uncertainties

James M. Sullivan, Michael S. Twardowski, J. Ronald V. Zaneveld, Casey C. Moore, WET Labs., Inc. (United States)

Instrumentation for estimating the backscattering coefficient by measurement of the volume scattering function over various angular weightings in the backward direction has been in common use for over a decade. Principles of operation, calibration and measurement protocols, and measurement uncertainties for WET Labs ECO-BB sensors will be discussed. Improved calibration techniques to minimize backscattering measurement uncertainties will be presented in a preliminary analysis to better understand the variability in the spectral backscattering ratio in different particle fields.

8724-20, Session 4

On the eigenvalue analysis using HH-VV dual-polarization SAR sata and its applications to monitoring of coastal oceans

Mitsunobu Sugimoto, Kazuo Ouchi, National Defense Academy (Japan); Chan-Su Yang, Korea Institute of Ocean Science & Technology (Korea, Republic of)

In the conventional SAR (Synthetic Aperture Radar) polarimetry, fully polarimetric HH-HV-VH-VV quad-polarization data are used. The advantage of using quad-polarization data is more information on the scattering objects than the single- and quad-polarization data; while the disadvantages are narrower swath and less frequent data takes. To fill the gap in-between, the present study examines the polarimetric analysis using HH-VV dual polarization. The model-based three- and four-component scattering power decomposion analyses are not possible with dual-polarization data, and thus, the study is focused on the eigenvalue decomposition analysis by comparing the entropy and mean alpha angle derived from dual-polarization data with those derived from quad-polarization data, acquired by ALOS-PALSAR (Advanced Land Observing Satellite – Phased Array L-band SAR) PLR (PoLaRimetric mode) and TerraSAR-X dual-polarization SpotLight mode over the Tokyo Bay, Japan. The preliminary results indicate that the values of dual-polarization entropy and alpha angle are almost the same as the quad-polarization values, indicating that dual-polarization data are as capable as quad-polarization data in the eigenvalue decomposition. The technique is then applied to ship detection and estimating the underwater laver cultivation fields in the same data sets of Tokyo Bay.

8724-21, Session 4

Estimating oil layer thickness: a vibrational spectroscopic approach

Lance E. Besaw, Gregory F. Hewitt, John W. Haas III, Applied Research Associates, Inc. (United States); Neal E. Van Wyck, Applied Research Associates Inc (United States); Ryan C. Langlois, Applied Research Associates, Inc. (United States); David W. Sweeten, BP p.l.c. (United States)

To assist in oil spill cleanup operations, it may be desirable to have a map of oil thickness in the slick. We are investigating Fourier transform infrared (FT-IR) spectroscopy for the in situ measurement of oil thickness. In our experiments, layers of Light Sweet Louisiana, West Texas Intermediate, Argentinian, Omani, Russian, and North Slope crude oils were prepared in a fixed area over an optically deep column of water at thickness ranging from 0.1 to 1000 µm. With a broad band IR source impinging on the samples, a stand-off FT-IR instrument with a large aperture recorded reflectance spectra from the oil slicks. The data can be grouped into three spectral regimes based on oil thickness. Each regime has different spectral features well correlated to the thickness of the oil slick. In this presentation, we will show the spectral results, describe the three thickness regimes, and demonstrate the ability to use statistical methods to quantify oil thickness, as well as classify the oil at a particular in situ location as “thick” or “thin.” Funding for this project is provided by BP as part of an oil spill technology R&D program that is enhancing the science of oil spill response.

8724-22, Session 4

Colombian ocean waves and coasts modeled by special functions

Simon Duque, Univ. EAFIT (Colombia)

Modeling the ocean bottom and surface of both Atlantic and Pacific Oceans near the Colombian coast is a subject of increasing attention due to the possibility of finding oil deposits that haven’t been discovered, and as a way of monitoring the ocean limits of Colombia with other countries not only covering the possibility of naval intrusion but as a chance to detect submarine devices that are used by illegal groups for different unwished purposes.

In the development of this topic it would be necessary to use Standard Hydrodynamic Equations to model the mathematical shape of ocean waves that will take differential equations forms.

Those differential equations will be solved using computer algebra software and methods. The mentioned solutions will involve the use of Special Functions such as Bessel Functions, Whittaker, Heun, and so on.

Using the Special Functions mentioned above, the obtained results will be simulated by numerical methods obtaining the typical patterns around the Colombian coasts (both surface and bottom). Using this simulation as a non-perturbed state, any change in the patter could be taken as an external perturbation caused by a strange body or device in an specific area or region modeled, building this simulation as an ocean radar or an unusual object finder.

It’s worth mentioning that the use of stronger or more rigorous methods and more advanced Special Functions would generate better theoretical results, building a more accurate simulation model that would lead to a finest detection.

8724-43, Session PTues

Spectral stability of the Libya 4 site using EO-1 Hyperion

Taeyoung Choi, Sigma Space Corp. (United States); Xiaxiong Xiong, NASA Goddard Space Flight Ctr. (United States); Amit Angal, Science Systems and Applications, Inc. (United States); Gyanesh Chander, U.S. Geological Survey (United States)

To assess the long-term on-orbit radiometric calibration stability, pseudo-invariant calibration sites (PICS) sites have been utilized by many satellites and recommended by the Committee on Earth Observation Satellites (CEOS) as reference sites. Libya 4 is one of best CEOS reference sites because of its spatial uniformity, temporal stability, and low atmospheric aerosol loading and has been frequently used to detect and quality long-term change. In this study, a region of interest (ROI) from the Libya-4 site centered at the latitude and longitude of 28.55 and 23.99 degrees with an area of 75 km by 75 km was used. A proper spectral characterization assessment of the test site is critical for accurate cross-calibration studies.

In this study, nine Earth Observing-1 Hyperion hyperspectral collections over the Libya 4 site are used. The day of year (DOY) of the each collection is selected to be around 170 to avoid yearly oscillations. Because of the limited narrow swath (7 km) of Hyperion sensor, a series of ROIs covering an approximate area of 3 by 3 km with 100 by 100 pixels is selected in the along-track direction from 28.07 to 29.55 degrees of latitude (about 170 km long) including a subset of CEOS target as a reference. In each ROI, there are 197 valid Hyperion bands covering spectral range from 0.42 µm to 2.4 µm with 10 nm spectral resolution. The top-of-atmosphere (TOA) reflectance variations in each ROI and bands are analyzed by using percentile information and spectral angle mapper (SAM) were used to characterize spectral signature of the Libya 4 CEOS reference site.

8724-44, Session PTues

Long-term band-to-band calibration stability of MODIS thermal emissive bands

Brian N. Wenny, Sigma Space Corp. (United States); Xiaoxiong Xiong, NASA Goddard Space Flight Ctr. (United States); Aisheng Wu, Yonghong Li, Sigma Space Corp. (United States)

The Terra and Aqua MODIS instruments have operated continuously for

over 12 and 10 years respectively and are key contributors to the NASA Earth Observing System mission. The calibration for the 16 thermal emissive bands (TEB) is maintained on-orbit through scan-by-scan observations of a temperature controlled blackbody and deep space. Recently a potential calibration issue with Terra Band 29 (8.55 µm) was identified resulting in a possible long-term drift in Band 29 detector response. The long-term performance of Band 31 (11 µm) is considered stable and is used as a reference to track the relative stability of other TEB. Multiple observations of different Earth targets with a range of scene temperatures as a function of time are analyzed to assess MODIS TEB band-to-band calibration stability, especially for Band 29.

8724-45, Session PTues

Design of integrated ship monitoring system using SAR, RADAR, and AIS

Chan-Su Yang, Korea Institute of Ocean Science and Technology (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of); Danbee Hong, Hyung-Wook Ahn, Korea Institute of Ocean Science and Technology (Korea, Republic of); Tae-ho Kim, Univ. of Science and Technology (Korea, Republic of)

This paper presents the idea behind the system which can give the complete overview of the ship monitoring by means of the fusion of microwave sensor data such as Synthetic Aperture Radar (SAR) and land-based RADAR and Automatic Identification System (AIS) which are onboard on to the ships. This work describes the preliminary design concept and prototype demonstration for an integration system of ships obtained from RADAR, SAR and AIS in the field experiment in coastal waters of Pyeongtaek Port, South Korea. Each system has its characteristics in ship detection or monitoring. SAR are used to acquire image data over large coverage area, AIS reports are obtained from ship-based transmitter, and FMCW and Pulse RADARs can monitor continuously ships for a limited area. We conducted field experiments for displaying the SAR (here, TerraSAR-X) and AIS, and the RADAR (X-Band) and AIS, separately. Simultaneous observation of RADAR, SAR and AIS is scheduled on the same date as of the SAR acquisition for the purpose to perform integration test. Here our main aim is to present the small integrated system results based on the time, area of coverage, geographic location for SAR, RADAR and AIS sensors. This system which is operating on Electronic Chart Display and Information System (ECDIS) may be useful in the near real time vessel surveillance.

8724-46, Session PTues

Sea surface signature of tropical cyclones using microwave remote sensing

Bumjun Kil, The Univ. of Southern Mississippi (United States); Derek M. Burrage, Joel Wesson, U.S. Naval Research Lab. (United States); Stephan D. Howden, The Univ. of Southern Mississippi (United States)

Measuring the sea surface during tropical cyclones is challenging due to severe weather conditions which prevent shipboard measurements, and clouds which mask the sea surface for visible satellite sensors. However, the recent development of L-band microwave remote sensing which can see through clouds, such as the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) sensor on the MIRAS satellite enables a view of the sea surface from which affects of tropical cyclones on sea surface emissivity can be measured. SMOS is used to estimate sea surface salinity (SSS) by measuring the L-band brightness temperature and by measuring and/or using ancillary sources of sea surface temperature (SST), and surface roughness to solve for the SSS from its modeled effect on surface emissivity (tropospheric and ionospheric effects have to be taken into account as do microwave and galactic radiation). In this research, we show correlations during Hurricane Isaac, in August 2012, by correlating the L2 sea surface temperature (SST) and the precipitation collected by NASA TMI sensor from TRMM satellite. SSS showed regions of lower value, with slightly increased SST, during the slower movement of storm just before landfall on the vicinity of Louisiana Shelf, along with increased precipitation. This increased trend of SST during the storm might be caused by the entrainment of vertical mixing by activated barrier layer (BL) due to heavy rainfall (Jacob and Koblinsky, 2007; Mignot et al., 2012; Balaguru et al., 2012). The SMOS L2 salinity retrievals were processed corrections by statistical removal of high uncertainty considering strong surface roughness which was known to create inaccuracy of brightness temperature (TB) under hurricane conditions. It is significant to use microwave remote sensing for relating distinctively low SSS, which may create a barrier layer and more effectively provide heat energy to the storm. Although further research is required, this study does show that there is a TB signal from the sea surface beneath a tropical cyclone, that does provide information on roughness and salinity.

8724-23, Session 5

The Navy’s focus on future remote sensing capabilities

Todd E. Bowers, Naval Oceanographic Office (United States)

Battlespace characterization, which combines meteorological, oceanographic, and other information into a comprehensive picture of the evolving battlespace environment from sea bed to space, is an inherently scientific enterprise dependent on scientific and technological innovation. Most of the data that drives numerical weather and ocean forecasts is derived from the constellation of satellite remote sensors, and airborne sensors will become an increasingly vital part of the local environmental sensing plan in the Navy of the future. To better communicate the Navy’s future environmental air and spaceborne remote sensing needs, the Navy Meteorology and Oceanography Command (NMOC) is drafting the first comprehensive Remote Sensing Strategic Plan. This plan is a first effort to identify in one document the overarching medium and long term guidance, bridging short term efforts with longer term operational command support requirements and future capabilities vision. It is designed to link validated COCOM and TYCOM requirements, near-term CNMOC and, longer-term strategies such as the Navy Vision for Information Dominance (NVID), Naval Oceanography 2025, the Quadrennial Defense review, other Navy Enterprise S&T strategies, and the Naval S&T Strategic Plan. In this paper we overview this developing strategic plan; highlighting the enterprise remote sensing operational vision for the next decade.

8724-24, Session 5

Evaluating VIIRS ocean color products for West Coast and Hawaiian waters

Curtiss O. Davis, Nicholas Tufillaro, Jasmine Nahorniak, Oregon State Univ. (United States); Burt H. Jones, The Univ. of Southern California (United States); Robert A. Arnone, Univ. of Southern Mississippi (United States)

Automated match ups allow us to maintain and improve the ocean color products of current satellite instruments MODIS, and since February 2012 the Visible Infrared Imaging Spectrometer Suite (VIIRS). As part of the VIIRS mission Ocean Calibration and Validation Team, we have created a web based automated match up tool that provides access to searchable fields for date, site, and products, and creates matchups between satellites (MODIS, VIIRS), and in-situ measurements (HyperPRO and SeaPRISM). The goal is to evaluate the standard VIIRS ocean color products produced by the IDPS and available through NOAA’s CLASS data system. Comparisons are made with MODIS data for the same location, and VIIRS data processed using the NRL Automated Processing System (APS) used to produce operational products for the Navy. Results are shown for one year of VIIRS data matching the satellite data with the data from Platform Eureka SeaPRISM off L. A. Harbor in the Southern California Bight, and HyperPRO data from Station ALOHA near Hawaii.

8724-25, Session 5

Analyzing radiometric requirements for diurnal observations of coastal/oceanic waters from geostationary orbits

Nima Pahlevan, Zhongping Lee, Univ. of Massachusetts Boston (United States); Chuanmin Hu, Univ. of South Florida (United States); John R. Schott, Rochester Institute of Technology (United States)

Over the decades, ocean color imaging sensors placed in Low Earth Orbits (LEO) have enabled nearly daily measurements of ocean water properties. Such observations, however, are restricted by cloud/atmospheric conditions. More importantly, such systems could not provide sufficient number of measurements to study the diurnal dynamics of coastal/oceanic ecosystems. One way to surmount such limitations is to leverage Geo-stationary orbits to significantly improve temporal sampling over such dynamical coastal/oceanic environments. In this study, top-of-atmosphere radiance (Lt) is modeled for the planned GEO-CAPE mission intended for monitoring coastal/oceanic waters. The input to this end-to-end radiometric modeling include diurnal remote sensing reflectances (Rrs), which are propagated through various atmospheric conditions, i.e., upper-air and aerosols, using a radiative transfer code. The simulations are carried out for different hours/seasons to encompass wide range of solar conditions. From these simulations and different intended system specifications (spectral bandwidths, ground sample distance (GSD), optical transmission, etc.), the baseline/threshold requirements of band-specific noise-equivalent-difference in radiance (NE∆L) as well as signal-to-noise ratios (SNRs) desired for quantifying diurnal variability of biogeochemistry properties are characterized. In addition, for a given SNR and calibration accuracy, the extent of measuring diurnal change of water properties from Geo-stationary platform is evaluated.

8724-26, Session 5

Evaluation of VIIRS ocean color data using measurements from the AERONET-OC sites

Samir Ahmed, Alex Gilerson, Soe Hlaing, The City College of New York (United States); Ionnis Ioannou, The City Univ. of New York (United States); Alberto Tonnizo, The City College of New York (United States); Menghua Wang, NOAA / NESDIS (United States) and The City College of New York (United States); Alan Weidemann, U.S. Naval Research Lab. (United States); Robert A. Arnone, The Univ. of Southern Mississippi (United States)

As an integral part of the VIIRS sensor calibration and validation efforts, we have been continuously monitoring the validity of the VIIRS's Ocean Color (OC) and atmospheric data stream through time series in-situ data acquired at our Long Island Sound Coastal Observatory (LISCO) platform, which supports multi- and hyper-spectral validations of present and future OC satellite missions for coastal water environments. The multispectral measurements at LISCO are part of the SeaPRISM NASA AERONET – Ocean Color Network. LISCO expands these observational capabilities with a HyperSAS instrument suite for continuous monitoring and assessment of the hyperspectral and polarized properties of coastal waters. Results of initial OC data retrievals of the VIIRS sensor based on LISCO water leaving radiance and aerosol data suggested that VIIRS data is strongly correlated with LISCO field data as well as data from current and heritage satellite missions: namely MODIS and MERIS. However, more recent match up comparisons between satellite and field data point out slight overestimations of aerosol optical thickness, resulting in underestimations in the water leaving radiance data for all three satellite missions. This is discussed along with results of further investigations of the impact of atmospheric corrections, specifically aerosol model selection, on the VIIRS's OC data retrieval performance using data acquired from LISCO as well as other coastal AERONET-OC sites. Updated validation results for the VIIRS sensor will be presented, along with observations of seasonal and temporal trends in aerosol optical thickness data for coastal AERONET-OC sites and analysis of the impact of aerosol mode selections on OC satellite imagery processing.

8724-27, Session 5

Bathymetry estimations using HOPE on vicariously calibrated HICO data

Mark D. Lewis, Richard W. Gould Jr., Alan Weidemann, Sherwin Ladner, U.S. Naval Research Lab. (United States); ZhongPing Lee, Univ. of Massachusetts Boston (United States)

The Hyperspectral Imager for Coastal Oceans (HICO) is a prototype sensor installed on the International Space Station (ISS) designed to explore the management and capability of a space-borne hyperspectral sensor. The Office of Naval Research (ONR) funded the development and management of HICO. The Naval Research Laboratory (NRL) built and now provides the day-to-day management of HICO. Bathymetry information is essential for naval operations in coastal regions. However, bathymetry may not be available in denied areas. HICO has a 100 meter spatial resolution, which makes it more capable for providing information within bays and estuaries than other sensors with coarser resolutions. Furthermore, its contiguous hyperspectral range is well suited to be uses as input to the Hyperspectral Optimization Process Exemplar (HOPE) algorithm, which along with other absorption and backscattering values, estimates bottom albedo and water depth. Vicarious calibration uses in situ data to generate new gains and offsets that when applied to the top-of-atmosphere radiance values improves atmospheric correction results and the measurement of normalized water-leaving radiances. In situ remote sensing reflectance data collected in St. Andrews Bay were used to vicariously calibrate a coincident HICO scene. NRL's Automated Processing System (APS) was used to perform atmospheric correction and estimation of remote sensing reflectances (Rrs). The HOPE algorithm used the vicariously calibrated HICO Rrs values to estimate water depth and bottom type. The results were validated with bathymetry maps from the National Coastal Data Development Center (NCDDC).

8724-29, Session 6

Monitoring bio-optical processes in coastal and lake waters using high spatial resolution channels on the NPP-VIIRS sensor

Ryan A. Vandermeulen, Robert A. Arnone, The Univ. of Southern Mississippi (United States); Sherwin Ladner, U.S. Naval Research Lab. (United States); Paul M. Martinolich, Qinetiq North America, Inc. (United States)

A spatially improved ocean color product is demonstrated by combining the 750 meter (M- channels) with the 375 m (I-channels) to produce an atmospherically corrected bio-optical product at a resolution of 375 m. The dynamic and small-scale spatial variability of bio-optical processes that occurs in coastal regions and inland lakes requires high resolution satellite ocean color feature detection. The Visual Infrared Imaging Radiometer Suite (VIIRS) sensor currently utilizes eight ocean color M-bands as well as two atmospheric correction M-bands in the near infrared (NIR; 765,865 nm) to produce ocean color products at a resolution of 750 m. VIIRS also has several high resolution (375 m) Imaging (I)-bands, including two bands centered at 640 nm and 865 nm. The new approach replaces the M7-band (865 nm) with the I2-band (865) nm to determine the atmospheric correction and aerosol optical depth at a higher resolution. Next, using the I-bands and the M-bands (bi-linearly interpolated to 375 m resolution), an estimate of remote sensing reflectance (Rrs) is determined. These true (I-band) and pseudo (M-band) high resolution Rrs are then utilized as input parameters into the Quasi Analytical Algorithm (QAA) to produce high resolution optical products, including absorption (total, detrital, CDOM, phytoplankton) and backscattering (particles). These finer resolution products are demonstrated and compared to 750 m resolution products as well as in

situ measurements in coastal estuaries and bays. The results show new capability for the VIIRS sensor for monitoring bio-optical processes in coastal waters.

8724-30, Session 6

Neural network approach for the derivation of chlorophyll concentration from ocean color sensors

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Using a data-set consisting of 9000 reflectance spectra simulated using HYDROLIGHT for a broad range of observable natural water conditions, we have developed three neural networks (NN) working in parallel to model the inverse problem for both oceanic and coastal waters. These NNs are used to relate the remote sensing reflectance at available MODIS visible wavelengths (412, 443, 488, 531, 547 and 667nm) to the phytoplankton , non-phytoplankton particulate, dissolved absorption and particulate back-scattering coefficients at 443nm. These reflectance derived parameters are then combined with the measured reflectance values and used as input to a fourth NN, to derive chlorophyll concentration ([Chl]). Unlike the previously developed networks that were trained based on a synthetic data-set and tested on the NOMAD, the last network was trained and tested solely on the NOMAD: although we can derive the inherent optical properties (IOP) through the optical signal, as they are directly related to the Rrs, the relationship of [Chl] to IOP varies with location and season and therefore it is difficult to model a global relationship. In order to show that including derived IOP estimates along with the radiance measurements can improve the derivation of [Chl], we construct a neural network that is trained to derive the [Chl] only from the reflectance measurements. Finally we compare our [Chl] product to the current MODIS OC3 algorithm.

8724-32, Session 6

Monitoring bio-optical processes using VIIRS: NPP and MODIS ocean color products

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Ocean color products from the NPP and MODIS provides new capability to monitor changes in the bio-optical processes occurring in the coastal waters. The combined use of multiple looks per day from several sensors can be used to follow the water mass changes of bio-optical properties. The dynamic changes in coastal waters in response to tides, resuspension and river plume dispersion, requires sequential ocean products per day to resolve bio-optical processes. We examine how these changes in bio-optical properties can be monitored using the NPP and MODIS ocean color products. Additionally, when linked to ocean circulation, we examine the changes resulting from current advection compared to bio-optical processes. The inter-comparison of NPP and MODIS ocean products are in agreement so that diurnal changes surface bio-optical processes can be characterized.

8724-34, Session 7

S-NPP/VIIRS SST and Radiance products: accuracy, stability, and consistency with AVHRR/MODIS

Alexander Ignatov, National Oceanic and Atmospheric Administration (United States); Xingming Liang, National Oceanic and Atmospheric Administration (United States) and Cooperative Institute for Research in the Atmosphere/Colorado State Univ. (United States); Prasanjit Dash, National Environmental Satellite, Data, and Information Service (United States) and Cooperative Institute for Research in the Atmosphere/Colorado State Univ. (United States); John Stroup, National Oceanic and Atmospheric Administration (United States) and STG, Inc. (United States); Yury Kihai, Boris Petrenko, National Environmental Satellite, Data, and Information Service (United States) and Global Science and Technology, Inc. (United States); John Sapper, National Environmental Satellite, Data, and Information Service (United States)

The S-NPP satellite launched in October 2011 with VIIRS instrument onboard is a bridge mission from POES/EOS towards JPSS. Sea surface temperature (SST) Team coordinated by NESDIS/STAR is in charge of generating high quality SST and clear-sky ocean radiance products. This presentation discusses status of two VIIRS products, the Interface Data Processing Segment (IDPS) and the Advanced Clear-Sky Processor for Oceans (ACSPO). The products are monitored in two STAR online systems: the SST Quality Monitor (SQUAM; www.star.nesdis.noaa.gov/sod/sst/squam/) and Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/). In situ data used for Cal/Val of satellite SST retrievals from another STAR system, in situ Quality Monitor (iQuam; www.star.nesdis.noaa.gov/sod/sst/iquam/). Both VIIRS SST products are monitored in SQUAM, along with similar products from NOAA-16, -18, -19 and Metop-A and -B AVHRRs, and Aqua and Terra MODIS. Corresponding radiances are monitored in MICROS. VIIRS radiances in SST bands have been very stable since their activation in January 2012, and consistent with AVHRR and MODIS radiances in similar bands. VIIRS SSTs have gradually matured and generally are consistent with SSTs from other sensors. The availability of several well-performing SST sensors in orbit (five AVHRRs, two MODIS, and VIIRS), offers unique opportunity for comprehensive consistency checks, quality control and product improvements.

8724-35, Session 7

VIIRS derived SST at the Naval Oceanographic Office: From evaluation to operation.

Jean-Francois Cayula, Qinetiq North America (United States); Doug May, Bruce Mckenzie, Keith Willis, Naval Oceanographic Office (United States)

The Naval Oceanographic Office (NAVOCEANO) produces Sea Surface Temperature (SST) retrievals from satellite data. NAVOCEANO also obtains satellite-derived SST data sets from other groups. To provide consistency for assimilation into analyses and models, all the SST data sets are evaluated for their accuracy with the same methodology. In this presentation, the focus is SST derived from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on-board the S-NPP satellite. Of particular interest is the evaluation of NAVOCEANO-produced SST with its NAVOCEANO Cloud mask (NCM), the VIIRS cloud mask (VCM), and VIIRS Environmental Data Record (EDR) SST. The evaluation results show that these products are in some ways comparable, with similar strengths and weaknesses, although they target different customers. For comparison, the reliability results for the Meteorological Operational (METOP-A) satellite-derived SST, which is a NAVOCEANO operational product, are presented. As a by-product of the NAVOCEANO VIIRS SST evaluation, the non-linear SST (NLSST) equations used to derive the SST values were found to be less than optimal depending on the unit of the field temperature term. NAVOCEANO VIIRS SST employs an expanded NLSST equation, which in effect refines the approximation of the gamma term by adding an offset. In view of the evaluation results, NAVOCEANO VIIRS SST is scheduled to become operational by the end of 2012.

8724-36, Session 7

Improvements of Satellite SST Retrievals at Full Swath

Walton McBride, U.S. Naval Research Lab. (United States); Bob A. Arnone, Univ. of Southern Mississippi (United States); Jean-Francois P. Cayula, QinetiQ North America (United States)

An ultimate goal of the prediction of Sea Surface Temperature (SST) from satellite data is to attain an accuracy of 0.30C or better when compared to floating or drifting buoys located around the globe. Current daytime SST algorithms are able to routinely achieve an accuracy of 0.50C for satellite zenith angles up to 53 degrees. The full scan swath of VIIRS (Visible Infrared Imaging Radiometer Suite) contains satellite zenith angles up to 70 degrees, so that successful retrieval of SST from VIIRS at these higher satellite zenith angles would greatly increase global coverage. However, the accuracy of the SST algorithms steadily degrades to nearly 0.70C as the satellite zenith angle reaches its upper limit, due to increased atmospheric path length and lower ocean surface emissivity. Both MCSST (Multiple-Channel) and NLSST (Non-Linear) algorithms were evaluated using a global data set of in-situ buoy and satellite brightness temperatures, in order to determine the impacts of satellite zenith angle on accuracy. Evaluation, testing and algorithm refinements and comparisons are demonstrated with an interactive MATLAB analysis tool. The analysis shows how accuracy in SST retrievals is impacted by filtering of buoy matchup using spatial and temporal constraints, and illustrates the importance of fully exploiting the information contained in the first guess temperature field used in the NLSST algorithm. The influence of the satellite zenith angle on the different algorithms is also reported. Preliminary results suggest that SST retrievals can be obtained using the full satellite swath with a 30% improvement in accuracy at large satellite zenith angles.

8724-37, Session 7

OSI-SAF operational NPP/VIIRS SST chain

Pierre Le Borgne, Gérard Legendre, Anne Marsouin, Sonia Péré, Hervé Roquet, Meteo-France (France)

Data of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard Suomi National Polar-orbiting Partnership (NPP) have been acquired at Centre de Météorologie Spatiale (CMS) in Lannion (Brittany) in direct readout mode since April 2012. CMS is committed to produce SST products from VIIRS data twice a day over an area covering North-East Atlantic and the Mediterranean Sea. A cloud mask has been developed (Lavanant, 2012) and cloud mask control techniques have been implemented. SST algorithms have been defined, as well as quality level attribution rules. Since Mid October 2012 a VIIRS SST chain, similar to that used for processing METOP AVHRR (EUMETSAT, 2010) has been run in a preoperational mode. The corresponding bias and standard deviation against drifting buoy measurements (up to December 2012) are -0.07 and 0.40K for nighttime and -0.08 and 0.46K for daytime, respectively.

This presentation will describe the algorithm determination, and the quality level attribution methods that have been implemented. The first validation result distribution as a function of these quality levels will be shown.

8724-38, Session 8

Evaluation and selection of SST regression algorithms for S-NPP VIIRS

Boris Petrenko, NOAA/NESDIS/STAR (United States) and Global Science and Technology, Inc. (United States); Alex Ignatov, NOAA/NESDIS/STAR (United States); Yury Kihai, NOAA/NESDIS/STAR (United States) and Global Science & Technology, Inc. (United States)

Sea surface temperature (SST) is a key environmental variable. Currently, several global SST products are generated at NOAA/NESDIS, OSI-SAF, NAVO, NASA and U. Miami from thermal IR measurements by multiple satellites and sensors. Most of SST retrieval algorithms use regression to derive SST from satellite brightness temperatures at similar bands (11 and 12 µm during day and 3.7, 11 and 12 µm at night). Although regression equations are designed to optimize retrieval accuracy, their forms essentially differ in different processing systems. This presentation compares regression SST equations with the objective to select the most efficient formulation for the VIIRS instrument onboard S-NPP launched in October 2011. The evaluation is based on several months of multi-satellite matchup dataset (MDS) created at STAR, between satellite data (NOAA-16, -18, -19 and METOP-A AVHRRs, Aqua and Terra MODIS and NPP VIIRS) and quality controlled in situ SST produced by in situ quality monitor system (iQuam; www.star.nesdis.noaa.gov/sod/sst/iquam/). All satellite data are processed with a single processing system, the Advanced Clear Sky Processor for Oceans (ACSPO), which minimizes the impact of the difference in the cloud masks on the SST statistics from different satellites and instruments. The algorithms are compared using the following characteristics averaged over the MDSs: global mean SST biases and standard deviations of "retrieved minus in situ SST", uniformity of these statistics as functions of view zenith angle and total precipitable water vapor content, stability of regression coefficients and SST statistics in time, and sensitivity of retrieved SST to variations in true SST.

8724-39, Session 8

Reduction of stripe noise in ACSPO clear-sky radiances and SST

Marouan Bouali, Alexander Ignatov, National Oceanic and Atmospheric Administration (United States)

Uncertainties in detectors radiometric responses introduce stripe noise in the images captured by multidetector spectroradiometers. Consequently, native resolution clear-sky radiances and derived sea surface temperature (SST) maps often display pronounced striping. This reduces the accuracy of the data and its usefulness for low-level processing tasks such as thermal front detection.

An algorithm is being designed and investigated at the National Environmental Satellite, Data and Information Service (NESDIS) to reduce the effect of striping and improve the imagery quality of the Advanced Clear-Sky Processor for Ocean (ACSPO) BT and SST products.

Using three days of Terra/Aqua MODIS and NPP VIIRS top of atmosphere clear-sky calibrated radiances, the performance of the proposed method was tested via quantitative and qualitative analysis. Preliminary results reported in this paper demonstrate substantial improvement in image quality without any impact on the geometrical features or global validation statistics of SST data.

8724-40, Session 8

Evaluating calibration of MODIS thermal emissive bands using infrared atmospheric sounding interferometer measurements

Yonghong Li, Aisheng Wu, Sigma Space Corp. (United States); Xiaoxiong Xiong, NASA Goddard Space Flight Ctr. (United States)

This paper evaluates the performance of MODIS (Terra and Aqua) thermal emissive bands using current Collection 5 (C5) and upcoming Collection6 (C6) Level 1 B products with a focus on relative differences between the two instruments. Data from Infrared Atmospheric Sounding Interferometer (IASI) serves as a transfer reference. Comparison was conducted using observations from simultaneous nadir overpasses (SNO) of Metop-A satellite and Terra/Aqua satellites. SNO times and locations were determined based on satellite orbital two-line element sets and the SNO time difference was limited to within 30 seconds. Each IASI instantaneous field of view of 12km is co-located with multiple (typically 30~40) MODIS pixels. The corresponding IASI simulated MODIS radiances are derived by convolutions of IASI hyperspectral data and MODIS relative spectral response functions. Data analysis results show that correlations of MODIS aggregated brightness temperature (BT) and IASI simulated BT are greater than 0.9. Differences between Aqua and Terra MODIS C5 are larger with a range of 2 ~ 8°K at lower BT and become smaller within ±1°K at higher BT for PV bands. For PC bands, measurements from MODIS C5 and C6 are within ±1°K between Aqua and Terra.

8724-41, Session 8

Terra and Aqua MODIS on-orbit spectral characterization for reflective solar bands

Taeyoung J. Choi, Sigma Space Corp. (United States); Xiaoxiong Xiong, NASA Goddard Space Flight Ctr. (United States); Zhipeng Wang, Daniel Link, Sigma Space Corp. (United States)

The MODrate resolution Imaging Spectroradiometer (MODIS) onboard the NASA EOS Terra and Aqua spacecraft was launched on December 18, 1999 and May 4, 2002 respectively. They have successfully operated on-orbit for more than a decade. The spectral characteristics of the MODIS instruments were calibrated pre-launch using a ground calibration device called the Spectral Measurement Assembly (SpMA). The ground spectral characterization was transferred to an on-board device called the Spectro-Radiometric Calibration Assembly (SRCA) for the Reflective Solar Bands (RSB) by measuring the sensor spectral responses at the same time with both SRCA and SpMA. After transferring calibration reference from the SpMA, the SRCA was able to track the on-orbit spectral changes by performing periodical spectral mode operations.

This paper provides brief descriptions of MODIS on-orbit spectral characterization via its on-board SRCA. In the algorithm description section, functional steps and spectral calibration methodologies are presented. This study will focus on MODIS SWIR band (bands 5, 6 and 7) as their center wavelengths are longer than the 1µm, which is beyond the specified SRCA spectral calibration range. In addition to the SWIR bands, band 2 results are also included. Because of the pre-launch and on-orbit configuration differences, band 2 spectral characterization is referenced to the first on-orbit results. A summary of Terra and Aqua MODIS on-orbit relative spectral response changes, such as center wavelength bandwidth changes, is provided in this paper for all the RSB bands.

8724-42, Session 8

Simultaneous measurement of temperature and pressure sensor for oceanography using Bragg gratings

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Pressure and temperature are fundamental properties of the oceanic water. They have varying effects on the processes that take place in oceans, be they biological, physical or chemical. While pressure always increases with respect to surface when you go down, temperature has a more complex variation with respect to the depth. Various tools and techniques are available to measure these properties. A combination sensor with high accuracy and response time would enable better measurements of these two parameters.

This paper presents a novel structure based on simultaneous measurement of temperature and pressure sensing using Fiber Bragg grating (FBG) sensors. For this, proposed sensor heads for both temperature and pressure. Temperature measurement, two different types of sensor heads has been designed for this implementation. The first sensor head consists of a FBG which is fixed between ceramic block on one side and a bimetallic strip made up of aluminum and copper on the other. The second sensor head consists of the FBG which is fixed between two bimetallic strips. For pressure, in first type the FBG is fixed between silicon rubber foil and sensor head wall. In second method the FBG is fixed between two silicone rubber foils. The pressure on walls of silicon rubber foils elongates FBG, which results in shift of wavelength. Theoretical studies carried out on these proposed sensor heads resulted in an increase in temperature sensitivity of about six times greater than that of bare FBG sensor and pressure sensitivity of about eight times greater than that of bare FBG. Further, the proposed sensors have shown good linearity and stability.

8725-1, Session 1

Nano-electro-mechanical-systems (NEMS) and Energy-efficient Electronics and the Emergence of Two-dimensional Layered Materials beyond Graphene *(Keynote Presentation)*

Anupama B. Kaul, National Science Foundation (United States)

Keynote - Carbon-based nanomaterials such as graphene and carbon nanotubes have been explored extensively by researchers as well as the semiconductor industry as viable alternatives to Si-CMOS. Besides nanoscale transistors, the exceptional mechanical, electrical, thermal and optical properties of carbon-based nanomaterials has stirred intense interest in considering these materials for applications ranging from interconnects, field-emission displays, photo-voltaics and nano-electro-mechanical-systems (NEMS). In particular, although graphene has been shown to exhibit remarkable electronic, thermal, mechanical and optical properties, the absence of a band-gap poses concerns for its attractiveness in some applications, particularly in digital electronics where high ON/OFF ratios desired. While a band-gap is induced in graphene through quantum confinement by creating graphene nanoribbons, the band gaps nonetheless are small (few hundred meV) and it is challenging to maintain pristine edge chirality due to defects that are induced during nanofabrication of the ribbons. Recently, layered 2D crystals of other materials similar to graphene have been realized which include insulating hexagonal-BN (band gap ~5.5 eV) and transition metal di-chalcogenides which display properties ranging from superconducting NbS2 to semiconducting MoS2. The device applications of such systems show promising characteristics where transistors derived from 2D monolayers of MoS2 show ON/OFF ratios many orders of magnitude larger than the best graphene transistors. In this talk, I will provide an overview of the Electronics, Photonics and Magnetic Devices (EPMD) program in the ECCS division where graphene, as well as other layered 2D nanomaterials, are playing an important role for enabling innovative device applications in electronics, photonics and sensing.

8725-2, Session 1

Twisted bilayer graphene: synthesis, Raman scattering, and highly sensitive tunable photodetector *(Invited Paper)*

Jiming Bao, Univ. of Houston (United States)

Two dimensional superlattices with tunable periodicity can be created by stacking two single layer graphene with relative rotation. Such superlattices have attracted considerable attention, but their experimental evidences remain elusive. Using chemical vapor deposition, we synthesized twisted bilayer graphene islands with well defined edge termination such that the relative rotation can be determined from the edge misalignment. The band structure of superlattice is revealed by new phonon mode and enhanced 2D line in Raman scattering. The folded phonons arise from the reduced Brillouin zone of the superlattices, while the enhanced 2D Raman intensity is due to the constructive quantum interference between two Raman paths as a result of degenerate Dirac cone. The spectra of the folded phonon and 2D line depend strongly on rotation angle and laser excitation energy, in agreement with our theoretical calculation. The rotation dependent band structure and high enhanced tunable optical absorption opens up new optoelectronic applications of bilayer graphene

8725-3, Session 1

Graphene-Si heterogeneous nanotechnology *(Invited Paper)*

Deji Akinwande, Li Tao, The Univ. of Texas at Austin (United States)

Wafer-scale monolayer graphene has been grown on annealed Cu (111) films on standard oxidized 100-mm Si wafers with high quality comparable to exfoliated graphene. Raman studies reveal outstanding uniformity (>99% coverage), and high nanomaterial quality (~95% negligible defect-density) on SiO2/Si wafer substrates. Key to these results is the phase transition of evaporated copper films from amorphous to (111) preferred crystalline orientation, which resulted in the subsequent growth of high quality graphene, as corroborated by X-ray diffraction and electron backscatter diffraction. Noticeably, such phase transition of copper film was observed on technologically ubiquitous Si wafer with a standard amorphous thermal oxide. In addition, insights gained from growth studies has resulted in large cu grain growth, about a factor of two larger than current achievements on cu film. The same growth insights have led to the CVD growth of graphene ribbons for the first-time and indicates the potential for as-grown graphene nanoribbons with atomically smooth edges. A modified two-step wafer-scale transfer process was introduced to preserve the clean material surface and electrical property of transferred monolayer onto 100mm wafers yielding over 10,000 graphene devices. In addition, a wafer bonding transfer strategy is investigated indicating that wafer-scale automated transfer process is within technological reach in the near future. Fabricated transistors yield high mobilities of ~5,000cm2/V-s and an on/off current ratio of about ten. This work enables industrial adoption and practical VLSI applications of graphene/Si heterogeneous systems.

8725-4, Session 1

Photodetection with heterojunctions of graphene and silicon *(Invited Paper)*

Fangze Liu, Xiaohong An, Swastik Kar, Northeastern Univ. (United States)

We present photodetection properties of heterojunctions of silicon formed with graphene and carbon nanotube networks. In these junctions, the photoexcitation processes occur in silicon, and graphene/carbon nanotubes act as carrier collectors with voltage-tunable non-linear photoresponses resulting from their unique density of states. The graphene/Si photodetectors were investigated for multi-mode operation. In the photodiode mode responsivities as high as 10^7V/W with sub-picoWatt/Hz^½ noise equivalent power and millisecond response-times were observed. With contrast sensitivity exceeding 10^6 V/W, these devices can potentially distinguish materials that transmit up to 99.95% of incident light, making them attractive for imaging and spectroscopy of ultra-transparent materials. In the second mode, which is a newly developed Quantum Carrier Reinvestment (QCR) Mode, the device utilizes the ultrafast carrier dynamics in graphene vis-à-vis the slow carrier recombination rate in silicon that results in extremely high quantum gain values with photocurrent responsivities obtained as high as 10^7 V/W. The single-wall Carbon Nanotube/Si (SWNT/Si) junctions have similar tunable responses with switching ratios as high as 10^4. The tunability of these devices can be traced to the manner in which the photoexcited carriers fill up the sparsely available but voltage tunable number of accessible states. We demonstrate their potentials for a variety of advanced applications, including arrays of photodetector elements mimicking camera pixels, bidirectional phototransistors, and novel digital optoelectronic switches (that combines both electrical and optical input signals) such as optoelectronic AND gates, ADDERs, and optoelectronic Digital-to-Analog converters. These architectures are highly suitable for tunable and scalable, low-power, on-chip photodetection, imaging, photometry, millisecond-switching, and on-chip ultrasensitive spectroscopy.

8725-5, Session 1

Band gap and correlated phenomena in bilayer and trilayer graphene *(Invited Paper)*

Chun Ning Lau, Yongjin Lee, Jairo Velasco Jr., Kevin Myhro, Nathaniel Gilgren, David Tran, Univ. of California, Riverside (United States)

Band Gap and Correlated Phenomena in Bilayer and Trilayer Graphene For Electronics and Optoelectronics

Graphene, a two - dimensional single atomic layer of carbon, has recently emerged as a new model system for condensed matter physics, as well as a promising candidate for electronic materials. Though single layer graphene is gapless, bilayer and trilayer graphene have tunable band gaps that may be induced by out-of-plane electric fields or arise from collective excitation of electrons. Here I will present our results on transport measurements in bilayer and trilayer graphene devices with mobility as high as 400,000 cm2/Vs. We demonstrate atomic switching, tunable band gap under applied electric field, spontaneous band gap opening, and stacking-order dependent transport. Our results have implications for band gap engineering for graphene electronics and optoelectronic applications.

8725-6, Session 1

New generation transistor technologies enabled by 2D crystals *(Invited Paper)*

Debdeep Jena, Univ. of Notre Dame (United States)

The discovery of graphene opened the doors to 2D crystal materials. The lack of a bandgap in 2D graphene makes it unsuitable for electronic switching transistors in the conventional field-effect sense, though possible techniques exploiting the unique bandstructure and nanostructures are being explored. The transition metal dichalcogenides have 2D crystal semiconductors, which are well-suited for electronic switching. In this presentation, we experimentally demonstrate field effect transistors with current saturation and carrier inversion made from layered 2D crystal semiconductors such as MoS2, WS2. We also evaluate the feasibility of such semiconducting 2D crystals for tunneling field-effect transistors for low-power digital logic.

8725-8, Session 2

Adaptive frequency selective surfaces *(Invited Paper)*

Walter R. Buchwald, Univ. of Massachusetts Boston (United States); Joshua R. Hendrickson, Air Force Research Lab. (United States); Justin Cleary, Air Force Research Lab./Sensors Directorate (United States); Junpeng Guo, The Univ. of Alabama in Huntsville (United States)

Split ring resonator (SRR) arrays are investigated for use as controllable optical impedance matching elements in the mid-IR wavelength range. Finite difference time domain (FDTD) simulations suggest such metallic plasmonic nanostructures can be externally controlled to resonate between the two conditions associated with a perfect SRR with a completely open SRR gap and a metallic ring with a completely closed SRR gap through modifications of the SRR gap impedance. Control of the SRR gap impedance is obtained through the addition of an appropriately designed semiconducting material located within the SRR gap region. This material can be engineered to provide voltage control, via the formation of a two dimensional electron gas and the addition of a gate electrode, or optical control through the use of low-doped material and an external optical source providing photogenerated free carriers excitations. The SRR ring dimensions investigated, namely a 2µm diameter, 0.5µm SRR line width and a 0.5µm SRR gap, indicate a mid-IR resonance at 6µm for the closed, low gap impedance case, and 11µm for the open, high gap impedance case, placing such frequency active resonators well within the range of typical ebeam lithographic fabrication capabilities. Such active frequency selective surfaces are proposed, for example, for use as tunable absorbing layers in mid-IR optical detectors or as active mid-IR filters.

8725-9, Session 2

Adaptive multifunctional composites *(Invited Paper)*

Daniel J. Inman, Ya D. Wang, Univ. of Michigan (United States)

This paper develops an adaptive wing spar which can sense the presence of wind gust disturbances and suppress consequent vibrations using a micro fiber composite actuator powered by self-harvesting the energy. Energy harvesting refers to the capture of ambient waste energy in order to power wireless sensing and telemetry control system. The equivalent electromechanical representations of this adaptive wing spar is derived theoretically and simulated numerically. A recent experimental result for a wing spar has shown that it is feasible to alleviate wind gust disturbance using harvested power from ambient vibrations, but requires the harvesting time to be 0.42 times longer than the wind gust duration.

Special attention is given to adaptive gust alleviation with the goal of using available harvested energy. A two mode reduced energy control law is implemented to reduce the actuation energy and the dissipated heat. This law integrates saturation control with a positive strain feedback controller, and is represented by a positive feedback operation amplifier (op-amp) and a voltage buffer op-amp for each mode. Experimental results exhibit that the system with reduced energy control requires 76% less energy than its conventional counterparts. Experiments also reveal the presence of substantial piezoelectric nonlinearities in the transducer. The voltage-dependent behavior of the electromechanical coupling coefficient is identified empirically and represented by curve-fit expression. A real-time adaptive control algorithm is developed to account for the voltage-dependent behavior of the electromechanical coupling coefficient, existing in the micro fiber composite transducer, enabling good agreement between the simulation and experimental results.

8725-10, Session 3

Materials research at DARPA addressing multifunctional and adaptive structural materials *(Invited Paper)*

Brian C. Holloway, Defense Advanced Research Projects Agency (United States)

The mission of the Defense Advanced Research Projects Agency (DARPA) is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research that connects fundamental discoveries and their military use. Within the Defense Sciences Office (DSO) at DARPA, several ongoing programs address both fundamental materials development, as well as the advancement of multifunctional and structural materials to address current Department of Defense technology needs. This talk will introduce some of these programs and concepts, including information on DSO programs in the areas of thin film processing, architectural design for structural materials, materials for mission-critical portable power and energy, and more, followed by a prospective on how novel materials science concepts can generate DARPA innovation.

8725-11, Session 3

Adaptive quantum-dot based materials for detection and broadband photovoltaic conversion *(Invited Paper)*

Vladimir V. Mitin, Nizami Z. Vagidov, Univ. at Buffalo (United States); Kimberly A. Sablon, U.S. Army Research Lab. (United States); Andrei V. Sergeev, Univ. at Buffalo (United States)

Currently IR sensing is widely used in radar and imaging applications. Advanced radar systems are employed for target detection, tracking, and identification. Numerous imaging applications include such large market segments as security, driving, and navigation. IR spectroscopy is also used in global environmental and industrial monitoring as well as in homeland security. All above applications will strongly benefit from the development of IR sensors with adaptable parameters. Even relatively simple firefighting IR camera should have large dynamic range to detect targets at varying background temperature. In general, optoelectronic materials for advanced IR sensing should combine wide spectral tunability, adjustable dynamic range for detection of high- and low-intensity radiation, manageable trade-off characteristics (such as noise equivalent power and operating time in the direct detection, and bandwidth and local oscillator power in the heterodyne detection), and high scalability to use in large sensor arrays. Also advanced photovoltaic materials, especially for concentrating photovoltaics, should provide optimal efficiency in a wide range of solar radiation and cover IR part of solar spectrum. In the current presentation we report results of theoretical and experimental investigations of adaptive nanomaterials based on charged quantum dots (QDs). We show that the charge of QDs may be effectively managed by the bias current and optical radiation (optical pumping). At the same time, the main photoelectron processes in QD structures are controlled by the dot charge. Therefore, manageable QD charge provides wide possibilities to control the photoelectron lifetime, spectral characteristics, detector responsivity, generation-recombination noise, and recombination losses.

8725-12, Session 3

Functional supramolecular nanomaterials: robust yet adaptive *(Invited Paper)*

Boris Rybtchinski, Weizmann Institute of Science (Israel)

Self-assembled nanoscale systems that are robust yet adaptive and prone to facile fabrication and reversible disassembly are of primary importance for creating multifunctional adaptive nanomaterials. We will introduce the emergent field of robust noncovalent nanomaterials and, using this context, will present our work on water-based noncovalent membrane materials that can be used for size-selective separations of nanoparticles and biomolecules. These findings advance a paradigm of noncovalent nanomaterials as a versatile and environmentally friendly alternative to covalent systems. We will also describe emerging rational design principles for creating highly ordered functional nanoarrays assembled from well-defined molecular units, enabling a general approach to photonic nanomaterials. In this context, directional hydrophobic interactions and kinetically controlled processes will be discussed.

8725-13, Session 3

Emission and detection of terahertz radiation using two-dimensional plasmons in semiconductor nano-heterostructures for nondestructive evaluations *(Invited Paper)*

Taiichi Otsuji, Takayuki Watanabe, Stephane Albon Boubanga Tombet, Akira Satou, Victor Ryzhii, Tohoku Univ. (Japan); Vyacheslav V. Popov, Institute of Radio Engineering and Electronics (Russian Federation); Wojciech Knap, Univ. Montpellier 2 (France)

This paper reviews recent advances in emission and detection of terahertz radiation using two dimensional (2D) plasmons in semiconductor nano-heterostructures for nondestructive evaluations. The 2D plasmon resonance is first presented as the operation principle to demonstrate its potentiality of broadband intense emission and sensitive detection of terahertz radiation. The Doppler-shift effect of the plasma wave velocity under an asymmetric plasmon cavity boundary and/or the spatial modulation of electron transit time in a sub-micrometer scale 2D plasmon system with a non-uniform 2D electron density distribution can promote the plasmon instability, resulting in self-oscillation of plasmons in the terahertz regime. The hydrodynamic nonlinearity of 2D plasmons can rectify the incoming electromagnetic radiation, resulting in photovoltaic detection of terahertz radiation under an asymmetric 2D plasmon cavity boundary. Second, the device structure that can provide practical emission and detection performances are addressed, which is based on a high-electron mobility transistor and incorporates the authors' original asymmetrically interdigitated dual-grating gates (DGGs). Numerical analysis reveals that in comparison with conventional symmetric DGG structure the asymmetric DGG can substantially improve the detection sensitivity as well as the instability (emissivity) by three to four orders of magnitude. Third, excellent terahertz emission and detection performances including coherent, monochromatic emission beyond 1-THz range and the record detection responsivity of 6.4 kV/W at 1 THz at 300 K are experimentally demonstrated by using InAlAs/InGaAs/InP and/or InGaP/InGaAs/GaAs heterostructure material systems. Finally their applications to nondestructive material evaluation based on terahertz imaging are demonstrated.

8725-14, Session 3

Graphene-based integrated electronic, photonic and spintronic circuit *(Invited Paper)*

P. Potasz, National Research Council of Canada (Canada) and Wroclaw University of Technology (Poland); A. D. Güçlü, National Research Council Canada (Canada) and Izmir Institute of Technology (Turkey); I. Ozfidan, National Research Council Canada (Canada) and Univ. of Ottawa (Canada); M. Korkusinski, Pawel Hawrylak, National Research Council Canada (Canada)

It has been recently predicted theoretically[1-10] that there exists a special class of nanoscale graphene triangular quantum dots (GTQD) with zigzag edges which fullfils all three functions needed for information processing: (1) size quantization turns graphene, a semimetal, into a semiconductor, like silicon, with bandgap tuneable from THz to UV, hence GTQD can be used for information processing, (2) unlike silicon, GTQD are equivalent to direct gap semiconductors, absorb/emit light hence can be used for communication, and (3) GTQD exhibit voltage tunable magnetic moment hence can be used for information storage. Therefore, it appears feasible that graphene quantum dots can form the basis of integrated electronic, photonic and spintronic circuits. Since carbon does not have nuclear spin, graphene based chips could form the basis of quantum technology. We will describe results of extensive numerical simulations of gated graphene quantum dots which demonstrate that the electronic, photonics and spintronic properties can be controlled by size, shape and edge engineering[4-10]. In particular, new results show that in a single graphene triangle with zigzag edges one can erase the magnetic moment by adding additional electron with a gate and restore the magnetic moment by absorption of a photon. This results in optical control of magnetization and optical spin blockade[11].

8725-15, Session 4

Harsh environment sensor development for advanced energy systems *(Keynote Presentation)*

Robert R. Romanosky, Susan M. Maley, National Energy Technology Lab. (United States)

Highly efficient, low emission power systems have extreme conditions of high temperature, high pressure, and corrosivity that require monitoring. Sensing in these harsh environments can provide key information that directly impacts process control and system reliability. To achieve the goals and demands of clean energy, the conditions under which fossil fuels are currently converted into heat and power are extremely harsh compared to previous combustion/steam cycles. Temperatures are reaching 1600 Celsius (C) in certain systems and pressures are reaching as high as 5000 pounds per square inch (psi)/340 atmospheres (atm). The lack of suitable measurement technology serves as a driver for the innovations in harsh environment sensor development. Two of the major considerations in the development of harsh environments sensors are the materials used for sensing and the design of the sensing device This paper will highlight the US Department of Energy, Office of Fossil Energy and National Energy Technology Laboratory's Program in Sensors which is aimed at addressing the technology development needs and drivers through the development of new sensor materials and designs capable of withstanding these extreme harsh environment conditions. Historical developments with harsh environment sensors as well as future directions towards the development of monitoring approaches for harsh environment will be highlighted.

8725-16, Session 4

Chemical sensor systems for environmental and emission control *(Invited Paper)*

Anita Lloyd Spetz, Linköping Univ. (Sweden); Christian Bur, Univ. des Saarlandes (Germany); Joni Huotari, Univ. of Oulu (Finland); Robert Bjorklund, Linköping Univ. (Sweden); Jyrki Lappalainen, Univ. of Oulu (Finland); Andreas Schütze, Univ. des Saarlandes (Germany); Mike Andersson, Linköping Univ. (Sweden)

Sensor systems based on SiC-FET sensors have been developed for environmental and emission control. Recently a sensor system for control of small and medium sized power plants was commercialized (www.sensic.se). A new layout of the SiC-FET device has considerably improved the high temperature operation and long term stability performance. Through applying different sensing layers, e.g. catalytic porous metals like Pt and Ir, and the choice of operation temperature, the SiC-FET sensors are able to monitor and control toxic emissions like CO, NO/NO2, SO2, H2S, VOCs and NH3. Operation of the sensors in temperature cycling mode and smart data evaluation improves the sensor performance and number of possible applications considerably. An NH3 sensor was for example developed for control of urea injection in small and medium sized power plants and stationary engines.

Recently it has been recognized that also particulate matter (PM10, PM2.5, ultra-fine particles) may pose danger to health. The adverse effects of particles seem to depend on size, concentration, shape and content. We recently started to develop methods like impedance spectroscopy of particles collected between IDEs (interdigital electrodes) for detection of e.g. concentration and size of particles. Controlled deposition of carbon nanotubes is used to develop the method. We have also worked on the issue of detecting content of particles by collection, heating, detection of emitted gases by gas sensor arrays and smart data evaluation. Environmental mass spectrometry is of high importance as a reference for emitted gases.

8725-17, Session 4

Miniaturized resonant sensors for harsh environments *(Invited Paper)*

Silja Schmidtchen, Denny Richter, Jan Sauerwald, Holger Fritze, Technische Univ. Clausthal (Germany)

Numerous energy conversion processes and safety monitoring approaches require operation temperatures up to 1000 °C. In order to control such high-temperature processes miniaturized sensor and actuator systems are increasingly demanded.

The research is focused on miniaturized active structures for operation temperatures between 500 and 1000 °C. Crystals like langasite (La3Ga5SiO14) [1,2] exhibit piezoelectrically excited bulk acoustic waves up to at least 1000 °C. Consequently, resonant sensors based on those materials enable new sensing approaches. Thereby, resonant high-temperature microbalances are of particular interest. They correlate very small mass changes during film deposition onto resonators or gas composition-dependent stoichiometry changes of thin films already deposited onto the resonators with the resonance frequency shift of such devices.

In this work the high-temperature properties, the operation limits and the measurement principles of langasite resonators are reviewed. Membranes and cantilevers are prepared and characterized with respect to their electrical (impedance, resonance frequency,..) and mechanical (displacement, ..) properties.

The stability of small langasite structures is confirmed up to 1350 °C. Further, biconvex membranes could be operated in the fundamental and overtone resonance modes up to 700 °C. The fundamental modes of 16 MHz resonators show quality factors of 500 at 700 °C. The mechanical displacement and the electrical response of vibrating membranes and cantilevers is characterized simultaneously and found to be consistent. Consequently, those active structures are suited to be applied at high temperatures as sensor platform.

Finally, application examples demonstrate the capabilities of high-temperature stable piezoelectric resonators. The simultaneous determination of mechanical and electrical properties of thin sensor films by resonant sensors enables, for example, the detection of CO in hydrogen-containing atmospheres at 600 °C.

1H. Fritze, High-temperature bulk acoustic wave sensors, Meas. Sci. Technol. 22 (2011) 12002 (28pp).

2H. Fritze, High-temperature piezoelectric crystals and devices, J. Electroceramics 26 (2011) 122-161.

8725-18, Session 4

III-N nanostructures for optical gas detection and pH sensing in liquids *(Invited Paper)*

Sumit Paul, EADS Deutschland GmbH (Germany); Konrad Maier, EADS Innovation Works (Germany); Aparna Das, Commissariat à l'Énergie Atomique (France); Florian Furtmayer, Justus-Liebig-Univ. Giessen (Germany); Andreas Helwig, EADS Deutschland GmbH (Germany); Jörg Teubert, Justus-Liebig-Univ. Giessen (Germany); Eva Monroy, Commissariat à l'Énergie Atomique (France); Gerhard Müller, EADS Deutschland GmbH (Germany); Martin H. Eickhoff, Justus-Liebig-Univ. Giessen (Germany)

Group III-nitride (III-N) nanostructures as e.g. quantum dots (QD) and nanowires (NW), were grown by plasma-assisted molecular beam epitaxy on low-resistivity n-type Si (111) and on optically transparent sapphire substrates. The low dimensional structures exhibit a strong photoluminescence (PL) which persists up to temperatures of 150°C and above. When QD samples are in contact with an electrolyte solution, the PL intensity shows a highly sensitive response to changes in the pH-value. The pH response of the QD transducers can be analyzed in an all-optical sensor system with a reduced number of electric contacts at

the place of detection.

Considering III-N nanowires with a large surface to volume ratio these opto-chemical transducers are also ideal for the detection of various gases. Depending on the specific application the NWs can be trimmed to detect the desired gas species. With a thin Pt coating, the PL intensity is dependent on the concentration of hydrogen or hydrocarbons in the surrounding atmosphere. Contrary to commercially available hydrogen sensors e.g. Pd or Pt gated transistors or catalytically activated metal-oxide-silicon-carbide FETs our all-optical sensor system allows detection of ppm concentrations of H2 at low operating temperatures (30°C-120°C). Without deposition of a catalytic metal layer the NWs are sensitive to oxidizing gases in low concentrations (few ppb) at room temperature. The opto-chemical transducer sensing principle is best suited for harsh environment and safety-critical applications where a reliable media separation between the medium to be sensed and the sensor's electrical circuitry is required.

8725-19, Session 4

Metal oxide nanowire gas sensors for indoor and outdoor environmental monitoring *(Invited Paper)*

Anton Köck, Elise Brunet, Thomas Maier, Giorgio C. Mutinati, Stephan Steinhauer, AIT Austrian Institute of Technology GmbH (Austria); Franz Schrank, Jochen Kraft, Jordi Teva, Joerg Siegert, austriamicrosystems AG (Austria)

Gas sensors are of great importance for various applications ranging from indoor air quality monitoring and industrial process control to breath analysis or outdoor environmental monitoring. The employment of metal oxide nanowires as sensor components is a very powerful strategy to improve gas sensor performance. Due to their high surface to volume ratio they show a strong interaction with the surrounding gas. With respect to the development of smart gas sensors heterogeneous integration of nanowires with CMOS devices is a great issue. We report on the implementation of SnO2, CuO and ZnO nanowires with CMOS fabricated micro-hotplate chips and demonstrate the extraordinary sensitivity of nanowire gas sensors, such as CuO-nanowire sensors, which are able to detect a H2S concentration as low as 10 ppb. Problems of nanowire fabrication, the challenging integration of nanowires with CMOS chips, and reliability issues with respect to device reproducibility and long-term stability will be discussed.

An important aspect is the fabrication of integrated gas sensor arrays for multi-parameter gas sensing, which will be discussed in detail. 3D-System-in-Package integration based on Through-Silicon-Via technology is a very promising approach for nanosensor integration by stacking them on CMOS electronic chips. 3D-integration provides both very small form factor as well as very low total power consumption, which are important issues for the realization of smart sensor systems. Such sensor systems could be integrated in portable devices, such as mobile or smart phones for individual environmental monitoring both indoors as well as outdoors.

8725-20, Session 5

Emerging approaches for nanopatterning of soft, hard, and hybrid structures *(Keynote Presentation)*

Vinayak P. Dravid, Northwestern Univ. (United States)

Surface patterned nanoscale architecture offers unprecedented opportunities for fundamental science as well as engineering technologies in diverse fields. Surface-patterned nanostructures flirt with thermodynamics of constrained systems on one hand and dynamics of nanoscale processes on the other.

The presentation will cover emerging nanopatterning, with an emphasis on multifunctional structures and associated phenomena. It will primarily focus on remarkable advances in scanned probe-based approaches such as dip-pen nanolithography (DPN) and its recent analogs, which have greatly enhanced the patterning resolution, speed and versatility of nanostructures spanning soft, hard and hybrid multifunctional materials. The various fundamental interactions between tip-substrate, mediated by diverse "inks" and the environment as well as practical considerations in extending probe-based nanopatterning approaches to diverse materials systems will be elaborated with examples from molecular, biomolecular and physical nanostructures. Advanced scanning probe, in-situ and ex-situ electron, ion and photon microscopy, spectroscopy and synchrotron x-ray scattering approaches are being employed to fathom the most intricate details of the "internal" structure of nanopatterns, coupled with innovative tools to validate their functional identity and localized properties.

It will be argued that despite impressive progress in probe-based nanopatterning approaches, there are considerable opportunities to extend and refine the probe-based techniques.

8725-21, Session 5

Dip-pen nanolithography on inorganic and biological surfaces: challenges and opportunities *(Invited Paper)*

Albena Ivanisevic, North Carolina State Univ. (United States)

Scanning probe based lithography has been widely used to explore and manipulate micro- and nanoscale surfaces. Many efforts have been directed towards engineering microfabricated devices that can function as ink cartridges and well systems. We present a simple modification scheme that allows one to place ink-reservoirs on cantilevers for chemical patterning by utilizing living spores of Bacillus Subtilis. AFM tips terminated with spore cells are used to directly pattern onto glass and tissue surfaces. The spore cells act as sponges and eliminate the need to use macrofabricated ink reservoirs during lithography. By varying the size of the spore at the end of the cantilever we can increase and decrease the gap between the spore tips and the surface. Therefore we can produce controlled, actuated patterning on the tissues without the need to heat, or apply current to forcibly actuate the tips. This results in essentially a low force patterning technique. Further, the tunable nature of the tips makes this technique applicable to a wide variety of users far beyond any other such developed technique. Variations to the microparticle system, such as progressively smaller spores or particles, could allow for complex actuation schemes.

8725-22, Session 5

Humidity effects in dip-pen nanolithography: multiple inks and hollow features *(Invited Paper)*

Brandon L. Weeks, Texas Tech Univ. (United States)

Ring shaped features were patterned with mercaptohexadecanoic acid (MHA) ink by Dip-pen Nanolithography (DPN) These features have a hollow inner core and are different from the filled dots usually obtained when writing with MHA. A model describing this effect will be presented along. By relying on the meniscus alone we propose the possibility to pattern multiple inks with a single tip soley by changing the humidity.

8725-23, Session 5

Nanoelectromechanical systems fabricated using tip-based nanofabrication *(Invited Paper)*

Huan Hu, Parsian K. Mohseni, Xiuling Li, Mark A. Shannon, William P. King, Univ. of Illinois at Urbana-Champaign (United States)

We present progress on fabricating silicon nanoelectromechanical systems (NEMS) using Tip Based Nanofabrication (TBN). A heated Atomic Force Microscope (AFM) probe deposits dense molten polymer on substrate to form nanopatterned polymer masks, which are transferred to silicon by etching processes.

In our first approach, the TBN-created polymer mask is used along with an aluminum wet etch and Bosch silicon etch. The polymer nano-patterns are written onto a 25 nm thick aluminum film on a single crystal silicon substrate. A wet aluminum etch transferred the polymer features into aluminum feature, which served as mask for subsequent Bosch silicon etching. This approach produced an array of vertical silicon nanowires with diameter as small as 200 nm and spacing varied from 800 nm to 3 µm. We also show an array of etched fins having width with 200 nm fin length varied from 5µm to 50µm. Various other structures such as rings, curved Fin arrays are also demonstrated.

In our second approach, we use Metal Assisted Chemical Etching (MacEtch) to transfer the polymer nanopatterns into silicon. This approach is capable of producing high aspect ratio silicon nanowires. Here, we wrote the polymer nanopatterns and transferred the nanopatterns to 35 nm thick gold film. In the next step, we used MacEtch to etch the silicon region that directly contacts the gold. The approach could produce an array of vertical silicon nanowires of height 20 µm and diameter 200 nm, achieving an aspect ratio of 100. The MacEtch process produced silicon nanostructures with smooth sidewalls.

8725-24, Session 5

Using heatable AFM probes for the nanolithography of graphene, polymers, and nanoparticles *(Invited Paper)*

Paul E. Sheehan, Woo K. Lee, U.S. Naval Research Lab. (United States); William P. King, Univ. of Illinois at Urbana-Champaign (United States)

Heatable AFM probes have proven to be a powerful means of shaping advanced materials on the nanometer scale. We have used these probes in two ways—as a stylus for directly writing material or as a heater to react small regions of existing films.

When used for deposition, the heat from the probe regulates the viscosity of an ink coated on its surface, a technique we call thermal Dip Pen Nanolithography (tDPN). Control over writing is exceptional—deposition may be turned on or off and the deposition rate easily changed without breaking surface contact. Moreover, the technique may be performed in UHV and is compatible with standard CMOS processing. tDPN has been successful at depositing metal, polymers, semiconducting and magnetic nanoparticles, quantum dots, etc. at speeds up to 200 µm/s. Importantly, the ability to shear and anneal the deposited material can engender new properties not present in the bulk such as conduction anisotropy in conducting polymers or to force alignment of nanoparticles into rows narrower than 10 nm.

The heatable probes can also focus heat to localize chemical reactions. Of recent interest has been using this heat to convert chemically-modified graphenes back to pristine graphene. For example, the heatable probe can directly write graphene nanoribbons by locally reducing graphene oxide back to graphene. The reduced GO nanostructures show an increase in conductivity up to four orders of magnitude as compared to pristine GO. No sign of tip wear or sample tearing was observed. Variably conductive nanoribbons with dimensions down to ~12 nm have been produced in oxidized graphene films in a single step that is clean, rapid and reliable. The method is fast, applies both to conducting and insulating substrates, and is reproducible.

8725-25, Session 5

Tip-induced nanolithography on semiconductors *(Invited Paper)*

Thomas G. Thundat, Ravi Gaikwad, Stojan Djokic, Univ. of Alberta (Canada)

Metallic nano dots and nanowires can be formed on semiconductor surfaces using tip-induced effects in a scanning probe microscope. Metal features form on tip-induced surface defects on semiconductor surface such as GaAs. The nano-scale features were fabricated by placing a drop of gold chloride solution on the semiconductor surface. The size of the nanodots could be controlled under 20 nm. In addition to nanodots, nanowires with widths around 20 nm could be fabricated using the same process. The AFM and SEM were used to image the nonodots and nanowires. This process can be used for direct fabricating of nanometer features on semiconductor surfaces. The mechanism of lithography and the limits of this technique will be discussed.

8725-26, Session 6

How adaptive optics may have won the cold war *(Keynote Presentation)*

Robert K. Tyson, The Univ. of North Carolina at Charlotte (United States)

The end of the Cold War and the dissolution of the Soviet Union, during the Reagan, Bush, and the Gorbachov leadership era, had many paths leading to it. One simplified theory is that the Strategic Defense Initiative (“Star Wars”) beginning in 1983 could not be economically matched by the Soviets and eventually bankrupted them. Prior to the 1983 Reagan speech, missile defense in general and high-energy laser development in particular were being intensely studied. Projecting a multi-kilowatt high energy laser beam through the Earth’s atmosphere to a target or relay satellite required the development of adaptive optics. In addition to x-ray laser weapons development, space-based high energy infrared lasers required technologies for beam control and wavefront correction to compensate aberrations on multi-megawatt systems. This talk will follow the timeline of adaptive optics development and show the relationship between the mostly classified research and geopolitical actions that resulted in a new map of Europe. By extending the timeline from the past to the future, we can argue that further adaptive optics advances and their spinoffs in micro-sensors, high-speed controllers, and micro-mirrors may help prevent another Cold War.

8725-27, Session 6

The use of MEMs and other micro-technology devices for adaptive optics *(Invited Paper)*

Sergio R. Restaino, Christopher C. Wilcox, Jonathan R. Andrews, Ty Martinez, U.S. Naval Research Lab. (United States)

Adaptive Optics (AO) is an ensemble of techniques that aims at the remedial of the deleterious effects that the Earth’s turbulent atmosphere induces on both imagery and signal gathering in real time. It has been over four decades since the first AO system was developed and tested. During this time important technological advances have changed profoundly the way that we think and develop AO systems. The use of Micro-Electro-Mechanical-Systems (MEMS) devices and Liquid Crystal Devices (LCD) has revolutionized these technologies making possible to go from very expensive, very large and power consuming systems to very compact and inexpensive systems. These changes have rendered AO systems useful and applicable in other fields ranging from medical imaging to industry. In this paper we will review the research efforts at the Naval research Laboratory (NRL) to develop AO systems based on both MEMs and LCD in order to produce more compact and light weight AO systems.

8725-28, Session 6

Adaptive optics for fiber-fed interferometers *(Invited Paper)*

Michael Hart, Hart Scientific Consulting International L.L.C. (United States); Thomas E. Stalcup Jr., Olivier Durney, Nicholas Emerson, Keith B. Powell, Jeffery Hagen, Michael Ward, The Univ. of Arizona (United States)

Optical interferometry has for a century now been a cost-effective means to extend the resolving power of astronomical instruments. Although the original stellar interferometer of Michelson was smaller than today's largest single-aperture telescopes, the same motivation has led to the construction of newer facilities with baselines of hundreds of meters. The approach typically has been to employ a number of separate collecting telescopes of modest aperture, a meter or less, with beams brought through vacuum pipes to a central combiner where the interference occurs. By making the telescopes movable, an image may be constructed whose fidelity is limited only by the time available to collect data at distinct baselines.

Concurrently with the new long-baseline interferometers, adaptive optics (AO) has been developed as a highly successful technology for improving the resolving power of large telescopes. In recent work, we have begun to develop a new generation of AO systems to allow the two technologies to be mated. In this concept, the interferometer's vacuum lines are replaced with optical fibers to reduce cost and allow greater flexibility in the choice of baselines. The role of AO, included on each of the interferometer's collecting telescopes, is not to enhance resolution per se, but rather to concentrate the light on the fiber inputs to achieve the greatest optical throughput. We describe the design of the AO systems under development, how their requirements differ from those of a traditional AO system, and how the addition of AO enables further enhancements to the design and performance of optical interferometers.

8725-30, Session 6

High-actuator-count MEMS deformable mirrors *(Invited Paper)*

Michael A. Helmbrecht, Min He, Carl J. Kempf, Iris AO, Inc. (United States)

Adaptive optics technology has enabled dramatic improvement in imaging performance for fields spanning astronomy, defense, microscopy, and retinal imaging. A critical component within the adaptive optics systems is the deformable mirror (DM) that applies the optical-path length corrections that compensate aberrated wavefronts. Iris AO has been actively developing microelectromechanical systems (MEMS) based DMs. The use of MEMS technology has both increased mirror performance and has reduced costs nearly tenfold compared to traditional piezoelectric DM technologies developed primarily for DoD applications. The segmented architecture enables high-stroke (5 or 8 µm) and high spatial frequency corrections in a compact form factor (1000 actuators / cm^2) that is suitable for clinical and industrial applications. Recent development into scaling and dielectric coatings to increase laser-power handling make the DM suitable for defense applications as well.

This paper introduces the Iris AO segmented MEMS DM technology to the DS&S community. It provides an overview of the fabrication process as well as a detailed description of the DM operation. The paper demonstrates correction capabilities of 111 and 489 actuator DMs and describes recent efforts into scaling to 1000-actuator class DMs. Finally, the paper presents laser testing results of dielectric coated DMs and describes the development path for MEMS DMs capable of handling 2 kW/cm^2 of average laser power.

8725-32, Session 7

Nanostructured black silicon for photovoltaics and photoelectrochemistry *(Keynote Presentation)*

Howard M. Branz, Todd G. Deutsch, Hao-Chih Yuan, Jihun Oh, National Renewable Energy Lab. (United States)

We demonstrate 18.2% nanostructured black silicon photovoltaic (PV) cells by closely controlling the nanostructured surface morphology and doping density. Our nanostructured black silicon surface provides excellent anti-reflection without any additional coating layers. To reach this high efficiency, it was necessary to understand the mechanisms of recombination at the nanostructured surface and reduce the amount of Auger and surface recombination. These silicon nanostructures can also provide good performance as photocathodes for solar hydrogen production because of their excellent anti-reflection (AR) properties and high surface area.

Novel processing schemes enable us to control both surface and emitter Auger recombination mechanisms in the nanostructures. The structures are fabricated by simple metal-assisted etching techniques, and consists of vertically aligned nanopores of random depths of more than 300 nm, and can have feature sizes smaller than about 50 nm. The etching provides a density-graded layer that reduces the reflection of silicon in air to below 4% across the usable solar spectrum with <1.2 µm.

Because reflection is reduced without the need for an insulating AR coating, our use of 1-D nanostructured surfaces in photocathodes for water splitting provides approximately 20 % increase in the rate of solar hydrogen production compared to planar Si. The nanostructured photocathodes also facilitate H2 bubble evolution and reduces the overpotential required for the water-splitting half-reaction by increasing the surface density of reaction sites.

All work was performed under DOE Contract No. DE-AC36-08-GO28308. The PEC H2 work was supported by the SISGR program of the U.S. Department of Energy (DOE), Office of Basic Energy Sciences, Division of Chemical Sciences, Biosciences, and Geosciences. The photovoltaic work was entirely supported by the U.S. DOE Office of Energy Efficiency and Renewable Energy, mainly through an American Recovery and Reinvestment Act (ARRA) grant.

8725-33, Session 7

Semiconductor nanorods in energy devices *(Invited Paper)*

Paul D. Dapkus, Ting-Wei Yeh, Yen-Ting Lin, Chun-Yung Chi, Maoqing Yao, Chongwu Zhao, The Univ. of Southern California (United States)

Semiconducting nanorods offer potentially revolutionary advancements in the cost and performance of light emitting diodes for solid state lighting and photovoltaic energy converters. GaN based LEDs are usually fabricated on expensive substrates and suffer from a high density of threading dislocations. In addition, the high current performance of the devices is degraded by efficiency decreases (efficiency droop) that seem to be inherent to current designs. GaN nanorods have been grown that are free of dislocations and serve as templates for the growth of InGaN active emitting regions on nonpolar facets of the nanostructures that may eliminate the causes of the high current efficiency droop. Dense arrays of dislocation free nanorods with InGaN quantum well active regions and LEDs made from them will be described.

High efficiency multijunction solar cells are among the most promising structures to increase the efficiency of solar cells to 50%. Achieving cells with efficiencies that high is impeded by the lack of appropriate sets of lattice matched materials to create multicomponent current matched monolithic structures. Nanorods of semiconductors to form the cell components of such structures are promising because the dislocations that typically form in lattice matched epitaxy can be avoided with the nanorod geometry to yield low defect-free, lattice mismatched structures.

As an example, dense, uniform arrays of GaAs nanorods on Si have been developed that promise to enable a new paradigm for the generation of efficient solar cells. We will describe the properties of these materials and discuss our progress towards realizing efficient solar cells.

8725-34, Session 7

Towards low-cost high-efficiency GaAs photovoltaics and photoelectrodes grown via vapor transport from a solid source *(Invited Paper)*

Shannon W. Boettcher, Andrew Ritenour, Univ. of Oregon (United States); Jason Boucher, Univ. of Oregon (United States)

GaAs is an attractive material for high-efficiency photovoltaics and water-splitting photoelectrodes, but its widespread implementation is limited in part by the high cost of metal-organic chemical vapor deposition, which employs toxic and pyrophoric gas-phase precursors. We report the study of GaAs grown by close-space vapor transport (CSVT), which uses solid GaAs as a source and water vapor as a transport agent as an alternative, and possibly low-cost, technique for depositing GaAs films. The photovoltaic properties of films grown under a variety of conditions are evaluated using a non-aqueous photoelectrochemical test cell and correlated with the film structure and impurity content.

8725-35, Session 7

Direct-bandgap nanopillar photovoltaics based on patterned catalyst-free epitaxy *(Invited Paper)*

Giacomo Mariani, Diana L. Huffaker, Univ. of California, Los Angeles (United States)

In this work, we present nanostructured core-shell solar cells based on patterned GaAs nanopillars (NPs) grown by MOCVD[1]. The patterns are lithographically defined and center-to-center pitch, hole size and tiling pattern can be precisely determined a-priori at nanometer resolution. The inherently catalyst-free approach eliminates any metal (i.e.) diffusion into the NPs that could reduce the carrier lifetime.

In the first part, hybrid core-shell solar cells comprised of n-doped GaAs NP cores and PEDOT conducting shells will be presented[2]. PEDOT is electrodeposited to ensure high controllability at low cost and high optical absorption coefficient whereas the semiconducting nanostructures are responsible for high mobility required in carrier extraction. The properties of the polymer are tuned in-situ by incorporating different anionic dopants in the backbone, allowing for the lowering of the HOMO level ($|\Delta E| \sim 0.28$ eV) that leads to an increased open-circuit voltage (Voc) and short-circuit current density (Jsc). A systematic tuning of the device properties results in a JSC of 13.6 mA/cm^2, VOC of 0.63 V, peak external quantum efficiency (EQE) of 58.5 %, leading to a power conversion efficiency (PCE) of 4.11 %.

In the second part, high-bandgap in-situ passivation[3] is applied to core-multishell GaAs NP photovoltaics. Optoelectronic modeling correlated to experimental results highlights Voc values yet partly affected by residual surface states after epitaxial passivation. Optically, dome-shaped ITO top electrode functions as a 2-D periodic array of subwavelength lenses that focus the local density of optical states within the NP region. Figures of merit such as rectification ratios in the order of >105, ideality factors of n ~ 1.86 and dark currents of ~ 48 nA at -1 V are indicative of high-quality p-i-n junctions. Under AM 1.5G conditions, VOC of 0.57 V, JSC of 18.9 mA/cm^2, fill factors of 69 % are measured, leading to PCE of 7.43 %. The data is presented in a comparative fashion with respect to state-of-the-art literature in the field.

8725-36, Session 7

Emerging nanomaterials for photovoltaic energy harvesting *(Invited Paper)*

Silvija Gradecak, Massachusetts Institute of Technology (United States)

Despite the fact that solar radiation accounts for most of the available renewable energy, only a small portion of it is currently being harnessed, mostly due to the production and installation costs of commercial photovoltaic (PV) devices. Emerging PV devices based on solution-processable conjugated polymers offer opportunities for the production of low-cost solar cells. To obtain high efficiencies of exciton dissociation and high photocurrent, it is desirable to have an interpenetrating network of electron-donor and electron-acceptor components within the device, referred to as a bulk heterojunction (BHJ). However, current limitations of the all-organic PV devices are inefficient hopping charge transport through the discontinuous percolation pathways in the BHJ films, and therefore modest power conversion efficiencies or non-competitive cost in the case of devices based on C60 derivatives.

We have developed a new type of nanowire-based solar cells that are based on organic/inorganic hybrid device structures and demonstrated two distinct hybrid BHJ architectures with enhanced power conversion efficiencies. The first device structure was composed of GaAs nanowires blended with a conjugated polymer poly(3-hexylthiophene) (P3HT) to form a uniform film consisting of dispersed nanowires in a polymer matrix. We observed that above a certain nanowire loading threshold, the nanowires facilitate P3HT molecular ordering, which leads to improved charge transport and yields devices with >2.3% power conversion efficiency. In the second device structure, CdS quantum dots were bound onto crystalline P3HT nanowires through solvent-assisted grafting and ligand exchange, leading to controlled organic-inorganic phase separation and an improved maximum power conversion efficiency of 4.1%.

In both cases, our results clearly demonstrate some of the benefits of organic-inorganic BHJ devices, mostly through enhanced absorption and improved carrier transport in the active region of the device. We have also identified several critical parameters to further boost the device efficiency and enable scalable, cost-efficient production, and these will be discussed.

8725-38, Session 8

Microscale technologies for imaging endogenous gene expression in individual cells within 3D tissues *(Invited Paper)*

Nitin Nitin, Univ. of California, Davis (United States)

Imaging gene expression in individual living cells within an intact tissue has significant potential to improve clinical detection and prognosis of diseases and to advance our fundamental understanding of cell and tissue physiology in a 3-d environment. For example, in situ gene imaging in cells of 3-d tissues can allow the scientists to probe how cells seeded in tissue engineering scaffolds react to biophysical forces and chemical cues in real time, and to understand the heterogeneity in solid tumors to find possible cures. Although significant development has been made in the design of imaging probes that can detect gene expression in 2-d culture models, there is lack of translation of these promising technologies to image gene expression in intact tissues. The key scientific challenges that limit this translation are: (i) lack of effective intra-tissue and intra-cellular delivery methods that can allow the probes to easily access cells in the tissue, and (ii) limited specificity of molecular sensing probes. To address these challenges we have developed a unique combination of microscale and imaging technologies that integrates the unique benefits of 1) microneedle technology to achieve minimally invasive intra-tissue delivery of oligonucleotide probes; 2) biochemical approaches to enhance intra-cellular cytoplasmic delivery of oligonucleotide probes; and 3) RNA-hybridization activated fluorescence resonance energy transfer (FRET) probes to improve specificity and sensitivity of RNA detection in tissues. The results of this study will demonstrate efficient delivery of nucleic acid probes and sensitivity of imaging RNA in individual cells within a tissue.

8725-40, Session 8

NIBIB activities in the areas of sensing, molecular sensing, mobile health and systems *(Keynote Presentation)*

William Heetderks, National Institutes of Health (United States)

The National Institute of Biomedical Imaging and Bioengineering (NIBIB) mission is improve human health by leading the development and accelerating the application of biomedical technologies. The Institute is committed to integrating the engineering and physical sciences with the life sciences to advance basic research and health care. Health care globally is poised to undergo major changes in the near future. This is being driven by multiple causes including a major shift in disease burden from acute diseases to chronic disease conditions, an aging population, a shift in the provider population toward less highly trained personnel especially in rapidly developing countries, and a significant expansion in the role of technology ranging from advanced medical decision support to mobile health and new diagnostic and delivery technologies.

Advanced sensing and mobile health will only be effective when they are integrated into a complete care delivery system that is capable of providing best available information about decisions that are made in an exceptionally complex medical decision space. This increasingly requires that the physical and life scientists work together to answer questions that exist at the convergence of the more traditional disciplines.

NIBIB supports a variety of sensor technologies that have potential for advancing health care. We will review some of these and also consider how such technologies might become integrated into a 21st century system of health care delivery. In particular we will consider some of the performance characteristics that will be needed if diagnostic and therapeutic systems are required to provide optimal care outside the traditional setting with less highly trained providers.

8725-41, Session 9

Present status and prospects of R&D of radiation-resistant semiconductor devices at JAEA *(Keynote Presentation)*

Hisayoshi Itoh, Japan Atomic Energy Agency (Japan)

Research and development of radiation resistant semiconductor devices have been performed at Japan Atomic Energy Agency (JAEA) for their application to electronic system used in harsh environments like space, accelerator and nuclear facilities. Such radiation resistant devices are also indispensable for robots and other remote-controlled equipment necessary for inspection of internal reactor pressure vessel as well as removal of fuel debris at Fukushima Daiichi Nuclear Power Plants, which were severely damaged owing to the earthquake and following tsunami disaster on March 11, 2011. In this R&D, we are focusing on wide band-gap semiconductor silicon carbide (SiC) because of its high temperature stability, excellent electrical properties and high radiation tolerance. So far, we have fabricated SiC-based transistors and examined their radiation degradation by using Co-60 gamma-rays. As a result, no significant degradation was observed for SiC-based transistors by gamma-ray irradiation at doses up to 1MGy whereas Si-based transistors were drastically damaged at 10kGy, indicating excellent radiation hardness of SiC devices. On the basis of the results, further investigations of radiation resistant devices used for the decommissioning of the damaged nuclear power plants are now in progress. Details of our R&D results and outline of future plans will be presented.

8725-43, Session 9

Radiation effects in solar cells *(Invited Paper)*

Mitsuru Imaizumi, Japan Aerospace Exploration Agency (Japan); Takeshi Ohshima, Japan Atomic Energy Research Institute (Japan)

Radiation effects in solar cells are described. Degradation behavior of space solar cells, such as silicon solar cells and InGaP/GaAs/Ge triple-junction solar cells, due to high-energy electrons and protons are elaborated in the presentation. Space solar cell design technology is also explained. In addition, technologies for practical application of solar cells in space including methodology for radiation protection and degradation prediction are interpreted. Furthermore, recent development status of state-of-the-art space solar cells is introduced.

8725-44, Session 9

Radiation tolerance of silicon and diamond detectors exposed to MeV ion beams: characterization using IBIC technique *(Invited Paper)*

Milko Jaksic, Natko Skukan, Veljko Grilj, Rugjer Boskovic Institute (Croatia); Tomihiro Kamiya, Wataru Kada, Japan Atomic Energy Agency (Japan); Michal Pomorski, CEA-Ctr. de Saclay (France)

Ion beam of the MeV energy range focused in the nuclear microprobe facility has been used to induce localized regions (50 x 50 µm2) with elevated defect concentrations in silicon and diamond detectors. Another microbeam technique - IBIC (ion beam induced charge), that employs single ions as a probe for the measurement of charge transport properties, was used to compare effects that different irradiation conditions (ion species, ion energy, fluence and rate) have on both materials. Additional information could be also acquired with the time resolved IBIC including the temperature dependent measurements. Results of comparison show that, for the exposure by MeV energy ions, silicon is more radiation tolerant than diamond. Although somehow controversial, this finding is not in conflict with approved superior hardness of diamond irradiated by GeV energy particles, where heavier nuclear reaction fragments for silicon are those responsible for its faster degradation. However, the high defect concentration and thus small drift lengths of charge carriers, does not exclude possibility of creating diamond detector with collection distance of only few micrometers, making them very resistant to excessive radiation by heavy ions in the MeV energy range. One such example that will be presented here is a membrane diamond detector that acts both as a trigger and as a vacuum window for single heavy ion irradiation in air.

8725-45, Session 9

Radiation-tolerant microprocessors in Japanese scientific space vehicles: how to maximize the benefits of commercial SOI technologies *(Invited Paper)*

Daisuke Kobayashi, Hirose Kazuyuki, Hirobumi Saito, Institute of Space and Astronautical Science (Japan) and Japan Aerospace Exploration Agency (Japan)

Semiconductor devices are inherently susceptible to high-energy particles such as cosmic rays; they create noise charge in materials, causing static parameter shifts and transient malfunctions or soft errors in circuits. Coping with these radiation problems has been the major hurdle in device development for applications in harsh radiation environments such as space and nuclear power plants–and now is also for ground-based systems: Today's consumer products that include microprocessors and power transistors suffer from natural terrestrial neutrons. To clear this hurdle textbooks often suggest use of the silicon-on-insulator (SOI) structure—but its drawbacks are seldom spoken. Careful optimization of device and circuit structures is necessary for maximizing the merits of the SOI use, as demonstrated in this communication.

Our optimization, which includes RC filters in SRAM cells, relies on a comprehensive study on static and dynamic responses of SOI devices to high-energetic particle bombardments. Highlighted is characterization of sub-nanosecond transient noise pulses due to single particle strikes, also known as single-event transients. Describing exactly what they are is the key to assure circuit reliability. Full waveforms of the pulses are experimentally revealed, also explained with curves estimated from single transistor responses. The revealed temporal-width evolution of the pulses conforms to a developed analytical model, a logarithmic function of a parameter of the radiation particle. Our expertise results in a design platform for space-use digital chips. Through this platform, low-power system-on-chips that include a 32-bit RISC-based microprocessor are developed; the SOI chips will be launched in the next Japanese scientific satellites.

8725-46, Session 9

Results of the CEASE instrument onboard TacSat-4 with associated solar cell experiment damage calculations *(Invited Paper)*

Scott R. Messenger, U.S. Naval Research Lab. (United States); Chadwick D. Lindstrom, William Johnston, Air Force Research Lab. (United States); Stu Huston, Atmospheric and Environmental Research, Inc. (United States); Phillip P. Jenkins, Jeffrey H. Warner, U.S. Naval Research Lab. (United States)

Proton fluxes ten times higher than mission baseline are reported by the CEASE instrument onboard TacSat-4 since launch in September 2011. The NRL SCREAM code is used to compare proton displacement damage effects on solar cells from both modeled and on-orbit measurements from the CEASE experiment. The extreme radiation effects on the solar cell experiments are found to be well correlated with CEASE on-orbit data using SCREAM. These results have prompted a new paradigm on solar cell shielding in space where thinner coverglass designs can be used in spacecraft power systems without enhanced power loss due to radiation.

8725-47, Session 9

Error-rate prediction for programmable circuits: methodology, tools and studied cases *(Invited Paper)*

Raoul Velazco, TIMA Lab. (France)

As present applications require more and more data processing power, this entails the use of complex advanced integrated circuits, such as processors and FPGA (Field Programmable Gate Arrays). The complexity of those devices makes difficult to achieve the evaluation of the sensitivity to errors provoked by radiation. Among these errors, SEU (Single Event Upsets) which result in the change of memory cell's content can have a large scope of consequences in the operation of the implemented application. Most of digital system architectures include processors (or processors implemented by means of FPGAs). In this work is described a methodology allowing to predict SEU error-rates for such complex devices. The approach is based in combining static-cross sections issued from radiation ground-testing with results obtained from hardware/software fault injection experiments, performed off-beam. The goal of this strategy is to obtain accurate results about different applications' error rates, without using particle accelerator facilities, thus significantly reducing the cost of the sensitivity evaluation. This will be illustrated for two significant devices: a complex processor, the Power PC 7448 executing a program issued from a real space application and a cryptoprocessor application implemented in an SRAM-based FPGA. This application was accepted to be embedded in the payload of a scientific satellite of NASA . Predicted error-rates will be confronted to the ones obtained from accelerated ground-tests performed with the cyclotron Cyclone cyclotron of HIF (Heavy Ion Facility) of Louvain-la-Neuve (Belgium).

8725-48, Session 9

Ion beam-induced charge analysis of radiation damage in semiconductors *(Invited Paper)*

Ettore Vittone, Univ. degli Studi di Torino (Italy)

The ion beam induced charge (IBIC) technique is a well-established analytical technique, which uses focused ion beams raster scanning the surface of a semiconductor device to evaluate its electronic transport properties. The physical observable is the charge induced at a sensing electrode by the movement of the free carriers generated by ionization, which is simultaneously acquired with the position of the ion beam, allowing the realization of micrometer resolution maps of charge collection efficiency (CCE) and, hence, allowing recombination sites, drift or diffusion lengths to be imaged.

IBIC can be considered also a valuable technique to study the degradation of CCE induced by radiation damage. It offers the advantage of providing wide range of damage levels induced by ions with different masses and energies in different regions of the same sample, and of using the same ions to monitor the CCE degradation as well as other ion probes to analyze the damage effects on the performances of semiconductor devices.

In this talk, an overview of the current research of IBIC analysis on the CCE degradation in semiconductor devices is presented. Particular emphasis will be given on an experimental protocol based on IBIC [1], which exploits the features of the IBIC technique to study the effects of radiation damage in different semiconductors. Moreover, this talk proposes an interpretative model of the IBIC experiment, which includes the displacement damage dose approach as a special case, and provides a general method to evaluate the effective radiation hardness of a material.

[1] Z. Pastuovic et al., "Probability of divacancy trap production in silicon diodes exposed to focused ion beam irradiation", Applied Physics Letters 98, 092101 (2011)

8725-49, Session 10

Reduction and identification for hybrid dynamical models of terrestrial locomotion *(Invited Paper)*

Sam Burden, S. Shankar Sastry, Univ. of California, Berkeley (United States)

The study of terrestrial locomotion has compelling applications ranging from design of legged robots to development of novel prosthetic devices and rehabilitation programs. From a first-principles perspective, the dynamics of legged locomotion seem overwhelmingly complex as nonlinear rigid body dynamics couple to a granular media substrate through viscoelastic kinematic chains called limbs. However, there is a surfeit of empirical data demonstrating that animals use a small fraction of their available degrees-of-freedom during locomotion on regular terrain, suggesting that a reduced-order model can accurately describe the dynamical variation observed during steady-state locomotion. Exploiting this emergent phenomena has the potential to dramatically simplify design and control of legged robots. Operationalizing this approach requires analytical techniques to extract a reduced-order model from a morphologically accurate description of the locomotor, and compatible computational algorithms that fit the resulting model to empirical data collected from the physical system. Since models of terrestrial locomotion are invariably non-smooth and typically nonlinear due to intermittent contact of the limbs with the substrate, these tools must be developed for nonlinear hybrid dynamical systems. We present an analytical technique for model reduction applicable to hybrid models of terrestrial locomotion and an associated scalable computational technique for parameter identification based on nonlinear programming. The tools are applied to a family of models for micro-scale robots with multiple legs.

8725-50, Session 10

Flight of the fruit fly *(Invited Paper)*

Itai Cohen, Cornell Univ. (United States)

There comes a time in each of our lives where we grab a thick section of the morning paper, roll it up and set off to do battle with one of nature's most accomplished aviators - the fly. If however, instead of swatting we could magnify our view and experience the world in slow motion we would be privy to a world-class ballet full of graceful figure-eight wing strokes, effortless pirouettes, and astonishing acrobatics. After watching such a magnificent display, who among us could destroy this virtuoso? How do flies produce acrobatic maneuvers with such precision? What control mechanisms do they need to maneuver? More abstractly, what problem are they solving as they fly? Despite pioneering studies of flight control in tethered insects, robotic wing experiments, and fluid dynamics simulations that have revealed basic mechanisms for unsteady force generation during steady flight, the answers to these questions remain elusive. In this talk I will discuss our strategy for investigating these unanswered questions. I will begin by describing our automated apparatus for recording the free flight of fruit flies and a new technique called Hull Reconstruction Motion Tracking (HRMT) for backing out the wing and body kinematics. I will then show that these techniques can be used to reveal the underlying mechanisms for flight maneuvers, wing actuation, and flight stability. Finally, I will comment on the implications of these discoveries for investigations aimed at elucidating the evolution of flight.

8725-51, Session 10

Stochastic receding horizon control: application to an octopedal robot *(Invited Paper)*

Shridhar K. Shah, Herbert G. Tanner, Univ. of Delaware (United States)

This paper deals with the application of a stochastic receding horizon control framework for navigation of an eight-legged miniature robot in a constrained environment. The objective is to show real-time application of a stochastic predictive control framework on miniature robots that are perturbed by stochastic noise and can carry processors at the lower end of the frequency scale. The kinematics of the eight-legged robot is abstracted as kinematics of a Dubin's car, while various effects due to un-modeled dynamics are abstracted using an additive stochastic noise, yielding a model description in the form of a continuous time stochastic differential equation (SDE). The control is achieved by a two-stage approach, where a path is planned using existing deterministic methods and local stochastic optimal controllers are used to navigate this path in a stochastic hybrid control framework. The framework provides probabilistic guarantees of convergence and obstacle avoidance. Our approach exploits developments in path planning methods to compute motion plans with lower computational burden while local stochastic controllers are pre-computed in an off-line manner through solution of the Hamilton-Jacobi-Bellman (HJB) partial differential equation (PDE) arising through the local stochastic optimal control problem. The algorithm is implemented on a 5.5 g, 720 MHz processor and experimental results are presented that show the effectiveness of our control framework for miniature autonomous systems perturbed by stochastic noise.

8725-52, Session 10

Robust multi-robot mapping and exploration *(Invited Paper)*

Henrik I. Christensen, John G. Rogers III, Carlos P. Nieto, Georgia Institute of Technology (United States)

The ability to deploy multiple mobile platforms for exploration and mapping of an environment before humans enter is essential to a number of scenarios both within the military and as part of rescue missions. A number of solutions have been presented in the past, but few of them have scaled to a large (N>>1) number of platforms, and robustness is typically a major challenge. To address these challenges we have designed a new strategy to multi-robot mapping and exploration. The approach utilizes a graphical model for representation of space covered and features detected. The graphical model allow easy integration of a diverse set of features. The diverse set of features are needed to achieve robustness in the presence of uncertain environment. Further the identification of unexplored space is easy to organize. Using evolving frontiers areas that have not been explored can be assigned to members of the year through an auction. A system has been designed, implemented and evaluated for exploration of buildings, urban settings, and major facilities. In this presentation we will present the overall framework for multi-robot mapping and exploration. We will discuss how robustness can be achieved. In addition we will present results of real-world evaluation with teams involving up to 10 robots. Finally we will present some of the open challenges for design of future systems.

8725-53, Session 10

Bio-inspired multi-mode optic flow sensors for micro air vehicles *(Invited Paper)*

Seokjun Park, Jaehyuk Choi, Jihyun Cho, Euisik Yoon, Univ. of Michigan (United States)

Monitoring wide-field surrounding information plays a key role in a vision-based autonomous navigation system for micro-air-vehicle (MAV) applications. Our image-cube (iCube) module, which consists of multiple sensors that are facing different angles in 3-D space, can be applicable to the wide-field of view optic flows estimation (μ-Compound eyes) and to attitude control (μ-Ocelli) in the MAST platforms. In this paper we report an analog/digital (A/D) mixed-mode optic-flow sensor, which generates both optic flows and normal images in different modes for μ-Compound eyes and μ-Ocelli applications. The sensor employs a time-stamp based optic flow algorithm which is modified from the conventional EMD algorithm to give an optimum partitioning of hardware blocks in analog and digital domains as well as adequate allocation of pixel-level, column-parallel, and chip-level processing. Temporal filtering, which may require huge hardware resources if implemented in digital domain, is remained in a pixel-level analog processing unit. The rest of the blocks, including feature detection and time-stamp latching, are implemented using digital circuits in column parallel. Finally, time-stamp information is decoded into velocity from look-up tables, multiplications, and simple subtraction circuits, thus significantly reducing core digital processing power consumption. In the normal image mode, the sensor generates 8-b digital images using integrated single slope ADCs. In the optic flow mode, the sensor estimates 8-b 1-D optic flow from the integrated mixed-mode algorithm core and 2-D optic flow with an external time-stamp processing.

8725-54, Session 10

Structure from motion in computationally constrained systems *(Invited Paper)*

Joseph Conroy, U.S. Army Research Lab. (United States); James S. Humbert, Univ. of Maryland (United States)

Micro-autonomous, robotic systems must be capable of navigating through complex environments without the aid of human guidance to accomplish the missions envisioned for them. This level of autonomy requires that the vehicle is able to perceive the immediate surroundings to obtain navigation landmarks and avoid obstacles. Vision is a promising sensing modality as it is utilized so effectively in biological systems and permits a large area of the environment to be perceived at once. The three dimensional structure of the environment can be extracted from sequences of monocular images and known motion using widely known structure from motion techniques. These techniques are typically performed using the power of a desktop PC and typically do not exceed a real-time update rate of 30 frames/s (fps). For our micro-autonomous applications, processing is extremely limited, suggesting the traditional techniques are not sufficient.

This research pursues an approach to estimating structure from motion that utilizes both visual perception hardware and processing algorithms specifically designed for micro-autonomous applications. The hardware setup is designed to provide high frame rates, nearly omni-directional vision, and parallel computing while using light-weight inexpensive sensing and processing.

Our approach to the estimation of structure from motion takes cues from insect neurophysiology to leverage the unique properties of high-frame rate, omni-directional vision. We compute optical flow, the apparent motion of the visual field, to provide input to an iterative, filter-based approach to update a continuously refining estimate of the surrounding structure.

8725-55, Session 10

Low power analog odometry circuit for miniature robotics *(Invited Paper)*

Pamela A. Abshire, Michael J. Kuhlman, Tsung Hsueh Lee, Univ. of Maryland, College Park (United States)

Miniature robots present a number of challenging problems in controls, as they often exhibit nonlinear dynamics and have strict power and size constraints. These constraints limit the sensing and processing capabilities drastically. Autonomous operation generally requires local modeling of system dynamics, since many control strategies require knowledge of the system state and direct realtime sensing of position is not always possible due to size and power constraints. On-board computation for small platforms is limited by available microcontrollers, which are relatively large, power-hungry, and slow. To alleviate this challenge we describe a mixed-signal circuit implementing an odometry function that maps motor commands to position using a kinematic model. The architecture is designed to support control of a differential-drive miniature robot.

The inputs to the kinematic model are assumed to be the left and right motor commands or the linear and angular wheel velocities. The outputs of the kinematic model are the coordinates from the nonlinear differential equations of motion. This approach requires 4 signal scaling elements, two summing nodes, three integrators, two trigonometric function blocks and two signal multipliers to model the nonlinear system dynamics. The circuit consumes 80 pJ per odometry computation, in comparison with approximately 35 nJ for an implementation on a low power microcontroller.

8725-58, Session 11

Bio-integrated electronics and sensor systems *(Invited Paper)*

John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Advances in materials, mechanics and manufacturing now allow construction of high quality electronics and optoelectronics in forms that can readily integrate with the soft, curvilinear and time-dynamic surfaces of the human body. The resulting capabilities create new opportunities for studying disease states, improving surgical procedures, monitoring health/wellness, establishing human-machine interfaces and many others. This talk summarizes these technologies, and illustrates their use in forms integrated with the brain, the heart and the skin.

8725-59, Session 11

Carbon nanotube macroelectronics: toward system-on-plastic *(Invited Paper)*

Chuan Wang, Univ. of California, Berkeley (United States); Kuniharu Takei, Toshitake Takahashi, Univ. of California, Berkeley (United States); Ali Javey, Univ. of California, Berkeley (United States)

Single-walled carbon nanotubes possess fascinating electrical properties and offer new entries into a wide range of novel electronic applications that are unattainable with conventional Si-based devices. In this talk, we report our recently developed platform for solution-based processing of high-purity semiconducting carbon nanotube networks that has led to low-cost fabrication of large quantity of thin-film transistors (TFTs) with excellent yield and highly uniform, respectable performance on mechanically flexible substrates. Such transistors exhibit excellent performance with on-current, transconductance, and field-effect mobility up to 15 uA/um, 4 uS/um, and 50 cm2/Vs. Based upon the semiconducting carbon nanotube TFTs, a wide range of macro-scale system-level electronics have been demonstrated including flexible integrated circuits (logic gates, ring oscillators, d-flip-flops, decoders, and counters), flexible full-color active-matrix organic light-emitting diode display, and a smart interactive skin sensor that can simultaneously map and respond to the outside stimulus. With emphasis on large-area systems where nm-scale accuracy in the assembly of nanotubes is not required, our demonstrations present a unique niche for nanotube electronics by taking full advantage of their superior electrical and physical properties. Our work shows carbon nanotubes' immense promise as a low-cost and scalable TFT technology for nonconventional electronic systems with excellent performances.

8725-60, Session 11

Heterogeneously integrated multifunctional systems via high-throughput transfer printing of micro/nano devices *(Invited Paper)*

M. Saif Islam, Hakan Karaagac, Mark Triplett, Logeeswaran Veerayah Jayaraman, Univ. of California, Davis (United States)

We will present a high-throughput method for large area fabrication of single crystal devices via transfer printing of 1D and 2D devices from mother substrates onto arbitrary low cost and flexible carrier substrates while simultaneously preserving the integrity, order, shape and fidelity of the transferred device arrays. The original substrates are repeatedly used for continual production of new devices and are minimally consumed. This method greatly decreases the cost of device fabrication by drastically reducing the material consumption and making it an environmentally benign process while offering high performance, flexibility, ease of packaging and integration. This heterogeneous integration technique offers the ability to integrate various single crystal micro- and nano-devices on secondary substrates to enable heterogeneously integrated systems for computing, communication, energy conversion, storage, sensing and imaging.

8725-61, Session 11

Skin-inspired sensor sheets for touch, chemical, and biological sensing *(Invited Paper)*

Zhenan Bao, Stanford Univ. (United States)

Organic and carbon nano materials are attractive for low cost electronic units for electronic skin as well as medicinal, food storage, and environmental monitoring applications. The ability to couple the sensory electrical output with on-chip signal processing can overcome the need for bulky, expensive equipment typically required for most optical detection methods. In this talk, I will present recent progress in materials and fabrication of chemical, biological and pressure sensors for electronic skin application.

8725-62, Session 11

Mechanically flexible optically transparent silicon fabric with high thermal budget devices from bulk silicon (100) *(Invited Paper)*

Muhammad M. Hussain, Jhonathan P. Rojas, Galo Torres Sevilla, King Abdullah Univ. of Science and Technology (Saudi Arabia)

A foldable high performance computer at an affordable price will empower us with instant access to information and communication for defense, health and societal purpose. However, wearable gadgets need to be bendable or flexible. Since 1990, many options of organic electronics to hybrid approach involving inorganic nano-ribbons or discrete device transfer to plastic substrate have been explored for flexible electronics such as displays, sensors, photovoltaic, etc. However, they have suffered from poor inherent electron mobility in organic electronics, limited thermal budget for plastic substrate, utilization of expensive substrate like silicon-on-insulator (SOI) or silicon (111), uncertain transfer process involved in hybrid approach and finally absence of a truly competitive high performance devices required in today's computers (3.2 GHz) or in cell phones (1.8 GHz). As of today a reliable process where semiconductor industry's most widely used low-cost bulk silicon (100) has not been used for macro-scale high-performance device integration for an application like flexible computers. Here we will show a generic process to release macro-to-nano-scale flexible and transparent silicon fabric (membrane) from bulk silicon (100) and then large-scale monolithic integration of semiconductor industry's most advanced high-k/metal gate technology based devices and thermoelectric generators on this released silicon fabric without compromising high-performance operation, high-thermal budget processing, low-cost, widely used substrates and state-of-the-art CMOS centered large-scale integration. With the rise of cloud computation, we believe our approach is the most pragmatic step towards highly flexible high performance mobile computation devices to empower world population with the power of information at an affordable price.

8725-63, Session 11

Transferable single-crystalline semiconductor nanomembranes and their versatile applications *(Invited Paper)*

Zhenqiang Ma, Univ. of Wisconsin-Madison (United States); Weidong Zhou, The Univ. of Texas at Arlington (United States)

Rigid semiconductor-based integrated circuit chips have changed our life for many decades. While they offer superior performance with high packing density, the rigidity of these chips often makes them hard to be implemented in many applications, such as very large-area, conformal, easy-to-bend and space-limited systems, and particularly bio-implantation systems. Traditional flexible electronics employing organic semiconductors, amorphous and polycrystalline silicon can fulfill some of these applications, but lacking the high performance that is needed in many of the advanced systems. Single-crystalline semiconductor nanomembranes that are released from various semiconductors are mechanically bendable, stackable, strainable, transferrable and conformal to any flexible and rigid substrates, with equivalent electronic properties as their bulk counterparts. These unique properties of semiconductor nanomembranes provide us with the unprecedented opportunities to develop fast flexible electronics, new types of electronic devices, optoelectronics and photonics devices. In this talk, I will present our recent research in these areas. Future research directions along this path will be outlined.

8725-64, Session 11

Biointerfaced nanopiezoelectrics *(Invited Paper)*

Michael C. McAlpine, Princeton Univ. (United States)

The development of a method for integrating highly efficient energy conversion materials onto soft tissue could yield breakthroughs in energy harvesting systems for implantable biomedical devices. Further, the scaling of such materials down to nanometer levels may yield novel probes for studying fundamental mechanical responses of cells. Of particular interest are materials and devices which can conform to soft, curved surfaces such as skin, and operate in vital environments that may involve both flexing and stretching modes. Piezoelectric crystals are a particularly interesting category of energy conversion materials whose properties have been extensively characterized in the bulk. They are brittle inorganic crystals which are processed at high temperatures, and thus are thermally and mechanically incompatible with soft biological matter. Our group has shown advances in the fabrication and integration of highly efficient nanopiezoelectrics on flexible and stretchable substrates. Yet, questions remain about how to engineer these interfaces to be compatible with fragile biological systems. Here we propose new strategies for addressing these questions. First, we have investigated the fabrication, characterization, and device integration of new classes of nanopiezoelectrics. Next, we have interfaced these materials with cells to act as fundamental probes of mechanical deformations of cells in response to electrical excitations. Finally, we have scaled these nanopiezoelectrics to macroscopic dimensions and biointerfaced them with tissue. This research suggests exciting implications for the direct biointerfacing of nanomaterials with cells and tissue, both as fundamental probes and for bioelectromechanical energy harvesting.

8725-65, Session 11

Ultraflexible and stretchable organic transistor integrated circuits for medical sensors *(Invited Paper)*

Takao Someya, Tsuyoshi Sekitani, The Univ. of Tokyo (Japan)

We will report recent progress of ultraflexible and stretchable, large-area sensors and actuators using printed organic transistor integrated circuits. Moreover, the issues and the future prospect of organic transistors and memories will be addressed. We will describe our recent research activities to apply ultraflexible and stretchable electronic systems for bio/medical applications

8725-66, Session 12

Graphene scaled up and down *(Keynote Presentation)*

Chagaan Baatar, Office of Naval Research (United States)

In the early days of graphene research, the Office of Naval Research (ONR) played a key role by championing and supporting the nascent graphene emerging, both in US and overseas. In this talk I will cover a brief history of graphene research sponsored by ONR and will describe the current scope and future vision for the program. Current ONR graphene portfolio range from molecular scale atomic precision synthesis of graphene nanostructures to larger scale graphene based flexible electronics research. I will draw examples from recent projects to give audience a snapshot of the current graphene portfolio at ONR.

8725-67, Session 12

Controlling growth of large area graphene on SiC *(Invited Paper)*

D. K. Gaskill, Luke O. Nyakiti, Virginia D. Wheeler, Rachael L. Myers-Ward, Nelson Y. Garces, Charles R. Eddy Jr., U.S. Naval Research Lab. (United States)

The Si sublimation approach for forming uniform layers of graphene on large area SiC substrates amenable to Si processing technology is described. Properties of SiC wafer technology that impact large area epitaxial graphene (EG) are illustrated. EG formation depends upon (0001)SiC surface preparation and uniform EG thickness on terraces is a function of surface misorientation. The impact of processing factors such as temperature control, laminar gas flow and substrate rotation on large area EG uniformity are described using examples from a commercial SiC epitaxy reactor. Contactless Lehighton resistivity maps of 100 mm wafers illustrate the current state-of-the-art, which is ±3%.

8725-68, Session 12

Single-walled carbon nanotubes and graphene for transparent electronics *(Invited Paper)*

John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

High mobilities and other attractive features of single-walled carbon nanotubes (SWNTs) and graphene create interest in their use in high speed (i.e. radio frequency) or unusual (i.e. flexible, stretchable, transparent) forms of electronics. This talk focuses on growth strategies that use chemical vapor deposition onto crystalline quartz substrates yield nearly perfectly linear, perfectly aligned, horizontal arrays of individual SWNTs. We describe methods for achieving high density arrays and for removing metallic SWNTs, and the properties of devices formed with them. Strategies for integrating graphene with such configurations of SWNTs provide routes to transparent transistors, with the capacity for integration onto plastic or rubber substrates.

8725-69, Session 12

Monodisperse carbon nanomaterials for electronic, optoelectronic, and energy conversion technologies *(Invited Paper)*

Mark C. Hersam, Northwestern Univ. (United States)

Recent years have seen substantial improvements in the structural, chemical, and electronic monodispersity of carbon nanomaterials, leading to improved performance in a variety of device applications. This talk will highlight our latest efforts to functionalize and assemble monodisperse carbon nanomaterials into architectures relevant to electronic, optoelectronic, and energy conversion technologies. For example, semiconducting single-walled carbon nanotubes (SWCNTs) allow the fabrication of thin-film field-effect transistors with concurrently high on-state conductance and on/off ratio. Using dielectrophoretic assembly, arrays of individual SWCNT transistors are also realized with high yield. Similarly, high performance digital circuits are fabricated from semiconducting SWCNT inks via aerosol jet printing. Beyond transistors, semiconducting SWCNTs have been utilized for light-emitting optoelectronic devices or chemical sensors, while metallic SWNCTs are well-suited as transparent conductors. This talk will also explore the utility of chemically functionalized graphene for high-frequency transistors, photovoltaics, and supports for the photocatalytic production of solar fuels.

8725-71, Session 12

Flexible transparent conducting networks of metal nanowires *(Invited Paper)*

Benjamin Wiley, Aaron Rathmell, Duke Univ. (United States)

There is an ongoing drive to replace rigid flat-panel devices (e.g. touch screens, solar cells) with devices that are more flexible in order to improve resistance to mechanical damage, and reduce cost by enabling high-throughput, roll-to-roll production. The brittleness and slow, vapor-based coating process (<0.01 m/s) of the standard transparent conducting material, indium tin oxide (ITO), are significant barriers to the production of low-cost, flexible electronics. This presentation will discuss the replacement of ITO with networks of copper nanowires. Copper nanowires can be produced in scalable, solution-phase syntheses, and can be coated from liquids at high rates (>1 m/s). Copper nanowire networks can be flexed more than 1000 times with no change in their conductance, can carry high currents (0.5 A/cm2), and can be rendered stable against oxidation with a Ni coating. A barrier to the use of copper nanowires for transparent conductive films was the fact that they had to be annealed under hydrogen to render them conductive due to the presence of a non-conductive oxide layer. This presentation will present new results showing that copper nanowire networks can be rendered highly conductive simply by dipping them in acetic acid.

8725-72, Session 12

Graphene-based hybrid films for high-performance transparent electrode applications *(Invited Paper)*

Iskandar Kholmanov, Rodney Ruoff, The Univ. of Texas at Austin (United States)

Today, indium tin oxide (ITO) is the main material used for transparent conductive films (TCFs). However, the brittle ceramic structure, poor compatibility with organic materials, and the growing cost of indium, seriously limit the use of ITO in TCFs. Therefore, several other materials including new oxide films, conductive polymers, carbon nanotubes (CNT), metal nanostructures, and graphene-based nanostructures have been investigated as alternatives to ITO. Among these materials, carbon nanotubes, metal nanowires (NWs), and graphene-based films garner interest due to their good TCF characteristics, i.e., low sheet resistance (Rs) and high optical transmittance (T),. However, their use in a wide range of devices is restricted by several specific drawbacks. In particular, metal NW and CNT films, are characterized by open spaces between nanostructures, high surface roughness, and poor adhesion to substrates. Drawbacks of graphene films include the currently costly fabrication that use vacuum and high temperature and the time-consuming and challenging multiple transfer steps from metal to the transparent substrate.

Here, we demonstrate a general strategy for fabrication of hybrid TCFs composed of metal nanostructures and graphene-based materials. We demonstrate that the shortcomings of single component TCFs might be overcome by hybrid films, in which the film properties can be improved due to synergy between individual components. Moreover hybrid TCFs may exhibit additional functionalities that can vary depending on their composition. This feature opens up possibilities for developing next generation multi-component and multifunctional TCFs.

8725-73, Session 12

Graphene and nanowire-based tunable and transparent RF front end *(Invited Paper)*

Kyung-Ah Son, H. C. Seo, David W. Barnes, Hyok J. Son, James H. Schaffner, Jeong S. Moon, HRL Labs., LLC (United States)

Optically transparent electrical conductors benefit a wide range of applications, including RF shielding, transparent antennas, frequency selective surfaces (FSS), and transparent electronics. Nanostructured (nanowires and graphene) transparent conductor materials are well-suited for these applications potentially beyond current Indium Tin Oxide films. We have developed nanowire films with optical transmission of 89% or 72% and sheet resistance of 15 ohm/sq or 4 ohm/sq at 550 nm wavelength. Recently we demonstrated microwave rejection of 25 dB in X-Ku band [1], transparent X-band antennas and Ku-band FSS using a metal nanowire network, with good antenna gain and efficient blocking of the Ku band with the FSS. In this talk, we present nanowire-based transparent conductors, graphene-based FETs, varactors, and passive electronic devices fabricated for a transparent RF front end and frequency-tunable transparent FSS.

[1] K.-A. Son et al., NT4D, 2012

8725-91, Session PThu

Ion irradiation effects on electric properties of hydrogenated amorphous silicon thin films

Shin-ichiro Sato, Takeshi Ohshima, Japan Atomic Energy Agency (Japan)

Progress in high energy physics and space technologies requires the development of semiconductor devices with high resistance to radiation. Since hydrogenated amorphous silicon (a-Si:H) semiconductors are expected to be utilized as a material for radiation-hardened devices such as space solar cells, particle detectors, and photo sensors, radiation effects on a-Si:H has been investigated. However, the radiation effects have not yet been systematically understood. In this paper, we report semiconductor properties of a-Si:H thin films irradiated with proton and Si ion irradiations. Variations of the dark conductivity (DC), the photoconductivity (PC), and the Seebeck coefficient of ion-irradiated a-Si:H are investigated in detail and their mechanisms are discussed. Also, the physical application limit for a-Si:H photoelectric devices in the radiation environments is found. The conductivity variations due to irradiation can be explained by the donor-center generation in the low fluence regime and the accumulation of dangling bonds. Both the DC and PC of undoped and n-type a-Si:Hs increase due to low fluence proton irradiation. However, with increasing the fluence, the decrease in DC and PC is caused by the carrier removal effect and the decrease in carrier lifetime. The further irradiation causes the loss of photoconduction and the drastic increase in DC. This indicates that the dominant electric conduction mechanism changes from the band transport to the hopping transport due to the excessive accumulation of dangling bonds. These complicated conductivity variations can be systematically categorized according to the ratio of the nuclear energy deposition to the electronic energy deposition of incident ions.

8725-92, Session PThu

Effects of x-ray and gamma-ray irradiation on the optical properties of quantum dots immobilized in porous silicon

Girija Gaur, Dmitry S. Koktysh, Sharon M. Weiss, Vanderbilt Univ. (United States)

In this work, we analyze the effects of X-ray and gamma-ray irradiation on the optical properties of colloidal CdTe/CdS quantum dots (QDs) immobilized in a porous silicon (PSi) film for potential applications in dosimeters, scintillators, solar cells, and light emitting diodes operating in acute, high-dose radiation environments. The PSi-QD samples were irradiated for variable total doses up to 10 Mrad(SiO2) under 10 keV X-rays and up to 2.2 Mrad(SiO2) under 662 keV gamma-rays. Quenching of QD continuous wave photoluminescence (CWPL) was observed, accompanied by an increasing blue shift of the reflectance spectra with increasing x-ray radiation exposure dose. The blue shift is attributed to a reduction in the effective refractive index of the PSi-QD film. Since surface-functionalized PSi control samples without QDs did not demonstrate a measureable shift in the reflectance spectra under the same conditions, we believe QD oxidation plays a major role in the observed CWPL quenching under x-ray irradiation. In order to further investigate the effects of ambient oxygen on the optical properties of QDs, PSi-QD films were subjected to gamma-ray irradiation in a nitrogen environment. The significantly higher energy gamma-rays demonstrated strong quenching of QD CWPL but no measurable shift in the reflectance spectra. Furthermore, a 20% reduction in the carrier lifetime for a 600 krad (SiO2) total dose and almost complete quenching of the QD CWPL at a total dose of 2.2 Mrad (SiO2) was observed suggesting that the creation of non-radiative defects may significantly alter QD properties under gamma irradiation. We believe that this study enables a better understanding of the interaction of high-energy radiation with semiconductor QDs and PSi, thereby improving the reliability of QD based devices subjected to high-dose radiation environments.

8725-93, Session PThu

Nonlinear-optical up and down frequency-converting backward-wave metasensors and metamirrors

Alexander K. Popov, Univ. of Wisconsin-Stevens Point (United States); Igor S. Nefedov, Aalto Univ. School of Science and Technology (Finland); Sergey A. Myslivets, Kirensky Institute of Physics (Russian Federation); Mikhail I. Shalaev, Vitaly V. Slabko, Siberian Federal Univ. (Russian Federation)

A concept of a family of unique backward-wave (BW) photonic devices, such as frequency up and down converting sensors, modulators, filters, amplifiers and oscillators is proposed. Novel materials are considered, which support coexistence of ordinary and BWs and thus enable enhanced nonlinear-optical (NLO) frequency-conversion processes. Extraordinary properties of coherent NLO energy exchange between ordinary and BWs are investigated. Energy flux and phase velocity are contra-directed in BWs. Two different classes of such materials are proposed: metamaterials (MM) with specially engineered spatial dispersion and crystals that support optical phonons with negative group velocity. Both do not rely on nanoresonators which provide negative optical magnetism and constitute current mainstream in fabricating negative index metamaterials (NIM). The appearance of electromagnetic BW (BEMW) in metaslabs made of standing carbon nanotubes, the possibilitiy and extraordinary properties of phase matched BW second harmonic generation in such a MM is described. The possibility to replace plasmonic NLO MMs, which are very challenging to make, by the ordinary, readily available crystals is another proposed option. The possibility to mimic extraordinary NLO frequency-conversion propagation processes attributed to NIMs is shown for some of such crystals whereby optical phonons with negative group velocity and a proper phase-matching geometry are implemented. Here, optical phonons are employed instead of BEMWs.

1. A.K. Popov and V.M. Shalaev, “Merging nonlinear optics and negative-index metamaterials,” Proc. SPIE, 8093-06, 1-27 (2011).

2. A.K. Popov, “Nonlinear optics of backward waves and extraordinary features of plasmonic nonlinearoptical microdevices,” Eur. Phys. J. D, 58, 263-274 (2010).

8725-95, Session PThu

Advanced nanoelectromechanical switches with longevity in ambient and extreme conditions

Philip Feng, Case Western Reserve Univ. (United States)

We report experimental demonstration of genuinely nanoscale electromechanical contact-mode switches with high performance, enabled by silicon carbide (SiC) nanoelectromechanical systems (NEMS). For the first time, we experimentally record the real-time evolution

of robust switching events in ambient air and high temperatures, by switching devices on and off for >10^4 to 10^6 cycles without failure (devices still alive, more cycles available if tests continue). These switches in SiC NEMS show >=10^4 on/off ratios, with highly repeatable performance over days. The real-time recorded long switching cycles also enable us a unique platform for studying the time evolution of the nanoscale contacts.

Contact-mode MEMS/NEMS switches (relays) have been rapidly emerging, and have been actively explored as a promising alternative toward ultralow-power applications. NEMS switches offer compelling advantages including ideally abrupt switching with minimal off-state leakage, suitable for extreme environments, and small footprints. In pursuing these advantages, however, challenges remain: (i) all the high-performance mechanical switches recently demonstrated are still well in the MEMS domain and are orders of magnitude larger in size/volume than today's mainstream transistors. In fact, recent MEMS switches with high cycle numbers are all >10,000 times larger in volume than our devices in this work. (ii) Most of today's truly nanoscale mechanical switches suffer from very short lifetimes, and some literally can merely switch one or a few cycles before failure. Here we report robust, gate-controlled NEMS switching, recorded in ambient and at high temperature (500 C), based on SiC, which is uniquely suited for NEMS logic for its outstanding properties.

Our NEMS devices typically have thicknesses, widths and gaps mostly ~200nm or smaller, and thus having motional volumes of ~1um^3 or less. For such small devices with orders of magnitude reduction in devices and contacts dimensions, our SiC NEMS has been unique and impressive in demonstrating switching and contact longevity, amongst all today's contact-mode NEMS devices. We expect such studies and lifetime engineering would accelerate the development of the technology.

8725-96, Session PThu

Effects of radiation-induced defects on the charge collection efficiency of a silicon carbide particle detector

Naoya Iwamoto, Shinobu Onoda, Takahiro Makino, Takeshi Ohshima, Japan Atomic Energy Agency (Japan); Kazutoshi Kojima, National Institute of Advanced Industrial Science and Technology (Japan); Shinji Nozaki, The Univ. of Electro-Communications (Japan)

Silicon carbide (SiC) is an attractive semiconductor material for high-energy particle detectors used under visible lights and a high temperature condition. Because of wide band gap, SiC particle detectors can be operated with a sufficient signal to noise ratio even at such conditions. In order to develop a particle detector, it is also important to study its radiation resistance. In this paper we study defects in 6H-SiC particle detectors created by high-energy electrons and discuss their impacts on the charge collection efficiencies (CCEs) of the detectors.

6H-SiC p+n diodes were used as particle detectors in this study. The diodes were irradiated with electrons with the energies of 0.1, 0.2, 0.5 and 1.0 MeV in order to create defects in the SiC crystal. CCEs of these diodes were measured using 5.5 MeV alpha particles with a standard pulse height analysis method. Defects in these diodes were characterized by a charge transient spectroscopy technique using alpha particles.

The CCE was not changed by 0.1 MeV electron irradiation. On the other hand, degradations of CCE were found in the diodes irradiated with electrons with 0.2 MeV and higher. A defect level with the activation energy of 0.5 eV, labeled as X, was found in diodes whose CCEs were degraded. Degraded CCEs were recovered to the initial value as the defect X was removed by thermal annealing. From these results, it is concluded that the defect X is responsible for the degradation of CCE of 6H-SiC particle detectors.

8725-97, Session PThu

Subwavelength resonant nanostructured films for sensing

Kyle J. Alvine, Bruce E. Bernacki, Wendy D. Bennett, Danny J. Edwards, Albert M. Mendoza, Jonathan D. Suter, Pacific Northwest National Lab. (United States)

We present a novel subwavelength nanostructure architecture that may be utilized for optical standoff sensing applications. The subwavelength structures are fabricated via a combination of nanoimprint lithography and metal sputtering to create metallic nanostructured films encased within a transparent media. The structures are based on the open ring resonator (ORR) architecture and have their analog in resonant LC circuits which display a resonance frequency that is inversely proportional to the square root of the product of the inductance and capacitance. Therefore, any perturbation of the nanostructured films due to chemical or environmental effects can alter the inductive or capacitive behavior of the subwavelength features, which can shift the resonant frequency and provide an indication of the external stimulus. This shift in resonance can be interrogated remotely actively using either laser illumination or passively using hyperspectral or multispectral sensing. These structures may be designed to be either anisotropic or isotropic, which can also provide polarization-sensitive interrogation. Due to the nanometer-scale of the structures, they can be tailored to be optically responsive in the visible or near infrared spectrum with a highly reflective resonant peak that is dependent solely on structural dimensions and material characteristics. We present experimental measurements of the optical response of these structures as a function of wavelength, polarization, and incident angle demonstrating the resonant effect in the near infrared region. Numerical modeling data showing the effect of different fabrication parameters such as structure parameters are also discussed.

8725-98, Session PThu

Cross-spectrum noise spectroscopy of silicon nanowire transistors

Deepak K. Sharma, National Institute of Standards and Technology (United States) and George Mason Univ. (United States); Sergiy Krylyuk, Univ. of Maryland (United States); Abhishek Motayed, Univ. of Maryland (United States) and National Institute of Standards and Technology (United States); Qiliang Li, George Mason Univ. (United States) and National Institute of Standards and Technology (United States); Albert V. Davydov, National Institute of Standards and Technology (United States)

Large surface to volume ratio in nanowire sensors leads to enhanced current modulation when various analytes adsorb on the surface. However, random current fluctuations resulting from bulk and surface generation and recombination (G-R) processes compromise the resolution of the sensors. Low frequency noise (LFN) spectroscopy is a highly sensitive technique to study these stochastic fluctuations. Since the device noise is proportional to the current signal, it becomes increasingly difficult to accurately measure the noise signal in low-current nanoscale devices. Furthermore, the noise measurement setup itself introduces instrumental noise which adds to the intrinsic noise of the device-under-test. To address these issues, we have implemented a noise measurement method based on dual-channel cross-spectrum analysis technique. This technique allowed us to reduce the power spectral density (PSD) by three orders of magnitude by effectively reducing the parasitic background 1/f noise and thus significantly enhance the sensitivity of the noise measurements. As a test-bed, we utilized Silicon nanowires (SiNWs) grown by vapor-liquid-solid method using Au and Ni catalysts. Field-effect transistors (FETs) were fabricated using both n- and p-doped SiNWs. Noise measurements were performed on the SiNW FETs in 80K to 320K temperature range. The PSD showed clear Lorentzian peaks due to the G-R processes. Temperature-

dependent noise analysis indicated that the traps responsible for the G-R noise correlate well with the deep-levels introduced by Ni and Au atoms diffused into the SiNWs during the growth.Important parameters such as trap energies and concentrations of the deep levels were calculated for both Ni and Au deep-levels. Such sensitive noise measurements will be useful in characterizing nanoscale devices, such as chemical-sensors, photodetectors, and transistors.

8725-100, Session PThu

Energy and power balance at interaction of ultrafast laser pulse train with a bandgap material

Michael K. Rafailov, Univ. of Alberta (Canada)

Here we report analysis and experimental verification of energy and power balance during the interaction of ultrafast laser with bandgap material when ultrafast bandgap photonic phenomena can be observed. Optically (light) induced superconductivity as well as multiple photonic phenomena observable at interaction of ultrafast laser and bandgap material are based on two effects: electron bandgap transfer hyper-saturation along bleaching of bandgap material and following changes in electronic (and) magnetic properties of the material that occur between pulses in ultrafast laser pulse train. At that point power and energy balance that needs to be maintained between peak power that is sufficient to induce bleaching and corresponding energy that is deposited in the material is the key point of ultrafast bandgap photonics. Applying concept to ultrafast bandgap photonics to laser interaction with InSb allows to demonstrate how this balance can be successfully managed in engineering photonic application with pretty common bandgap material. As a result practical engineering recommendations is made toward system engineering and architecture of

8725-101, Session PThu

Development of a versatile lab-on-a-chip enzyme assay platform for pathogen detection in CBRNE scenarios

Richard Klemm, Sebastian Schattschneider, Tobias Jahn, Nadine Hlawatsch, Holger Becker, Claudia Gärtner, microfluidic ChipShop GmbH (Germany)

Being able to integrate complex assays on a single microfluidic chip helps to greatly simplify instrument requirements and allows the use of lab-on-a-chip technology in the field. A core application for such field-portable systems is the detection of pathogens in a CBRNE scenario such as permanent monitoring of airborne pathogens, e.g. in metro stations or hospitals etc. As one assay methodology for the pathogen identification, enzymatic assays were chosen. In order evaluate different detection strategies, a generic enzyme assay module has been designed as a general chip-based test platform. In all application cases, the assays are based on immobilized probes located in microfluidic channels. Therefore a microfluidic chip was realized containing a set of three individually addressable channels, not only for detection of the sample itself but also to have a set of references for a quantitative analysis. It furthermore includes two turning valves and a waste container for contamination-free storage of potential pathogenic liquids. All liquids remain in the chip and can be disposed of in proper way after running the assay. The chip design includes four inlet ports consisting of one sample port (Luer interface) and three mini Luer interfaces for fluidic support of e.g. washing buffer, substrate and enzyme solution. The sample can be applied via a special, sealable sampling vessel with volumes between 0.5 and 5 ml with integrated female Luer interface. Thereby also pre-anaytical contamination of the environment can be prevented. Other reagents that are required for analysis will be stored off chip.

8725-102, Session PThu

Radiation detection with CdTe quantum dots in silica-glass and polymer nanocomposites

Kavin Manickaraj, SENSIAC (United States); Brent K. Wagner, Georgia Tech Research Institute (United States); Zhitao Kang, Georgia Tech Research Institute (United States) and Georgia Institute of Technology (United States)

Optically based radiation detectors in various fields of science still suffer from low resolution, low sensitivities, and efficiencies that restrict their overall performance. Quantum dots (QD) are well-suited for such detectors due to their unique optical properties. CdTe QDs show fast luminescence decay times, high conversion efficiencies, and have band gaps strongly dependent on the particle radius. These properties are advantageous for alpha-particle and potentially neutron detection. In this work, CdTe QD-based polymer or glass matrix nanocomposites will be synthesized and used in alpha-particle scintillators by absorbing the incident particle energy and re-emitting it in the form of visible or near-infrared radiation. Since QD particle sizes are well below the wavelengths of their emissions, they remain optically transparent when incorporated in both polymer and sol-gel based silica glass due to negligible optical scattering. The fast photo-response and decay times provide excellent time resolution. Also, the QD emission photon can be fine-tuned to that best suited for the photo-detector. We will study the radiation response of such nanocomposites, and the energy transfer between the polymer or glass matrices and the QDs will be compared. In addition, as these composite materials can greatly improve the mechanical robustness of alpha-particle detectors, conventionally known to have delicate components, CdTe QDs show high promise for radiation sensing applications.

8725-103, Session PThu

Super-period metal nanostructures for integrated surface plasmon resonance spectrometer sensors

Junpeng Guo, Hai-Sheng Leong, The Univ. of Alabama in Huntsville (United States)

Extraordinary optical transmission through subwavelength period metal nanohole arrays occurs when the frequency of incident light is tuned to the surface plasmon resonance frequency of the periodic metal nanostructures. The phenomena have been widely investigated for biochemical sensing applications. Presence of chemical or biological agents onto surfaces of metal nanostructures changes the local surface plasmon resonance. Change of the surface plasmon resonance can be measured by using optical spectrometers. In this talk, a new type of surface plasmon resonance spectral sensors will be presented. In our new surface plasmon resonance spectral sensors, super-period metal nanohole array gratings are created for surface plasmon resonance sensing. A super-period metal nanohole array grating has two periods: one is a small subwavelength period that contributes to localized surface plasmon resonance and another is the “super-period,” that is created by periodically removing lines of the nanoholes in a regular periodic nanohole array. The super-period nanohole array is a surface plasmon resonance nano-grating that diffracts local surface plasmons into non-zeroth order diffractions. Due to the intrinsic angular dispersion of diffractions, the resonance spectrum in diffraction orders can be measured with a linear photodetector array or a CCD. A surface plasmon resonance spectrometer sensor using an e-beam lithography patterned super-period gold nanohole array grating is experimentally demonstrated [1]. The surface plasmon resonance spectrometer measures the surface plasmon resonance from the spatially dispersed first order diffraction with a CCD. Surface plasmon resonance in super-period metal nanohole array grating was investigated by measuring resonance spectra in the zeroth order transmission and the first order diffraction. It is found that the first order diffraction resonance peak wavelength is slightly blue-shifted from the zeroth order transmission peak wavelength. The integrated surface

plasmon resonance spectrometer eliminates the use of external optical spectrometer for surface plasmon resonance spectral measurement and sensing

Reference

[1] H. Leong and J. Guo, "A surface plasmon resonance spectrometer using a super-period nanohole array," Optics Express, vol. 20, no. 19, pp. 21318-21323, 2012.

8725-104, Session PThu

Solution-based photodetectors for monolithically integrated low-cost short-wave infrared focal plane arrays

Emre Heves, Huseyin Kayahan, Yasar Gurbuz, Sabanci Univ. (Turkey)

Conventional IR detectors are typically composed of crystalline substrates that are different from silicon and they require mechanical bonding with silicon electronics to from the complete imaging array. Therefore, size, yield, reliability and the cost of the bonds between these substrates dominate the size and resolution of these arrays. Solution-processed photodetectors allow monolithic integration of IR sensitive imaging arrays and eliminate the restrictions of these mechanical bonds. In most of the previous works, colloidal quantum dot IR detectors are implemented on glass substrates discretely. In this work, however, in the direction of fully integration of PbS CQD photodiodes on read out electronics (ROIC) that are fabricated using conventional IC processes; we fabricated mimics of top layers of ROICs on Si substrates and fabricate our self-aligned PbS CQD Schottky diodes on top of them. This work presents a proof of concept of fabricating PbS CQD photodiodes on ROICs in order to have monolithically integrated SWIR focal plane array. Under 140 μW/cm2 illumination at 1550 nm, the PbS photodiode that is realized on ROIC mimics, achieved responsivity of 0.2 A/W and efficiency of 15% at 1 V reverse bias with a normalized detectivity of 1.36 x 10^11 Jones, extracted assuming that shot noise is dominating the noise current. Under 2V reverse bias, they show a photoconductor behavior with a responsivity of 5.73 A/W and 1.41 x 10^12 Jones detectivity, which is comparable with the single crystal compound semiconductor detectors.

8725-105, Session PThu

Large-aperture active optical carbon fiber reinforced polymer mirror

Matthew E. L. Jungwirth, Honeywell, Inc. (United States) and Sandia National Labs. (United States); Christopher C. Wilcox, U.S. Naval Research Lab. (United States); David V. Wick, Michael S. Baker, Clinton G. Hobart, Jared J. Milinazzo, Sandia National Labs. (United States); Joseph L. Robichaud, L-3 Communications IOS-SSG (United States); Robert C. Romeo, Robert N. Martin, Composite Mirror Applications (United States); Jerome Ballesta, Imagine Optic (United States); Emeric Lavergne, Imagine Optic (France); Eustace L. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States)

Active optical elements can be used to induce a spatially varying phase shift in incoming wavefronts (for imaging) or outgoing coherent beams (for directed energy applications). This paper presents initial results for a large-aperture variable radius of curvature (ROC) mirror constructed of carbon fiber reinforced polymer (CFRP). Specifically, we will present opto-mechanical designs and initial closed-loop actuation results showing that closed-loop control maintains good optical performance when the active CFRP mirror is used in conjunction with a commercial deformable mirror. The base ROC is increased from 2000mm to 2010mm using a novel annular ring actuation method.

8725-74, Session 13

Biointerfaced graphene nanosensors *(Invited Paper)*

Michael C. McAlpine, Princeton Univ. (United States)

Direct interfacing of nanosensors onto the human body could revolutionize areas ranging from health quality monitoring to adaptive threat detection. Due to its exceptional electrical properties, nanosensors based on graphene have been shown to exhibit extremely sensitive analyte detection. Further, the high interfacial adhesion exhibited by graphene renders it ideal for interfacing onto curvilinear and rugged surfaces. Here we introduce a new approach to directly interfacing graphene nanosensors onto biomaterials. Specifically, we demonstrate that graphene can be printed onto water-soluble silk. This in turn permits intimate biotransfer of graphene nanosensors onto biomaterials including tooth enamel and skin, like the attachment of a temporary tattoo. The result is a fully biointerfaced sensing platform, which can be tuned to detect specific target analytes. For example, via bifunctional self-assembly of antimicrobial peptides onto graphene, we demonstrate bioselective detection of bacteria at single-cell levels. The incorporation of a resonant circuit consisting of interdigitated electrodes and an inductive coil eliminates the need for onboard power and external connections. Combining these elements yields two-tiered interfacing of peptide-graphene nanosensors with biomaterials. In particular, we demonstrate integration onto a tooth for remote monitoring of breath and detection of bacteria in saliva at single cell levels. The key functionalities of this hybrid sensing element are thus derived from a synergistic integration of the individual materials properties and components. Overall, this strategy of hierarchically interfacing biomolecules with nanosensors and biomaterials represents a versatile approach for ubiquitous detection of biochemical targets.

8725-75, Session 13

Microbial culture and cell manipulation in picoliter droplet microfluidics *(Invited Paper)*

Joshua T. Wolfe, Johns Hopkins Univ. Applied Physics Lab. (United States)

Viral evolution in response to selective pressures is a complex process that is currently difficult to predict. We have developed a high-throughput microfluidic culture system for viral infection of host cells. This water-in-oil emulsion system results in large numbers (kiloHertz) of single-cell infection chambers with volumes as low as 65pL. These droplet-based reaction chambers can be sorted, merged, split, injected and sampled. Furthermore the integrity of the droplet reaction vessels can be maintained over several days and at temperatures of 95 degrees Celsius.

Our model system for platform testing and evaluation is infection of RAW264.7 cells by murine norovirus. We have demonstrated infection of single cells encapsulated with virus, with a corresponding increase in viral number. At droplet multiplicities of infection of 0.025, 0.25, and 2.5 we observed a 1000-fold increase in viral genome number after cell infection compared to the number of viruses encapsulated initially by Taqman-based quantitative real-time polymerase chain reaction (qRT-PCR). We also demonstrate that the droplet-infection-derived viral particles retain infectivity by plaque assay. Despite working with adherent cells, we also demonstrate that cells encapsulated in droplets can be transfected with recombinant DNA constructs using Lipofectamine, and remain viable for up to 48 hrs. We are currently demonstrating droplet-based one-step reverse-transcriptase-PCR for amplifying viral RNA, and a series of other manipulations for coupling this microfluidic technology with reverse-genetics, and next-generation sequencing platforms. Data from this culture system will be used to inform predictive algorithms of viral evolutionary trajectory.

8725-76, Session 13

Energy-transfer based nanocomposites for radiation detection *(Invited Paper)*

Wei Chen, The Univ. of Texas at Arlington (United States)

Scintillation nanoparticles have a bright future in radiation detection for preventing terrorism and enhancing homeland security. However, nanoparticles must be in the forms of thin films or 'crystals' for practical applications. Encapsulation of nanoparticles is surely a good strategy to fabricate bulky nanostructured thin films or 'crystals'. While almost all polymers are not transparent to ultraviolet (UV) light and most Ce3+ doped scintillators have emissions in the UV range. Thus, simply encapsulation of Ce3+ doped nanoparticles into polymers cannot obtain transparent 'crystals' with high detection efficiency. Here we investigate LaF3:Ce/CdTe nanocomposites for radiation detection based on the energy transfer from Ce3+ to CdTe quantum dots not only can have visible emission which is transparent to the polymer selected but also have very fast decay lifetimes. In addition, the energy transfer can enhance the quantum yield of the quantum dots, and the system combines high stopping powers, high sensitivity and high energy resolution of LaF3:Ce with the high quantum efficiency, short decay lifetimes and size tunnability of CdTe quantum dots. In this presentation, we report the progresses in nanoparticle synthesis, X-ray luminescence as well as our plans for integrating of research with education and training for the purpose of homeland security.

8725-77, Session 13

SpinDx: a rapid, sensitive, and deployable platform for diagnostics of biological and radiological threats *(Invited Paper)*

Chung-Yan Koh, Stanley A. Langevin, Matthew E. Piccini, Anup K. Singh, Sandia National Labs., California (United States)

There remains an unmet need for deployable diagnostic platforms that are rapid, sensitive, and amenable to biodefense applications in low resource areas. Existing technologies tend to be fast and portable (e.g. lateral flow) or sensitive and quantitative (e.g. ELISA or qPCR) but platforms which are both are rare. Here we present SpinDx™, a sedimentation-based centrifugal microfluidic platform which is both fast (<20 minute) and sensitive (pg/mL limit of detection) while maintaining a simple one-step assay format amenable to multiplexed protein and nucleic acid detection (up to 64 parallel assays) directly from complex samples (i.e., clinical and environmental) with no sample preparation required.

For protein detection, a sandwich immunoassay format is used. Antibody-conjugated microparticles are incubated with the analyte of interest as well as a fluorescently-labeled reported antibody. Upon application of centrifugal force, the resulting sandwich immunocomplex travels through a pre-loaded density medium. Any antigen, detection antibody, or matrix component that is unbound remains above the density medium. The microparticles pellet to the bottom of the channel where the signal is read; this novel approach both concentrates the signal and thoroughly washes the particles thereby dramatically reducing background while increasing signal. Similarly, for nucleic acid detection, a double stranded quenched FRET DNA probe is used and the resulting signal corresponds to hybridization of the target strand to the fluorescently-labeled reporter strand. For known pathogenic sequences, new assays can be developed and optimized in just a few days. We demonstrate sensitive detection using this platform for both viral nucleic acids and toxin proteins from the NIAID ABC list.

The simplified disc-based assay architecture facilitates ready incorporation into an integrated deployable diagnostic platform. This assay's rapid (<20 min) sample-to-answer time, low limits of detection (pg/mL), compatibility with complex biological samples, low cost (~$2,200 per instrument, <$2.00 per disk), and rapid assay development time provide vast improvements over current state-of-the-art approaches for deployable pathogen diagnostics in low resource areas.

8725-78, Session 14

Non-intrusive telemetry applications in the oilsands: from visible light and x-ray video, to acoustic imaging and spectroscopy *(Keynote Presentation)*

John M. Shaw, Univ. of Alberta (Canada)

While the production, transport and refining of oils from the oilsands of Alberta, and comparable resources elsewhere is performed at industrial scales, numerous technical and technological challenges and opportunities persist due to the ill defined nature of the resource. For example, bitumen and heavy oil comprise multiple bulk phases, self-organizing constituents at the microscale (liquid crystals) and the nano scale. There are no quantitative measures available at the molecular level. Non-intrusive telemetry is providing promising paths toward solutions, be they enabling technologies targeting process design, development or optimization, or more prosaic process control or process monitoring applications. Operation examples include automated large object and poor quality ore during mining, and monitoring the thickness and location of oil water interfacial zones within separation vessels. These applications involve real-time video image processing. X-ray transmission video imaging is used to enumerate organic phases present within a vessel, and to detect individual phase volumes, densities and elemental compositions. This is an enabling technology that provides phase equilibrium and phase composition data for production and refining process development, and fluid property myth debunking. A high-resolution two-dimensional acoustic mapping technique now at the proof of concept stage is expected to provide simultaneous fluid flow and fluid composition data within porous inorganic media. Again this is an enabling technology targeting visualization of diverse oil production process fundamentals at the pore scale. Far infrared spectroscopy coupled with detailed quantum mechanical calculations, may provide characteristic molecular motifs and intermolecular association data required for fluid characterization and process modeling. X-ray scattering (SAXS/WAXS/USAXS) provides characteristic supramolecular structure information that impacts fluid rheology and process fouling. The intent of this contribution is to present some of the challenges and to provide an introduction grounded in current work on non-intrusive telemetry applications - from a mine or reservoir to a refinery! challenges from a mine or reservoir to a refinery!

8725-79, Session 14

Micro- and nanostructure of asphaltene aggregates in situ characterization via monochromatic x-ray microtomography *(Invited Paper)*

Michael K. Rafailov, Univ. of Alberta (Canada) and The Reger Group (United States); Victor E. Asadchikov, Alexei V. Buzmakov, Denis A. Zolotov, Anna S. Osadchaya, Arsen E. Muslimov, A.V. Shubnikov Institute of Crystallography (Russian Federation); Svetlana A. Rubtsova, Ctr. for Nano-Technology (Russian Federation)

Here we report work done toward detection and characterization of micro-and nano-structures containing V, Co, Mo, Re, Ni Co or other metals in colloidal mixture. X-ray micro-tomograph with monochromatic radiation has been used to detect nano-and-microstructures containing metal-organics formed by metals particularly, as porphyrines in oil disperse systems. In order to detect and characterize nano-and micro-structures containing metal-organics the tomograph's operational wavelength has been tuned to a wavelength of absorption in X-ray spectrum of one of the metals. Contrast between resonant X-ray absorption of specific metal and average colloidal mixture absorption provides a tool for measurement of metal mass concentration in the structures as well as distribution of micro-and nano structures not only on surface but in the volume. Work specifically has been focused at measurement of oil disperse system containing porphyrines where concentration of metals changing as a function of asphalten concentration changing along oil processing.

8725-80, Session 14

Chemical sensing and imaging in microfluidic pore network structures relevant to natural carbon cycling and industrial carbon sequestration *(Invited Paper)*

Jay W. Grate, Changyong Zhang, Michael Wilkins, Marvin G. Warner, Norman C. Anheier Jr., Jonathan D. Suter, Ryan Kelly, Mart Oostrom, Pacific Northwest National Lab. (United States)

Energy utilization and climate change represent significant factors in global security in the twenty first century. Atmospheric carbon dioxide levels, while global in scope, are influenced by pore-scale phenomena in the subsurface. Specifically, natural terrestrial carbon cycling stores and releases carbon, processes that could offset or exacerbate anthropogenic carbon releases. Alternatively, industrial sequestration of carbon from fossil fuel combustion may directly inject carbon dioxide into subsurface reservoirs to prevent release into the atmosphere. We are developing tools to visualize, measure, and investigate pore scale processes using pore network microfluidic structures with transparent covers as pseudo two dimensional representations of poreous media. For the study of processes related to terrestrial carbon cycling we have developed in situ fluorescent oxygen sensing methods and cellulosic materials that can be imaged using fluorescence, where the pore network serves as a habitat for cellulytic respiring microorganisms. Related to carbon sequestration, we are using pore network structures to investigate the displacement of water from pore spaces by hydrophobic fluids including liquid and supercritical carbon dioxide, using fluorescence microscopy for quantitative measurements.

8725-81, Session 14

Intercalation of Asphaltene nano-aggregates into natural and artificial substrates *(Invited Paper)*

Michael K. Rafailov, Univ. of Alberta (Canada); Vladimir F. Sapega, A.P. Karpinsky Russian Geological Research Institute (Russian Federation)

Here we report work done in oil nano-aggregates intercalation. Asphaltene precipitation is the foundation of oil processing technology. Convenient oil processing is based on high temperature water consumptive technology with extensive use of chemicals. However, separation of asphaltenes from oil disperse system may happen naturally via intercalation into natural mineral substrates. Process of asphaltene natural precipitation appears to be quite effective in some types of oil sands: oil sands with elevated concentration of specific minerals and presence of mineral substrates. We did reverse engineering of naturally occurred processes of asphaltene precipitation. Rare and heavy metals have been used to mark asphaltene nano-aggregates. Metals that are widely presented in oil disperse system mostly in form of porphyrines have been able to mark asphaltene nano-aggregates and to indicate oil and bitumen phase changing processes that occur via precipitation of asphaltenes. Reverse engineering of naturally occurred intercalation is effective tool for simulation of intercalation of asphaltene aggregates of oil disperse system. Reverse engineering demonstrated high efficiency of intercalation with specific types of mineral substrates. Our focus is to develop non-aquatic non-chemical ambient temperature oil processing technology.

8725-82, Session 15

Micro- and nanodevices in millimetre and sub-millimetre imaging systems *(Keynote Presentation)*

Roger Appleby, Queen's Univ. Belfast (United Kingdom)

This paper will review the impact of micro and nano technology on millimetre and sub millimetre wave imaging from the post war years to the present day. Where possible simulation based on OpenFx will be used to demonstrate how changes in this technology impacted on imaging performance. Whisker contacted diodes in mixers and vacuum tubes were used in the post war years to realise both radiometers and radars but required considerable skill to realise the performance required. Development of planar semiconductor diodes revolutionised mixer performance and provided considerable improvement. The next major breakthrough was high frequency transistors based on gallium arsenide which were initially used at intermediate frequencies but later after further development at higher frequencies. More recently Monolithic Microwave Integrated circuits(MMICs) now offer exceptional performance and when coupled with Monolithic Electro-Mechanical Switches(MEMS) offer the opportunity for innovative design in imaging systems. In the future the use of micro and nano technology will continue to drive system performance and we can expect to see more integration of antennae, millimetre wave and sub millimetre wave circuits and signal processing.

8725-83, Session 15

Airborne nanoparticle detection with nanomechanical string resonators *(Invited Paper)*

Silvan Schmid, Maksymilian Kurek, Anja Boisen, Technical Univ. of Denmark (Denmark)

We present a nanomechanical sensor for the real-time detection of single airborne nanoparticles for the implementation in low-cost portable personal nanoparticle monitors. The use of engineered nanoparticles in commercial applications has increased and personal monitoring devices for the assessment of nanoparticle exposure doses are highly demanded. Nanomechanical sensors have a low power consumption and an unprecedented mass sensitivity required for the application as a portable nanoparticle exposure monitor.

8725-84, Session 15

Antenna coupled detectors for 2D staring focal plane arrays *(Invited Paper)*

Michael A. Gritz, Leonard P. Chen, Robert Burkholder, Raytheon Co. (United States); Brian A. Lail, Florida Institute of Technology (United States); Borys P. Kolasa, 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 the sub-mmW/THz region. Raytheon's innovative nano-antenna based detector enables low-cost production of 2D staring 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.

8725-85, Session 15

Diffraction limit investigation with sub-wavelength pixels *(Invited Paper)*

Alain Bergeron, Marc Terroux, Linda Marchese, Denis G. Dufour, Loic Le Noc, Claude Chevalier, INO (Canada)

Current state-of-the-art pixel dimensions for both visible and long-wave infrared (LWIR) imagers are approaching the wavelength of measurement. It is expected that technological advances will continue and that sub-wavelength pixels for these wavebands will become a reality. In light of the diffraction limit, scientists and engineers in the visible and infrared domains have now begun pose the question as to whether it is worth having a focal plane array (FPA) with pixel dimensions smaller that the imaging wavelength. Meanwhile, in the terahertz domain, FPAs have already been fabricated and cameras designed around them with sub-wavelength pixels. INO has developed two versions of THz cameras, one with dimensions 160x120 pixels with a pixel pitch of 52 µm and the other 388x284 pixels with pixel pitch of 35 µm. The THz wavelength range of 40 µm to 1 mm and thus both FPAs have pixel dimensions below that of the imaging illumination. This paper discusses experimental results of diffraction limit investigations using sub-wavelength pixel THz cameras.

8725-87, Session 16

Raman and photothermal spectroscopies for explosive detection *(Invited Paper)*

Eric Finot, Thibault Brulé, Padmnabh Rai, Univ. de Bourgogne (France); Aurélien Griffart, Univ. de Bourgogne (France); Alexandre Bouhélier, Univ. de Bourgogne (France); Thomas G. Thundat, Univ. of Alberta (Canada)

Detection of explosive residues using portable devices for locating landmine and terrorist weapons must satisfy the application criteria of high reproducibility, specificity, sensitivity and fast response time. Vibrational spectroscopies such as Raman and infrared spectroscopies have demonstrated their potential to distinguish the members of the chemical family of more than 30 explosive materials. The characteristic chemical fingerprints in the spectra of these explosives stem from the unique bond structure of each compound. However, these spectroscopies, developed in the early sixties, suffer from a poor sensitivity. On the contrary, MEMS-based chemical sensors have shown to have very high sensitivity lowering the detection limit down to less than 1 picogram, (namely 10 part per trillion) using sensor platforms based on microcantilevers, plasmonics, or surface acoustic waves. The minimum amount of molecules that can be detected depends actually on the transducer size. The selectivity in MEMS sensors is usually realized using chemical modification of the active surface. However, the lack of sufficiently selective receptors that can be immobilized on MEMS sensors remains one of the most critical issues. Microcantilever based sensors offer an excellent opportunity to combine both the infrared photothermal spectroscopy in their static mode and the unique mass sensitivity in their dynamic mode. Optical sensors based on localized plasmon resonance can also take up the challenge of addressing the selectivity by monitoring the Surface Enhanced Raman spectrum down to few molecules. The operating conditions of these promising localized spectroscopies will be discussed in terms of reliability, compactness, data analysis and potential for mass deployment.

8725-88, Session 16

Comparison of thermal and laser sources in standoff IR detection experiments *(Invited Paper)*

Samuel P. Hernandez-Rivera, Leonardo C. Pacheco-Londoño, Univ. de Puerto Rico Mayagüez (United States); Iris Vazquez-Ayala, Naval Explosive Ordnance Disposal Technology Div. (United States); Carlos A. Ortega-Zúñiga, Nataly Y. Galán-Freyle, John R. Castro-Suarez, Univ. de Puerto Rico Mayagüez (United States)

Standoff infrared (SOIR) detection systems were evaluated in detection of threat chemicals and biological agents simulants. Chemometrics enhanced data analysis provided with robust methodologies for identification, quantification and discrimination highly energetic materials (HEM) and microorganisms using infrared spectroscopy. SOIR systems were evaluated in terms of their sources: modulated heated ceramics (Globar: SiC), non-modulated heated sources, and mid-IR laser sources; in terms of range; in terms of quantification capabilities at the maximum range attained; and in terms of the off normal incidence (back reflection/scattering, even at angles as large as 70. A laser induced thermal emission (LITE) standoff infrared system was also evaluated and compared with active sensing using the mentioned sources. Low limits of detection values were as low as ng/cm2. HEM used in this work were both nitroaromatic (DNT and TNT) and nitroaliphatic (PETN and RDX). Calibration curves were based on the use of robust chemometrics routines such as partial least squares (PLS) regression analysis. These algorithms were used to evaluate the angular dependence, range dependence, quantification of surface concentration of HEM deposited and the detection limits and statistical significance of analyses performed.

8725-89, Session 16

Data Analysis of Multi-Laser Standoff Spectral identification of chemical and biological compounds *(Invited Paper)*

Ali Passian, Rubye Farahi, Viktor Zaharov, Laurene Tetard, Oak Ridge National Lab. (United States); Thomas Thundat, Univ. of Alberta (Canada)

While obtaining compositional information for objects from a distance remains a major challenge in chemical and biological sensing, recently we demonstrated that capitalizing on mid-infrared excitation of target molecules by using quantum cascade lasers (QCLs) and invoking a pump–probe scheme can provide spectral fingerprints of substances from a variable standoff distance. By employing a variation of the photothermal process, we present the non-contact detection of the dominant thermal effects due to response to an infrared source that allows compositional analysis of the target sample via absorption spectroscopy. Pump–probe photothermal spectroscopy configurations which have demonstrated vibrational spectroscopy, such as mirage detection and photothermal deflection spectroscopy, where the pump and probe beams are transverse, are not scalable to measurements at longer distances. Near co-linear pump-probe spectroscopy configurations where the pump and probe beams are nearly parallel and are able to interrogate a target sample at distances have not previously employed vibrational spectroscopy. We have demonstrated QCL-based pump–probe vibrational spectroscopy that can be applied to standoff sensing without the use of elaborate infrared cameras, telescopes or detectors in acquiring a return signal, as is the case with current scattered radiation collection and thermal infrared imaging methods. For cases where the molecular species, the substrate on which they are found, or the superstrates in which they reside exhibit strong absorption in the spectral part of interest, the presented technique can provide an important circumvention to the often difficult collection of weak infrared emission.

8725-90, Session 16

Recent advances in quantum cascade lasers for standoff detection *(Invited Paper)*

Timothy O. Day, William B. Chapman, David B. Arnone, Allen Priest, David B. Caffey, Michael Pushkarsky, Alex Whitmore, Vivek Kamath, David Ruiz, Justin Kane, Christopher Armacost, Leigh J. Bromley, Daylight Solutions Inc. (United States)

For standoff detection of trace amounts of material, only laser-based techniques appear to offer the potential to provide sufficient detection sensitivity. Mid-infrared (mid-IR) laser spectroscopy presents a particularly promising approach, given the presence of strong molecular absorption features—and windows of atmospheric transparency—in the well known mid-IR spectral 'fingerprint' region. Further, the high brightness, power, and broad mid-infrared tuning ranges inherent to External Cavity quantum cascade lasers (ECqcLs™) make them ideally suited to the remote detection requirements for: safe standoff distance; high chemical sensitivity and specificity; and the ability to identify a range of threats unambiguously with one instrument. Commercial ECqcL systems, such as those pioneered by Daylight Solutions for commercial and military markets, have also demonstrated that these platforms can provide the ruggedness, compact size, efficiency and turn-key operation necessary for field-deployable standoff detection systems. This paper surveys several key recent results obtained with ECqcL systems by researchers in standoff detection. New ECqcL product developments by Daylight Solutions that bring new, unique performance capability to this field will also be reviewed.

8726-1, Session 1

Snapshot hyperspectral imaging systems for real-time applications *(Invited Paper)*

Robert T. Kester, Rebellion Photonics (United States)

Rebellion Photonics has developed innovative products based on its core innovation of "snapshot", i.e. non-scanning, hyperspectral imaging which is capable of collecting an entire datacube in a single moment in time. This has several advantages for applications where the scene or object is moving and changing in time. Some of these advantages include increase sensitivity, improved robustness, and the elimination of motion artifacts. Current products and their applications as well as systems under development will be discussed.

8726-2, Session 1

A full-spectrum VNIR and SWIR hyperspectral imager in a single instrument

Timo Hyvärinen, Kari J. Kataja, Risto Jaskari, Jukka T. Okkonen, Ilkka Kormano, Esko Herrala, Aappo A. J. Roos, Petri Nygren, Specim Spectral Imaging Ltd. (Finland)

The best full spectrum solutions currently integrate two separate push-broom hyperspectral cameras, VNIR and SWIR, in a platform where they are mechanically aligned to image the target with two parallel field of views (FOV). It results in a bulky construction which is prone to misalignment. The biggest issue with two separate FOVs is that pixel registration in the VNIR and SWIR image changes with varying distance to the target. It complicates image processing, particularly in near real-time applications, like detection of IEDs and camouflaged objects, environmental monitoring and mineral mapping on open mine wall and ore processing lines.

This paper presents the first commercial full spectrum push-broom imager that resolves all the above problems. It images the target in 380-2500 nm spectral region with 650 bands through single front optics and single input slit, keeping all wavebands spatially co-registered independently of the distance to the target. The imager employs an innovative imaging spectrometer which, behind the single input slit, consists of two diffraction gratings and focal plane arrays (FPA), separately optimized for highest sensitivity and SNR (1000:1) in both the VNIR and SWIR region. Spot size matches the FPA pixel size and smile and keystone remain smaller than 20% of the pixel size. The imager is independent of polarization and high image rate (up to 130 Hz) enables excellent spatial sampling resolution.

The imager is extremely compact, weighs 15 kg, is temperature stabilized and meets MIL-specification for vibration and shock. It fits to pan&tilt platforms, stabilized airborne turrets and UAVs.

8726-3, Session 1

High-performance hyperspectral imaging using virtual slit optics

Bradford B. Behr, Tornado Spectral Systems (United States); Jeffrey T. Meade, Arsen R. Hajian, Andrew T. Cenko, Tornado Spectral Systems (Canada)

The High Throughput Virtual Slit (or HTVS) is a new optical technology which can significantly increase the throughput and spectral resolution of a dispersive spectrometer. The HTVS is able to preserve spectrometer etendue, mitigating photon losses normally associated with a slit. Originally implemented in multimode fiber-input spectrometers, HTVS has now been shown to be broadly applicable to a wide variety of spatially scanning hyperspectral imagers and standoff sensors, enhancing their performance and unlocking new application areas. In essence, the anamorphic elements of the HTVS optical system provide a means to decouple the spatial (iFOV) and spectral resolution of nearly any HSI system. In some scenarios, HTVS can be used to achieve better spectral resolution with the same input slit width. Alternatively, the slit can be widened (to increase the collected signal) while maintaining the same spectral resolution. This newfound flexibility in optimizing critical performance parameters not only improves the performance of HSI systems in existing remote sensing contexts, but also opens up numerous new application areas which were previously inaccessible to hyperspectral techniques. This method adds substantial value to existing HSI designs, particularly in applications involving targets with large spatial extent and requiring high spectral resolution (e.g. standoff Raman spectroscopy). We present recent experimental results from our prototype HTVS pushbroom imager and discuss case studies of standoff Raman detection of hazardous materials, passive detection of faint narrowband and monochromatic sources, and optimal disentangling of target spectral signatures from the solar spectrum under daytime illumination.

8726-4, Session 1

Development of a handheld widefield hyperspectral imaging (HSI) sensor for standoff detection of explosive, chemical and narcotic residues

Matthew P. Nelson, Marko Horvat, Patrick J. Treado, ChemImage Corp. (United States)

The utility of Hyper Spectral Imaging (HSI) passive chemical detection employing widefield, standoff imaging continues to be advanced in detection applications. With a drive for reduced SWaP and increased speed of detection and sensitivity, developing a handheld platform that is robust and user-friendly increases the detection capabilities of the individual warfighter. In addition, easy to use handheld detectors could improve the effectiveness of locating and identifying threats while reducing risks to the individual.

ChemImage has developed a handheld sensor that uses HSI for real time, wide area surveillance and standoff detection of explosives, chemical threats, and narcotics. Employing liquid crystal tunable filter technology, the HSI system has an intuitive user interface that produces automated detections and real-time display of threats with a built in library of threat signatures that is easily updated allowing for new hazardous materials.

Unlike existing detection technologies that often require close proximity for sensing and so endanger operators and costly equipment, the handheld sensor allows the individual operator to detect threats from a safe distance. Uses of the sensor include locating production facilities of illegal drugs or IEDs by identification of materials on surfaces such as walls, floors, doors, deposits on production tools and residue on individuals. In addition, the sensor can be used for longer-range standoff applications such as hasty checkpoint or vehicle inspection of residue materials on surfaces or bulk material identification.

8726-6, Session 1

MEOMS-based Fabry Perot array for SWIR-MWIR imaging spectroscopy

Michele Hinnrichs, Pacific Advanced Technology, Inc. (United States); Neelam Gupta, U.S. Army Research Lab. (United States)

MOEMS based Fabry-Perot tunable infrared filter array uses electrostatic actuation for Etalon gap tuning. The Etalons are made up of fixed and

spring mounted movable mirrors which are metal plated and act as the electrodes in the electrostatic control system. The Fabry-Perot tunable array (FPTA) has 16 elements in a 4 x 4 configuration. When coupled to a 1024 x 1024 pixel element focal plane array give 256 x 256 pixel based resolution. Each Etalon in the FPTA is tuned to a different quiescent frequency between 1 and 4 microns thus allowing simultaneous spectral imaging each frame of the camera. Coupling the MOEMS based FPTA with a lenslet array and a fore-optic collimator will give simultaneous spectral imaging of the same target in the field of view. Then tuning the Etalon gap each frame will fill in the spectral bands between the quiescent wavelengths thus allowing hyperspectral imaging in less than 1 second over the SWIR and MWIR bands in a single sensor.

The concept design of the FPTA along with the fundamental processing techniques used to manufacture the MOEMS device will be presented. A conceptual system architecture will also be presented.

This work is being sponsored by an SBIR program with the US Army. It is anticipated that this technology can be used for both defense and commercial applications in the area of gas imaging and analysis, IED threat detection, chemical and biological warfare agent detection, medical and chemical imaging just to name a few.

8726-7, Session 2

Performance modeling of MEMS standing-wave Fourier transform microspectrometers

Dilusha K. Silva, John M. Dell, Lorenzo Faraone, The Univ. of Western Australia (Australia)

Due to the bulk and fragility of existing grating based and Fourier transform spectrometers, many efforts are under way in a search for a spectrometer technology that is miniature while maintaining many of the performance features of the bench-top systems. Of key interest are MEMS based technologies because of their potential low cost, vibration resistance, and ruggedness.

The MEMS standing wave spectrometer, originally demonstrated by Kung et al., in 2002 is one attempt in this search. This spectrometer operates on the principle of sampling a portion of the interferogram, and reconstructing the optical spectrum via transform techniques. The spectrometer consists of a partial MEMS movable mirror in opposing configuration with a static photodetector. Light is incident from the side of the photodetector, part of which passes through to the movable MEMS mirror. Light reflected from the movable mirror interferes with incident light at the photodetector. Moving the mirror position changes the optical path difference (OPD) and allows measurement of the interferogram within the OPD range allowed by the moving mirror.

We present here the development of a simple mathematical model, and the resulting simulations to illustrate the operation of this device, the expected spectral resolution, and spectral range. In particular, we demonstrate that the finite thickness of the photodetector places a limit on the ability of this system to accurately reconstruct the optical spectrum of a broad-band input signal. However, the system can measure the spectrum of a narrow-band optical signal with high accuracy.

8726-8, Session 2

Hydrocarbon gas detection with microelectromechanical Fabry-Perot interferometer

Rami Mannila, Mikko Tuohiniemi, Jussi H. Mäkynen, Ismo Näkki, Jarkko E. Antila, VTT Technical Research Ctr. of Finland (Finland)

VTT Technical Research Centre of Finland has developed microelectromechanical (MEMS) Fabry-Perot interferometer (FPI) for hydrocarbon measurements. Fabry-Perot interferometer is a structure where is two highly reflective surfaces separated by a tunable air gap. The MEMS FPI is a monolithic device, i.e. it is made entirely on one substrate in a batch process, without assembling separate pieces together. The gap is adjusted by moving the upper mirror with electrostatic force, so there are no actual moving parts.

Manufactured MEMS-FPIs will be characterized. According of the simulations the tuning wavelength range of the MEMS-FPI is 3.1-3.7 µm and its spectral resolution is 30-50nm. In this wavelength range hydrocarbon gases has a strong absorption. Each hydrocarbon gas has its own spectral signature, thus they can be detected and identified. The developed MEMS-FPI can be utilized for example in methane, propane or butane gas detection. The size of the MEMS-FPI chip is 3x3mm, therefore it is possible to design small size gas detection system based on this chip.

VTT will design and manufacture a handheld size demonstrator device during 2012 based on technique presented in this abstract. This device will demonstrate gas analyze by detecting cigarette lighter gas and also various plastic materials. The handheld size demonstrator will contain a light source, gas cell, MEMS-FPI, detector and also control electronics. It is connected to a laptop by USB connection.

8726-9, Session 2

First application close measurements applying the new hybrid integrated MEMS spectrometer

Heinrich Grüger, Tino Puegner, Jens Knobbe, Harald Schenk, Fraunhofer-Institut für Photonische Mikrosysteme (Germany)

NIR (780nm – 2500nm) spectroscopy is a very often used technique for both qualitative and quantitative material analyses. It provides access to molecular transitions of organic compounds. In combination with the typical penetration depth of several millimetres, NIR spectroscopy is very important for food quality sensing, environmental monitoring, medical analysis and many other applications.

Grating spectrometers have been designed in many different configurations. Today potential high volume applications ask for extremely miniaturized and ultra low cost systems. By the use of an integrated MEMS (micro electro mechanical systems) scanning grating device a less expensive single detector can be used in the NIR instead of array detectors required for fixed grating systems. Meanwhile the design of a hybrid integrated MEMS scanning grating spectrometer has been drawn. The MEMS device was fabricated in the Fraunhofer IPMS own clean room facility. This chip is mounted on a small circuit board together with the detector and than stacked with spacer and mirror substrate. The spectrometer has been realized by stacking several planar substrates by sophisticated mounting technologies. Finally the optical bench has an outline of 17mm x 12mm x 16mm. The spectrometer is working in the 950nm – 1900nm range with 9nm resolution.

First measurements have been performed on organic solutions and samples of thin plastic stripes. The performance of the new hybrid integrated spectrometer is compared with the established MEMS scanning grating spectrometer SGS 1900. Options for applications in different field will be discussed in detail.

8726-10, Session 3

Real time CRDS detection of explosives precursors using widely tunable QCLs

Charles C. Harb, The Univ. of New South Wales (Australia); Thomas G. Spence, Loyola Univ. New Orleans (United States); David S. Moore, Los Alamos National Lab. (United States)

We have developed a real-time Cavity Ringdown Spectroscopy system as a high-throughput screening tool for trace explosive detection. Our new approach has been implemented in the mid-infrared region of the electromagnetic spectrum, between 6.4 and 7.4 micrometers, where we can take advantage of chemically specific molecular vibrations to unambiguously identify explosives and explosive-related compounds in

terms of each compound's molecular fingerprint. Particular application of this spectroscopic technique is screening, perimeter protection and mitigation of threats from large vehicle-borne improvised explosive devices. We expect to develop this broadly applicable, highly sensitive, real-time chemical detection system for post-blast forensic analysis.

Our system has enabled us to make various general advances in cavity ringdown spectroscopy. In particular, we have successfully devised an efficient, and sensitive instrument for mid-IR CRDS that reach an MDAL of 4e-9cm^-1 Hz^-0.5 from a 1s scan and gathered 150000 data points from a widely tuneable pulsed QCL (between 6.4 and 7.4 micrometers), and used this instrument mid-IR CRDS instrument for molecular fingerprinting of explosives at trace level. For example, we were able to detect unambiguously the presence of TNT, nitromethane, acetonitrile, and acetone in real time. To date this type of molecular fingerprinting has not, to our knowledge, been achieved in any other instrument.

8726-11, Session 3

Tunable picosecond spectroscopy for detection of nitric oxide (NO)

Chakree Tanjaroon, Christopher J. Lue, Scott W. Reeve, Jeffrey B. Johnson, Susan D. Allen, Arkansas State Univ. (United States)

Nitric oxide (NO) is a major chemical byproduct of many photochemically active nitrogen-containing compounds. As a prototypical free radical with very well characterized high resolution spectrum, NO provides a standard spectroscopic fingerprint for indirect quantitative analysis and detection of a number of low vapor nitroaromatic compounds in air through either direct photochemical decomposition of a parent molecule or from its relatively high vapor pressure chemical constituents. In this paper, we will discuss application of picosecond laser spectroscopy for measurements and detection of NO and the nascent NO generated from photolysis. We will give a general overview of our tunable picosecond laser and detection system that we routinely use for probing and exciting the NO gamma band in the 200 - 300 nm wavelength range.

This broad wavelength tuning capability of our laser allows us to set up pump-probe type experiments for detecting blue-shifted rovibronic bands, transferring population via stimulated emission pumping, and probing the relative population distribution for NO.

In all cases, experiments were performed using laser pulses with a duration of less than 10 ps. As a result, our measurements could be complete before NO undergoes collisional relaxation.

8726-12, Session 3

Low-cost lightweight airborne laser-based sensors for pipeline leak detection and reporting

Michael B. Frish, Richard T. Wainner, Matthew C. Laderer, Mark G. Allen, Physical Sciences Inc. (United States); James Rutherford, Paul Wehnert, Heath Consultants Inc. (United States); Sean Dey, John Gilchrist, Ron Corbi, New Era Technology, Inc. (United States); Daniele Picciaia, TEA Sistemi S.p.A. (Italy); Paolo Andreussi, Univ. of Pisa (Italy); David L. Furry, Leak Surveys Inc. (United States)

Aircraft, especially helicopters, are routinely deployed to survey natural gas transmission pipelines. Traditionally, sensors onboard the aircraft sample the surrounding air to detect increased methane concentration indicating a pipeline leak. Such sampling requires the aircraft to fly through a gas plume, usually at low altitude, to detect the leak. Laser sensing technology enables remote or standoff detection: a laser beam directed from the aircraft to the ground below detects the amount of gas transited by the laser; only the laser beam, not the aircraft, need penetrate the gas plume. This paper describes adaptations of commercial laser-based methane sensing technology that provide relatively low-cost lightweight aerial leak detectors. The underlying technology is near-infrared Standoff Tunable Diode Laser Absorption Spectroscopy (sTDLAS). In one configuration, currently in commercial operation, sTDLAS is combined with automated data reduction, alerting, navigation, and video imagery, integrated into a single-engine single-pilot light fixed-wing aircraft or helicopter platform. At airspeeds of 200 km/h and altitudes of 150 – 400 m AGL, it detects plumes from natural gas leaks smaller than 20 m3/hr, corresponding to the flow through a sub-millimeter hole in a transmission pipeline pressurized at 5500 kPa. In a novel configuration, a miniaturized ultra-lightweight (1.4 kg) sTDLAS sensor flies pre-programmed routes at altitudes up to ~50 m aboard a small (3.2 kg) quad-rotor unmanned aerial vehicle. The sensor requires less than 1.5W and operates for several hours from a pair of AA-sized batteries. In open field controlled methane releases, this system has detected leaks as small as 1.0 m3/hr.

8726-13, Session 3

Trace-gas sensing using the compliance voltage of an external cavity quantum cascade laser

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Quantum cascade lasers (QCLs) are increasingly being used to detect, identify, and measure levels of trace gases in the air. External cavity QCLs (ECQCLs) provide a broadly-tunable infrared source to measure absorption spectra of chemicals and provide high detection sensitivity and identification confidence. Applications include detecting chemical warfare agents and toxic industrial chemicals, monitoring building air quality, measuring greenhouse gases for atmospheric research, monitoring and controlling industrial processes, analyzing chemicals in exhaled breath for medical diagnostics, and many more. Compact, portable trace gas sensors enable in-field operation in a wide range of platforms, including handheld units for use by first responders, fixed installations for monitoring air quality, and lightweight sensors for deployment in unmanned aerial vehicles (UAVs).

We present experimental demonstration of a new chemical sensing technique based on intracavity absorption in an external cavity quantum cascade laser (ECQCL). This new technique eliminates the need for an infrared photodetector and gas cell by detecting the intracavity absorption spectrum in the compliance voltage of the laser device itself. To demonstrate and characterize the technique, we measure infrared absorption spectra of chemicals including water vapor and Freon-134a. Sub-ppm detection limits in one second are achieved, with the potential for increased sensitivity after further optimization. The technique enables development of handheld, high-sensitivity, and high-accuracy trace gas sensors for in-field use.

8726-14, Session 3

Mid-infrared spectroscopic imaging with a quantum cascade laser

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Conventional mid-infrared (FT-IR) spectral imaging systems employ an incoherent glow bar source and gain spectral contrast through interferometry. While this approach is suitable for many general applications, recent advancements in broadly tunable external cavity Quantum Cascade Lasers (QCL) offer new approaches to and perhaps new possibilities in mid-IR micro-spectroscopic imaging as QCLs offer orders of magnitude greater intensity. While QCLs have yet to achieve the full mid-infrared range that FTIR instruments record, the full spectrum is not always necessary if only a few spectral bands are needed for sample diagnostics. Here, we present a QCL based infrared microscope and explore its utility in mid-infrared imaging. In our prototype instrument, spectral contrast by tuning the QCL to bands in our spectral region of

interest. Detection is achieved with dual liquid nitrogen cooled Mercury Cadmium Telluride (MCT) detectors. We demonstrate raster scanning using the single element MCT. We also demonstrate wide-field imaging employing a 128x128 pixel focal plane array (FPA), coupling to objectives of various magnifications for spatial resolutions as high as 1 micron per pixel, as well as mitigating the consequences of beam coherence on image quality where images with single wavenumber resolution are achievable in less than a second. We will discuss the effects of coherence on the image and compare our instrument to conventional mid-IR imaging instrumentation.

8726-15, Session 4

Performance characterization of a combined material identification and screening algorithm

Robert L. Green, Michael D. Hargreaves, Craig M. Gardner, Thermo Fisher Scientific Inc. (United States)

Portable analytical devices based on a gamut of technologies (Infrared, Raman, X-Ray Fluorescence, Mass Spectrometry, etc.) are now widely available. These tools have seen increasing adoption for field-based assessment by diverse users including military, emergency response, and law enforcement. Frequently, end-users of portable devices are non-scientists who rely on embedded software and the associated algorithms to convert collected data into actionable information. Two classes of problems commonly encountered in field applications are identification and screening. Identification algorithms are designed to scour a library of known materials and determine whether the unknown measurement is consistent with a stored response (or combination of stored responses). Such algorithms can be used to identify a material from many thousands of possible candidates. Screening algorithms evaluate whether at least a subset of features in an unknown measurement correspond to one or more specific substances of interest and are typically configured to detect from a small list potential target analytes. Thus, screening algorithms are much less broadly applicable than identification algorithms; however, they typically provide higher detection rates which makes them attractive for specific applications such as chemical warfare agent or narcotics detection. This paper will present an overview and performance characterization of a combined identification/screening algorithm that has recently been developed. It will be shown that the combined algorithm provides enhanced detection capability more typical of screening algorithms while maintaining a broad identification capability. Additionally, we will highlight how this approach can enable users to incorporate situational awareness during a response.

8726-16, Session 4

Progress in implementing spectroscopic recognition algorithms for standoff detection on solids using quantum cascade lasers in diffuse reflectance

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Short-range, non-destructive standoff detection of CWA/TICs and explosives on a variety of surfaces has been demonstrated for bulk and areal concentrations as low as 1-10 μg/cm< sup>2< /sup> using mid-infrared quantum cascade lasers (QCL) with specificity for each compound presented. The detection modality, absorption by diffuse infrared reflectance, is enabled by the high spectral radiance of the QCL. The QCL is also inherently compact and suitable for use in a handheld device.

The combination of portability, sensitivity and specificity is unique among the proposed technologies for use by the dismounted warfighter. The difference between demonstration of the technology capabilities and practice is taking the expertise of a spectroscopist and the software tools available and encapsulating that in an expert algorithm so that accurate detection can occur in real-time. The parameters that need to be encapsulated inside the instrument are: a degree of environmental awareness; knowledge of the compounds to be detected, and what kinds of surfaces those compounds can contaminate; how those compounds present themselves in diffuse reflectance at different levels of contamination from bulk to trace; and what optical effects occur for each compound and contamination level that affects the absorption spectrum. Clearly, the algorithms are complex. This paper will review the important effects, how they have been dealt with historically in a number of different fields, and indicate the level of success in encapsulating that knowledge in an algorithm in laboratory testing.

8726-17, Session 4

Discrimination methodologies using femtosecond LIBS and correlation techniques

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Laser induced breakdown spectroscopy (LIBS) is an attractive, versatile spectroscopic technique employed successfully for the detection of hazardous substances with encouraging attributes such as stand-off detection capability, trace detection, and high speed capability. Using ultrashort lasers, novel and sensitive systems for (LIBS) analysis could be developed. The specific advantages of using ultrashort pulses for efficient detection of explosives include lower ablation threshold, and reduced background Continuum emission. An amplified femtosecond (fs) pulse at 800 nm (1 kHz, ~40 fs FWHM, ~2.5 mJ) was used for the experiments. For detection of spectral emission a gated spectrometer (ANDOR, Mechelle spectrograph ME5000, coupled to an ANDOR iSTAR DH734 ICCD) with resolving power 5000 was used in our experiments. Most of the energetic materials are composed of hydrogen, carbon, oxygen, and nitrogen the task of discriminating one material from the other is complicated. In addition to atomic peaks in the plasma the molecular peaks (CN and C2) assay an important role in classifying these samples. Effort have been made to discriminate HEMs using statistical analytical techniques to classify the several chemical warfare samples like RDX, NTO, TNT, ANTA and DADNE. LIBS spectra were recorded from samples made in the form of pellets and also mixed in PMMA matrix. Correlation statistics were used to discriminate the samples. This paper will discuss in detail the simple correlation techniques applied for the LIBS spectra recorded with fs pulses.

8726-18, Session 5

Portable sub-terahertz resonance spectrometer combined with microfluidic sample cell

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Radiation in the Terahertz frequency range interacts with vibrations in the weakest molecular couplings such as hydrogen bonding, van der Waals forces, and hydrophobic interactions. The work presented here demonstrates our recently developed, portable, sub-Terahertz spectrometer integrated with a microfluidic device as the sample cell for presenting liquid samples within the detection region of the spectrometer. An improved design of the continuous-wave, frequency-domain spectrometer, operating at room temperature between 315 and 480 GHz with spectral resolution of 0.5 GHz, demonstrates highly intense and specific signatures from nano-gram samples of dry biological molecules and whole bacterial cells. The microfluidic device design utilizes a single channel or set of channels formed with metal sidewalls to enhance the interaction between the THz radiation and the sample, increasing the sensitivity of the system. Combined with near field effects, through use of a detection probe close to the surface of the sample cell, spatial resolution less than the diffraction limit can be achieved, reducing the amount of sample required for analysis. The work focuses on the design, fabrication methods, and implementation of the microfluidic sample cell device within our THz spectrometer. The very low absorption by water in this sample cell and a low disturbance from a water vapors in the near field sensor configuration, allow for the use of liquid samples and eliminate the need for purging of the detection system. The device is utilized for characterization of different cell types, showing that THz interrogation of liquid samples is possible and effective.

8726-19, Session 5

THz-Raman: accessing molecular structure with Raman spectroscopy for identification, analysis and monitoring

Randy A. Heyler, James T. Carriere, Frank Havermeyer, Ondax, Inc. (United States)

Spectroscopic measurement of rotational and vibrational modes is of increasing interest for many applications, since these spectra can reveal unique and important structural and behavioral information about a wide range of materials including hazardous chemicals, biological agents, radionuclides and explosives. However these modes correspond to very low frequency (10cm-1 - 100cm-1, or 300 GHz-3THz) emissions, which have been traditionally difficult and/or expensive to access through conventional Raman and Terahertz spectroscopy techniques.

Terahertz spectroscopy can directly measure these low energy modes by emitting radiation in the 300GHz to 3THz frequency range (10cm-1 to 100cm-1 region) and detecting the corresponding absorption spectrum, however source and detector availability and expense have limited the potential sensitivity, resolution, and/or economics of using this technique. Alternatively, traditional Raman systems employ edge or notch filters to block Rayleigh scattered light that remove most, if not all of these low frequency signals, as well as the entire anti-Stokes region.

We present results from a new approach for extending the range of Raman spectroscopy into the Terahertz regime using an ultra narrow-band volume holographic grating (VHG) based notch filter system. An integrated, compact Raman system is demonstrated utilizing a single stage spectrometer to show both Stokes and anti-Stokes measurements down to <10cm-1 on a wide variety of materials including but not limited to explosives, pharmaceuticals, and biological specimens. These all are shown to exhibit characteristically different low frequency peaks that can be exploited for chemical analysis, identification, monitoring, forensics, and contamination.

8726-20, Session 5

Design and industrial testing of ultrafast multi-gas Raman spectrometer

Michael P. Buric, Steven D. Woodruff, Benjamin Chorpening, Jessica C. Mullen, National Energy Technology Lab. (United States)

We previously reported the use of hollow metal and dielectric lined waveguides as gas cells used in real-time gas-Raman spectroscopy. Our team has constructed a multi-gas Raman sensor system capable of measuring molecular components in most gas mixtures with sub-percent accuracy and a sub-second sampling rate. This combination of speed and accuracy is enabled by the novel combination of optimized sample-cell collection and appropriate gas-stream configuration. We believe that this system will produce a paradigm shift in the use of Raman spectroscopy by eliminating issues with low-density samples or weak gas Raman cross-sections. Current research seeks improvements in hollow waveguide fabrication for use with harsh gas streams containing sulphur compounds or laden with steam and oil. Material systems for waveguide linings including gold, silver, silver iodide, and cyclic olefin polymer will be discussed with respect to those contaminants. Instrument sensitivity improvements are demonstrated using techniques like polarization control and optical component noise minimization. Sample stream cleanup and delivery are also optimized to provide gas samples without removing measurable steam and heavy hydrocarbon constituents. Such improvements are aimed at the energy, natural gas, chemical, and pharmaceutical manufacturing markets. Auxiliary system components such as the on-board laser, miniature spectrometer, coupling optics, and support electronics are optimized for use with the hollow-waveguide sample cell. Together, these techniques permit the feed-forward control of industrial processes through a-priori determination of the composition of gaseous reactants, fuels, or products. Recent real-world industrial field trials and laboratory experiments report considerable advantages over most existing gas-analysis methods.

8726-21, Session 5

High-throughput spectrometer designs in a compact form-factor: principles and applications

Scott M. Norton, Wasatch Photonics, Inc. (United States)

Many compact, portable Raman spectrometers have entered the market in the past few years with applications in narcotics and hazardous material identification, as well as verification applications in pharmaceuticals and TSA screening. Often, the required compact form-factor has forced designers to sacrifice throughput and sensitivity for portability and low-cost. There is a misconception that transmissive designs using high-efficiency VPH gratings require large footprints and thus most designers have chosen the compact Czerny-Turner design using reflective optics to achieve their required compact packaging. In this presentation we will describe the VPH-based design and detail how it can lead to superior f/# designs over the Czerny Turner design. We will outline advantages and disadvantages of each. An in-depth look at throughput, f/# and the influence of front-end optics and S/N in spectroscopy will highlight the discussion Limit of detection experiments will be used to illustrate the sensitivity offered by a VPH-based spectrometer system and it will be shown that enhanced sensitivity can lead to new applications.

8726-22, Session 5

Spectral analysis of improvised explosives

Amy J. R. Bauer, Applied Research Associates, Inc. (United States); Andrzej W. Miziolek, U.S. Army Research, Development and Engineering Command (United States)

The analysis of suspected Improvised Explosives (IEs) and their ingredients is challenging, especially in the field, due to the fact that the broad IE umbrella contains a wide variety of chemistry including nitro/nitrate/nitrite, metals (e.g. Al, Mg), chlorates/perchlorates or, peroxide. They have also been observed to include food products such as cumin, sugar, flour, and other powders. The wide variety of possible chemistry poses a major challenge for current field analytical tools which largely tend to focus on specific subgroups such as nitro/nitrite/nitrate, metals, and peroxides. A better detector would be a more universal one where a single device could be used to identify many more types of unknown materials. Unfortunately, such a universal sensor does not yet exist. Laser Induced Breakdown Spectroscopy (LIBS) has potential toward the solution of this problem in that it provides the elemental inventory of the unknown material, regardless of the form of the material (e.g. solid, residue, liquid, aerosol, vapor). With the recent progress in using advanced chemometrics, there is a growing body of literature that demonstrates very good performance with regards to unknown identification/classification, usually with >95% True Positive and <5% False Positives. Additionally new commercial LIBS devices are now available that are suitable for field use (battery operated). This presentation will discuss recent results in evaluating the potential of LIBS for the correct identification/classification of various IE materials and precursor ingredients.

8726-23, Session 5

A novel laser-based approach for cleaning contaminated metallic surfaces coupled with rapid residue analysis

Robert V. Fox, Idaho National Lab. (United States); Frank C. De Lucia Jr., U.S. Army Research Lab. (United States); Andrzej W. Miziolek, U.S. Army Research, Development and Engineering Command (United States); Andrew I. Whitehouse, Applied Photonics, Ltd. (United Kingdom); Lauren Roberts, Idaho National Lab. (United States)

We are developing a novel approach for cleaning and confirming contaminated metallic surfaces that is based on laser ablation to clean the surfaces followed closely in time and space by laser analysis of the degree of cleanliness. Laser based surface cleaning is a well-established technology and is commercially available (e.g. Adapt Laser). The new development involves the integration of a LIBS (Laser Induced Breakdown Spectroscopy) surface analytical capability to analyze the surface right after the cleaning step for presence or absence of unwanted residues. This all-laser approach is being applied to stainless steel vessels which are being used for the destruction of chemical munitions using explosives. This destruction results in the creation of contaminated and corroded surfaces that need to be cleaned down to the acceptable levels. The initial focus is on chemical munitions that involve Arsenic where LIBS has been demonstrated to analyze surfaces at below 1 microgram per square centimeter surface loading levels. Recent progress and future directions will be presented.

8726-25, Session 5

Frequency-agile, rapid scanning spectroscopy

David A. Long, National Institute of Standards and Technology (United States); Gar-Wing Truong, National Institute of Standards and Technology (United States) and the Univ. of Western Australia (Australia); Kevin O. Douglass, Stephen Edward Maxwell, Roger D. van Zee, Joseph T. Hodges, National Institute of Standards and Technology (United States)

We present frequency-agile, rapid scanning (FARS) spectroscopy, a novel, high bandwidth technique in which laser radiation is stepped between successive optical frequencies. FARS removes the need for slow thermal or mechanical wavelength tuning and allows for fast and accurate measurements of trace gas analytes. We have recently combined FARS with cavity ring-down spectroscopy to produce an ultrasensitive spectrometer capable of recording entire absorption spectra at rates up to 100 Hz with sensitivity of 2x10-11 cm-1 Hz-1/2 and an absolute frequency accuracy of 10 kHz (3x10-7 cm-1). This rate is orders of magnitude faster than traditional cavity ring-down spectrometers and does not rely upon sweeping the laser frequency or cavity length which would significantly reduce the measurement duty cycle. We present initial measurements of trace atmospheric gases and discuss avenues for the use of the technique in low-cost sensors.

8726-26, Session 5

The evaluation of a new technology for gunshot residue (GSR) analysis in the field

Danielle M. Andersen, Ellen Hondrogiannis, Towson Univ. (United States); Andrzej W. Miziolek, U.S. Army Research, Development and Engineering Command (United States)

There continues to be a need for improved technology to be used in theater to quickly and accurately identify the person who shot any weapon during a terrorist attack as well as to link a suspect to the actual weapon fired during a crime. Beyond this, in areas of conflict it would be desirable to have the capability to establish the source country for weaponry and ammunition. Gunshot residue (GSR) analysis is a reasonably well-studied technology area. Recent scientific publications have reported that the residues have a rich composition of both organic and inorganic compounds. For the purposes of identifying the manufacturer or country of origin for the ammunition, the inorganic components of GSR appear to be especially promising since their presence in the propellant and primer formulations are either specific to a given chemical formula, or they represent impurities in the manufacturing process that can be unique to a manufacturer or the source country for the chemicals used for propellants and primers. The Laser Induced Breakdown Spectroscopy (LIBS) technology has already demonstrated considerable capability for elemental fingerprinting, especially for inorganic/metallic components. A number of reports have demonstrated LIBS capability in forensics for matching materials such as inks, fabrics, paper, glass, and paint. This presentation will describe the results of a study to assess a new commercial field-portable (battery operated) LIBS system for GSR analysis.

8726-27, Session 5

Spectroscopy methods for identifying the country of origin

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There is a need in many industries and government functions to identify the source of origin for various materials. For example, the food industry needs to ensure that the claimed source of some of the food products (e.g. coffee, spices) are in fact legitimate due to the variation of quality from different source locations world-wide. Another example is to identify the source country for imported commodities going through Customs so as to assess the correct tariff which varies depending on the source country. Laser Induced Breakdown Spectroscopy (LIBS) holds promise for being a field-portable tool for rapid identification of the country of origin of various materials. Recent research at Towson University has identified the elemental markers needed for discrimination of select spices back to their country of origin using Wavelength Dispersive X-Ray Fluorescence (WDXRF). The WDXRF device, however, is not particularly suitable for convenient and fast field analysis. We are extending this study to evaluate the potential of a new commercial field LIBS device (battery operated) and to compare its performance with WDXRF. The presentation will provide the results of this study and the comparison.

8726-28, Session 6

Handheld spectrometers: the state of the art

Richard A. Crocombe, Thermo Fisher Scientific Inc. (United States)

“Small” spectrometers fall into three broad classes: small versions of laboratory instruments, providing data, subsequently processed on a PC; dedicated analyzers, providing actionable information to an individual operator; and process analyzers, providing quantitative or semi-

quantitative information to a process controller. The emphasis of this paper is on handheld dedicated analyzers.

Increasingly, the lab is moving to the field. Many spectrometers have historically been large, possible fragile, expensive and complicated to use. The challenge over the last dozen years has been to make spectrometers smaller, affordable, rugged, easy-to-use, but most of all capable of delivering actionable results. Actionable results can dramatically improve the efficiency of a testing process and transform the way business is done.

There are several keys to this handheld spectrometer revolution. Consumer electronics has given us powerful mobile platforms, compact batteries, clearly visible displays, new user interfaces, etc., while telecomm has revolutionized miniature optics, sources and detectors. While these technologies enable miniature spectrometers themselves, actionable information has demanded the development of rugged algorithms for material confirmation, unknown identification, mixture analysis and detection of suspicious materials in unknown matrices. These algorithms are far more sophisticated than the 'correlation' or 'dot-product' methods commonly used in benchtop instruments.

Finally, continuing consumer electronics advances now enable many more technologies to be incorporated into handheld spectrometers, including Bluetooth, wireless , GPS, cameras and bar code readers, and the continued size shrinkage of spectrometer 'engines' leads to the prospect of dual technology or 'hyphenated' handheld instruments.

This talk will describe the applications and the technologies (hardware and software) in handheld analyzers, and prospects for the future.

8726-29, Session 6

A microfabricated, low dark current a-Se detector for measurement of microplasma optical emission in the UV for possible use on-site

Shiva Abbaszadeh, Karim S. Karim, Vassili Karanassios, Univ. of Waterloo (Canada)

In classical chemical analysis, samples are collected in the field (e.g., on-site) and are shipped to a laboratory for chemical analysis. In the last few years, an attractive alternative began to emerge in the form of miniaturized, portable instruments that can be used for chemical analysis on-site (i.e., in the field).

For measurements by optical emission spectrometry in the UV region, we recently reported use of a portable, fiber-optic spectrometer. The spectrometer utilizes a linear, un-cooled CCD-detector. To take full advantage of the capabilities of CCDs (and in order to obtain improved chemical analysis performance for use on-site), cooling of the CCD and thermal management are required. But cooling and thermal management hinder portability because they add weight and burden the power budget. Based on these considerations, an alternative was sought and utilized.

In this presentation, a miniaturized detector for UV detection that does not require cooling (due to its low dark current) will be described in detail. Unlike crystalline Silicon CCD-detectors, this low-cost detector utilizes amorphous Selenium [1] . Spectra acquired using a microplasma will be compared and contrasted with those obtained with a portable, fiber-optic, CCD-based spectrometer.

1. S. Abbaszadeh, K. S. Karim and V. Karanassios, Measurement of UV from a microplasma by a microfabricated amorphous selenium detector, IEEE Transactions on Electron Devices (submitted)

8726-30, Session 6

A handheld FTIR spectrometer with swappable modules for chemical vapor identification and surface swab analysis

Walter J. Doherty III, Brendan Falvey, Greg Vander Rhodes, Leonid Krasnobaev, Kenneth Vachon, Thermo Fisher Scientific Inc. (United States)

ThermoFisher Scientific (formerly Ahura Scientific) has developed a handheld, modular detection and identification system for trace-level gases, chemical vapors and aerosols, and swab analyses. The system main housing contains a single, miniature FTIR spectrometer, batteries, and the user interface keypad and screen. The sample chamber is contained in a separate, removable module that clamps to the main housing. The modules are interchangeable and can be tailored specifically to the users' needs. A vapor/aerosol module pulls ambient air into a four-meter pathlength White cell. This single module can operate in three modes: ambient sampling, vapor/aerosol preconcentration, and direct injection. A swab module can be used to analyze thermally desorbed vapors from a sample swab, allowing analyses of bulk liquids or solids or trace chemicals swabbed from surfaces. Limits of identification for vapors are approximately 20 ppm ambient or as low as 0.1 ppm following a 15-min preconcentration period. The swab module is able to detect as little as 5 ug of TNT in the presence of various interferents.

8726-31, Session 6

Advanced sampling techniques for hand-held FT-IR instrumentation

Josep Arnó, Michael Frunzi, Chris Weber, Dustin Levy, Smiths Detection (United States)

FT-IR spectroscopy is the technology of choice to identify solid and liquid phase unknown samples. The challenging ConOps in emergency response and military field applications require a significant redesign of the stationary FT-IR bench-top instruments typically used in laboratories. Specifically, field portable units require high levels of resistance against mechanical shock and chemical attack, easy of use in restrictive gear, quick and easy interpretation of results, and reduced size. In the last 20 years, FT-IR instruments have been re-engineered to fit in small suitcases for field portable use and recently further miniaturized for handheld operation. This article introduces a FT-IR instrument designed to balance the portability advantages of a handheld device with the performance challenges associated with miniaturization. Special focus will be given to the different alternatives to collect and interrogate samples using the on-board ATR press. Specifically, the application of a novel sample swipe accessory to collect material from surfaces will be discussed. The accessory was tested and evaluated for the detection of explosive residues before and after detonation. Experimental results derived from these investigations will be described in an effort to outline the advantages of this technology over existing sampling methods.

8726-32, Session 6

Tapered air-core Bragg waveguide spectrometers for lab-on-a-chip applications

Brian Drobot, Aaron Melnyk, Trevor Allen, Ray G. DeCorby, Univ. of Alberta (Canada)

Lab-on-a-chip and optofluidic micro-systems often rely on bulky off-chip optical components such as lenses and spectrometers for detection. There is a growing demand for compact microspectrometers that can be integrated on-chip, to increase portability and potentially reduce the cost and complexity of these systems. Portability is especially important in applications such as point-of-care diagnostics and field-deployable threat detectors.

We have previously reported chip-scale microspectrometers based on tapered air-core Bragg waveguides with omnidirectional Bragg claddings. Position-dependent cut-off results in spatial dispersion of a polychromatic signal. By tailoring the Bragg cladding materials, we have fabricated prototype devices operating in both the near-infrared and the visible ranges, exhibiting operational bandwidths of several hundred nanometers and resolution on the order of 1 nm. Here, we describe the integration of these air-core waveguide spectrometers with PDMS-based microfluidics, including results for a prototype sensing system based on spectrally-resolved fluorescence detection. We will also describe preliminary work aimed at applying these techniques to on-chip surface-enhanced Raman spectroscopy.

8726-33, Session 7

Feasibility study of birefringent electro-optic NIR FTS imaging systems

Valerie A. Finnemeyer, Philip J. Bos, Liquid Crystal Institute, KSU (United States)

Fourier-transform imaging systems can rapidly provide a great deal of information in a scene. Many applications require systems with no moving parts. One proposed approach uses birefringent crystal stages interspersed with liquid crystal cells acting as achromatic polarization rotators. Previous research has revealed that this system may have limited applicability because of severe limitations of the field-of-view for systems with large OPD. We provide a more in-depth analysis of these limitations using mostly Extended Jones Matrix simulations. We also propose a design modifications which greatly improves FOV, allowing higher resolutions to be achieved.

8726-34, Session 7

Continuous-wave near-photon counting spectral imaging detector in the mid-infrared by upconversion

Jeppe S. Dam, Peter Tidemand-Lichtenberg, Christian Pedersen, Technical Univ. of Denmark (Denmark)

Imaging and detection of light at infrared wavelengths are of great technical and scientific interest due to many important applications, e.g. within thermal imaging and spectroscopy. Low light level detection in the mid-infrared is challenging, and typically requires cryogenic cooling to reach low noise levels. Although significant advances have been made within the electronics and detector materials, fundamental noise issues are considered unavoidable for efficient detection at longer wavelengths. However, we demonstrate a different, fundamentally noise free principle where mid-infrared light, containing image and/or spectral information, are converted to near visible wavelengths with high quantum efficiency. After conversion the radiation can be detected by any near visible light detector, thus effectively extending its working range of e.g. Si-based detectors to the mid-infrared. The method is based on upconversion in a non-linear crystal by mixing with a strong laser field. Since the crystal is transparent there is virtually no dark noise in the system - even when working at room temperature. The dark noise has been measured to be less than 0.2 photons per spatial element per second. The conversion principle is generic, and can be applied over a huge dynamic range from single photons to milliwatts of power. The generic principle presented, even allows for further build-in functionality, e.g. multi- and hyperspectral imaging, allowing for identification of substances with a specific spectral fingerprint. Furthermore, the mixing process allows for high temporal resolution and high image frame rate, in principle limited only by available Si-technology.

8726-35, Session 7

Remote bi-photon spectroscopy using a single-photon up-conversion detector

Oliver T. Slattery, National Institute of Standards and Technology (United States) and Univ. of Limerick (Ireland); Paulina Kuo, Young-Su Kim, Lijun Ma, Xiao Tang, National Institute of Standards and Technology (United States)

Correlated bi-photon spectroscopy is the technique used to measure the spectrum of an object by monitoring the coincidence counts from correlated signal and idler photon pairs generated by spontaneous parametric down-conversion (SPDC). We describe a scheme using a strongly non-degenerate SPDC source and a tunable up-conversion detector. The spectral function at one wavelength range of a remote object can be reproduced exactly by locally measuring another wavelength range using a tunable single-photon sensitive up-conversion detector and monitoring the coincidence counts. The up-conversion detector operates in the difficult to detect infrared range and thus extends remote spectroscopy into the infrared. The spectral resolution of the system is better than 0.1-nm corresponding to the acceptance width of the up-conversion detector while the measurement range is determined by the spectral bandwidth of the source.

Applications include remote spectroscopy since only a spectrally non-resolving intensity detector, rather than a spectrometer, is needed for photons interacting with the object. The spectral measurements can be achieved by spectrally resolving the correlated photon beam locally. This technique may also provide a solution where security or privacy is required but difficult to achieve at the object site since neither the spectrally non-resolved signal, having interacted with the object, nor the spectrally resolved idler, having no interaction with the object, contain any spectral information individually – both are required to complete the spectral profile. And since the spectrum is generated on the basis of coincidence measurements, rather than intensity, a significantly improved signal-to-noise ratio can be achieved.

8726-36, Session 7

Fourier transform infrared phase-shift cavity ring-down spectrometer

Elizabeth C. Schundler, David J. Mansur, Robert Vaillancourt, Ryan Benedict-Gill, Scott P. Newbry, James R Engel, Julia R Dupuis, OPTRA, Inc. (United States)

We report on our current status towards the development of a prototype Fourier transform infrared phase shift cavity ring down spectrometer (FTIR-PS-CRDS) system under a U.S. EPA SBIR contract. Our system uses the inherent wavelength-dependent modulation imposed by the FTIR on a broadband thermal source for the phase shift measurement. This spectrally-dependent phase shift is proportional to the spectrally-dependent ring down time, which is proportional to the losses of the cavity including those due to molecular absorption. Our approach is a broadband and spectral range enhancement to conventional CRDS which is typically done in the near IR at a single wavelength; at the same time our approach is a sensitivity enhancement to traditional FTIR owing to the long effective path of the resonant cavity. In this paper we present a summary of the theory including performance projections and the design details of the prototype FTIR-PS-CRDS system.

8726-37, Session PTues

Broadband absorption and emission millimeter-wave spectroscopy between 220 and 325 GHz

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A millimeter-wave spectroscope for the detection of triatomic gases has been constructed and characterized for frequencies between 230 GHz and 325 GHz (H-band).The spectrometer achieved results as well as high sensitivity and low threshold detection. A circular lensed horn antenna transmits millimeter- waves into a gas-filled vacuum tube and excites three atomic gas molecules to a higher energy level, if the rotational resonance frequency of the molecule matches with the excitation frequency. At the other end of the tube a second lensed horn antenna receives the propagated electromagnetic wave and the millimeter-wave power is measured by a heterodyne receiver. By sweeping the radiated transmit frequency, the molecule specific absorption can be detected. The measured absorption results are superposed by standing wave effects within the tube.

To eliminate the standing wave effects, spectroscopy on the basis of rotational spontaneous millimeter-wave emission were examined. This kind of spectroscopy decouples the transmitted from the received signal, whereby independent excitation and detection of the molecules are realized. The use of additional absorbers at the end of the gas tube decreases the decay-time of the radiated wave inside the gas cell.

In this paper, the detection of spontaneous emission of three atomic gas molecules with the use of a pulse controlled transmitter and receiver is shown. Optimizations improved the stability and reproducibility of the measurements and the detections threshold of nitrous oxide could be decreased to a ratio of 1/400. Furthermore, the implementation of a differential measurement method reduces the measurement time by factor 150 and simultaneously decouples of environmental influences.

8726-38, Session PTues

Probing vibrational absorption of ultra-thin samples by plasmonic-enhanced infrared photoexpansion nano-spectroscopy

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Mid-IR photoexpansion nano-spectroscopy measures spectra of samples on nanoscale by detecting local thermal expansion associated with light absorption using standard AFM. Cantilever deflection is directly proportional to sample absorption. This method results in a simple experimental setup with no optical detectors. We have recently demonstrated that the sensitivity of photoexpansion nano-spectroscopy can be dramatically enhanced by moving the laser pulses repetition frequency in resonance with the mechanical frequency of the AFM cantilever. We were able to produce spectra from ~100 nm thin films using low energy (4 nJ) pulses from a tunable quantum cascade laser (QCL). The spatial resolution, which is determined by thermal diffusion length, has been demonstrated to be better than 50 nm. Sample heating is limited to ~10 mK.

Here we present a novel approach to increase both the sensitivity and spatial resolution of photoexpansion nano-spectroscopy. We utilize the plasmonic local-intensity enhancement below a gold-coated AFM tip. We successfully produced high-quality vibrational absorption spectra from samples as thin as 10 nm positioned on top of gold-coated silicon substrates. In addition to higher photoexpansion signal, our technique features higher spatial resolution, which is no longer limited by thermal diffusion length but is instead determined by the dimensions of the high-intensity field region below the metal tip, which can be 10 nm or smaller.
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8727-1, Session 1

Hyperentanglement and related technologies for quantum telecommunications *(Invited Paper)*

Nicholas A. Peters, Anjali Agarwal, Applied Communication Sciences (United States); Thomas E. Chapuran, Telcordia Technologies, Inc. (United States); Paul Toliver, Applied Communication Sciences (United States)

We demonstrate the first measurement of hyperentangled photon pairs, both of which are at telecom wavelengths, via simultaneous polarization tomography and time-bin interference measurements. Without cryogenic cooling of the nonlinear element, we measure polarization entanglement with tangle of 0.4 ± 0.2 and time bin entanglement with visibility of 83% ± 6%, both exceeding classical thresholds by approximately two standard deviations.

8727-3, Session 1

Towards spatially dense time-domain multi-view detection in diffuse optical tomography with single-photon avalanche diodes and integrated TCSPC electronics *(Invited Paper)*

Yves Bérubé-Lauzière, Univ. de Sherbrooke (Canada); Matteo C. Crotti, Ivan Rech, Politecnico di Milano (Italy)

The advent of high timing resolution (<50ps) single photon avalanche diodes (SPADs) and progresses in time-correlated single photon counting (TCSPC) integrated electronics opens the way to multi-view higher spatial detection density time-domain (TD) diffuse optical tomography (DOT) scanners with unprecedented temporal resolution down to possibly below 30ps. The alternative to achieve high spatial density TD optical detection is to resort to time-gated cameras. However, such cameras have timing resolutions of ~300ps, and the time gate over which photons are acquired needs to be scanned resulting in a waste of useful photons and increased acquisition times compared to what could possibly be achieved. In recent years my group has been developing a TD DOT scanner for small animal imaging using discrete detectors and high performance TCSPC electronics. A first generation scanner using photomultiplier tubes (PMTs) has been realized, achieving a temporal resolution of ~200 ps. This scanner comprises 7 dual-wavelength channels for detecting excitation and fluorescence light. Its performances in terms of number of channels, acquisition time, and temporal resolution are, however, limited by the use of PMTs, expensive TCSPC cards and routers. Recently, work has been initiated on the development of a second generation scanner using SPADs and fully parallel TCSPC electronics (one TCSPC channel per detector). The development of the first generation scanner and a first prototype of the second generation scanner will be presented, along with results obtained therewith. Future work and promising applications of such technology, notably in in vivo FLIM-FRET imaging will also be described.

8727-4, Session 2

Ladar detection methods and an update on photon-counting detector arrays *(Invited Paper)*

Richard M. Marino, MIT Lincoln Lab. (United States)

The size, weight, and electrical power requirements (SWaP) for laser-based remote sensing systems, such as lidar or laser radar (ladar), are often critical constraints in sensor system architecture design considerations and tradeoffs. Additional requirements that affect system design often include ranges of operations, thermal management and operating environments, data acquisition times, and data processing and data product latencies. The choice of ladar detection method and associated detection statistics will directly affect the performance of the sensor system and man be a critical driver in the design space that can satisfy mission and system requirements. For example, ladar systems that use optical receivers that can minimize the effects of noise and unwanted clutter while efficiently extracting information from the detection of minimal optical signal (i.e. single photons) can have superior performance to those with more conventional receivers. Recent advances in photon-counting detector array technologies have enabled development and instantiation of ladar sensor systems that demonstrate unprecedented high-performance and capabilities.

In this talk, a variety of ladar detection methods are compared, and an outline is provided of recent and ongoing advances in photon-counting detector arrays.

8727-5, Session 2

Laser ranging at few-photon level with a photon-number-resolving detector *(Invited Paper)*

Guang Wu, Zhiyuang Wang, Weibin Kong, Min Ren, Yan A. Liang, Xiaomeng Wang, Jianhua Huang, E. Wu, Heping Zeng, East China Normal Univ. (China)

We demonstrated a system for laser ranging and remote reflection coefficient discrimination at few-photon level with a multi-pixel photon counter (MPPC) at 532 nm. Thanks to the photon-number-resolving capability of the detector, the laser ranging system could distinguish the reflected photon pulses from a non-cooperation target successfully in high-illumination sunlight environment by increasing the discrimination threshold to multi-photon level to reduce the error counts. Moreover, two remote targets with different reflection coefficient could be fast figured out through comparing the number of detected photons. Compared with the technique of conventional single-photon detection, this system could make full use of the capability of photon number to obtain the distance information as well as the reflection coefficient difference, which may lead to a breakthrough in remote sensing.

Furthermore, an eye-safe 3D laser imaging system was achieved, working at 1550 nm with an InGaAs/InP-APD single-photon detector operated in 1.5-GHz sinusoidally gated Geiger mode. In the system, the focal-plate array consisting of 100-fiber bundles was employed to guide the photons from the telescope to a single-photon detector. As the timing jitter of the system was about 300 ps when the laser pulse source and the single-photon detector was free running without synchronization, the depth resolution was measured to be about 3 cm. Since the high speed single-photon detector applied in the system, the laser imaging system with low-energy level for long-distance measurement outdoor may be promoted.

8727-6, Session 2

Laser depth ranging and imaging using low-jitter SNSPD system

Lixing You, Sijin Chen, Dengduan Liu, Shanghai Institute of Microsystem and Information Technology (China); Yuhao He, SIMIT, CAS (China); Wenxing Zhang, Shanghai Institute of Microsystem and Information Technology (China)

Superconducting nanowire single photon detection (SNSND) technology is a promising technology due to its high quantum efficiency, low dark count rate, low timing jitter, high repetition rates and broad spectrum response ability. SNSPD has been demonstrated to be a good candidate for quantum information, single photon source characterization, time of flight mass spectroscopy as well as time of flight depth ranging.

Using the SNSPD made of NbN ultrathin film with a typical meander structure, we developed a SNSPD system based on G-M cryo-cooler for 1550 nm wavelength, which is feasible for unmanned long-term operation. By extensively analyzing the origin of the timing jitter and system optimization, the system timing jitter was successfully suppressed to be lower than 35 ps. Using time of flight approach based on time-correlated single photon counting (TCSPC) method, we demonstrated the laser depth ranging experiment at the stand-off distance of 100 m. The surface to surface depth resolution of 5 mm is achieved directly, which is the best result reported at the wavelength of 1550 nm to our knowledge. The result shows potential applications of SNSPD in improving the performance of light detection and ranging (LIDAR) systems. The preliminary results of imaging experiments will also be shown and discussed.

8727-7, Session 3

Advanced time-correlated single-photon counting applications with superconducting nanowire single-photon detectors *(Invited Paper)*

Robert H. Hadfield, Heriot-Watt Univ. (United Kingdom)

Single-photon detectors are a key enabling technology for a host of applications at the frontiers of science, from imaging and ranging to quantum information processing. These advanced photon counting applications place exacting demands on detector performance, spurring the development of new detector technologies. A new class of single-photon detector, based on a superconducting nanowire, holds particular promise for time-correlated single-photon counting at infrared wavelengths. These detectors offer wide spectral sensitivity (visible to mid-infrared) combined with low dark counts, short recovery times and exquisite timing resolution. These low temperature detectors can now be integrated into practical cryogen-free refrigerator systems. I will discuss how these high performance detectors have been demonstrated in a range of important new applications including quantum key distribution, time-of-flight depth imaging, fibre temperature sensing and singlet oxygen luminescence detection.

References

1. CM Natarajan, MG Tanner, RH Hadfield ‘Superconducting nanowire single photon detectors: physics and applications’ Superconductor Science and Technology 25 063001 (2012)

8727-8, Session 3

Technologies for superconducting nanowire single-photon detector array system *(Invited Paper)*

Shigehito Miki, Taro Yamashita, Hirotaka Terai, Kazumasa Makise, Zhen Wang, National Institute of Information and Communications Technology (Japan)

We present the development of key technologies for realization of superconducting nanowire single photon detector array system, which enables high counting rates, and allow spatial and pseudo photon number resolution. Toward the realization of practical large-scale SSPD array system, primary issue is how to avoid heat flow into cryocooler system. One of the challenging tasks is the development of their readout electronics. In the conventional readout technique used for single pixel devices, the number of high-frequency coaxial cables increases proportionally with the number of arrays. This causes a significant increase in the heat load from room temperature, which makes the implementation of the SSPD arrays in a compact refrigerator difficult. To overcome this problem, we proposed applying readout electronics with superconducting single-flux-quantum (SFQ) logic circuits. Another challenge is the bias current feeding to each pixel of the SSPD array. If the bias current is introduced to each pixel individually, the large number of required cables for bias feeding is necessary. To solve this problem, we proposed the parallel bias scheme with a single introduced cable. We show the implementation and successful operation of four pixels SSPD array connected to SFQ readout electronics with parallel bias scheme in a 0.1W GM cryocooler system.

8727-9, Session 3

Membrane-integrated superconducting nanowire single-photon detectors *(Invited Paper)*

Faraz Najafi, Massachusetts Institute of Technology (United States); Jacob Mower, Xiaolong Hu, Francesco Bellei, Prashanta Kharel, Columbia Univ. (United States); Hasan Korre, Adam McCaughan, Kristen Sunter, Massachusetts Institute of Technology (United States); Dirk R. Englund, Columbia Univ. (United States) and Massachusetts Institute of Technology (United States); Karl K. Berggren, Massachusetts Institute of Technology (United States)

Superconducting Nanowire Single-Photon Detectors (SNSPDs) [Gol’tsman et al., APL 79, 705-707 (2001)] based on sub-100-nm-wide Niobium Nitride (NbN) nanowires offer a unique combination of sensitivity [Korneev et al., IEEE T Appl Supercon 15, 571-574 (2005)], speed [Hadfield, Nat Phot 3, 696-705 (2009)] and timing jitter [Dauler et al., IEEE T Appl Supercon 17, 279-284 (2007)]. We have previously demonstrated sub-35-ps timing jitter [Najafi et al., APL 100, 152602 (2012)], which could enable GHz-rate Quantum Key Distribution (QKD) [Takesue et al., Nat Phot 1, 343-348 (2009)] with previously unmatched secure key rates. However, system efficiencies with NbN-SNSPDs have been limited to 24% at 1550nm wavelength [Hu et al., Opt Lett 34, 3607-3609 (2009)]. When trying to integrate SNSPDs efficiently with optical components we faced two major challenges: Matching the optical mode with the active area of the detector, and non-destructive fabrication of efficient SNSPDs on top of delicate optical structures. We have developed membrane-integrated SNSPDs that have the potential to overcome those challenges: SNSPDs based on 20- to 80-nm-wide NbN nanowires were fabricated on top of silicon nitride (SiN). Wet and dry etch processes were used to release small SiN membranes (100x50μm2) with SNSPDs on top. These membrane-SNSPDs were then picked up from the SiN substrate and placed on top of waveguides in tight contact to ensure high absorption (evanescent coupling). Mode matching was achieved by aligning the active area of the membrane-SNSPD to the optical waveguide with sub-micron accuracy. We report on our detector design, fabrication and alignment processes.

8727-10, Session 3

Superconducting nanowire single-photon detectors integrated with waveguide circuits for quantum information science *(Invited Paper)*

Alessandro Gaggero, Istituto di Fotonica e Nanotecnologie (Italy); Döndü Sahin, Technische Univ. Eindhoven (Netherlands); Francesco Mattioli, Roberto Leoni, Istituto di Fotonica e Nanotecnologie (Italy); Giulia Frucci, Saeedeh Jahanmirinejad, Arjan Sprengers, Technische Univ. Eindhoven (Netherlands); Johannes Beetz, Matthias Lermer, Sven Höfling, Martin Kamp, Julius-Maximilians-Univ. Würzburg (Germany); Andrea Fiore, Technische Univ. Eindhoven (Netherlands)

The integration of single-photon sources and single-photon detectors with passive quantum photonic circuits would enable important functionalities in the field of quantum information processing. In this work we present our progress in the integration of superconducting nanowire single-photon detectors with waveguide optical circuits. The GaAs technology is the promising platform for the integration of quantum-dot single-photon sources and passive photonic circuitry. In the past we developed a superconducting single-photon detector on a GaAs/AlAs distributed Bragg reflector mirror [1], showing that a full integration of active and passive elements is possible using the GaAs technology. We have recently demonstrated the first waveguide single photon detectors (WSPDs), based on superconducting nanowires patterned on top of a GaAs/AlGaAs ridge waveguide, with a quantum efficiency of ~20% and a jitter of ~60ps [2]. Here we present the development of an integrated autocorrelator based on two separated detectors integrated on top of the same ridge waveguide. An efficiency >2% at 1300 nm for both detectors and independent of the polarization of the incoming photons, is reported. The $g(2)(\tau)$ measurement of a laser source is experimentally demonstrated as a proof of principle. This ultracompact device enables the on-chip measurement of the second-order correlation function $g(2)(\tau)$. We will further discuss ongoing work on the integration of detectors with single-photon sources.

8727-11, Session 4

Multiphoton detection in superconducting nanowires: nonlinear optics in the detector *(Invited Paper)*

Andrea Fiore, Zili Zhou, Giulia Frucci, Saedeeh Jahanmirinejad, Döndü Sahin, Rosalinda Gaudio, Technische Univ. Eindhoven (Netherlands); Francesco Mattioli, Alessandro Gaggero, Roberto Leoni, Istituto di Fotonica e Nanotecnologie (Italy); Jelmer J. Renema, Michiel J. A. de Dood, Martin P. van Exter, Leiden Univ. (Netherlands)

The absorption of single photons in superconducting nanowires biased close to the critical current triggers a transition to the resistive state, resulting in a voltage pulse. This process is at the basis of superconducting single-photon detectors [1]. We have recently studied a different regime of lower bias currents in superconducting nanodetectors, where two or more photons are needed to trigger the transition [2-4]. This results in a N-photon threshold detector, where the threshold N is controlled by the bias current, and opens the way to integrating nonlinear functions, such as squaring, with the detector. We will show how this can be used to realise an optical autocorrelator with a sensitivity orders of magnitude better than conventional approaches using nonlinear optics [4]. The temporal and spatial dynamics associated to the multiphoton detection process will also be discussed.

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[2] D. Bitauld et al., Nano Lett. 10, 2977 (2010).

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[4] Z. Zhou et al., arxiv:1209.2747 (2012)

8727-12, Session 4

93% system detection efficiency with tungsten silicide superconducting nanowire single photon detectors *(Invited Paper)*

Francesco Marsili, Varun B. Verma, National Institute of Standards and Technology (United States); Jeffrey A. Stern, Jet Propulsion Lab. (United States); Sean Harrington, Adriana E. Lita, Thomas Gerrits, Igor Vayshenker, Burm Baek, National Institute of Standards and Technology (United States); Matthew D. Shaw, Jet Propulsion Lab. (United States); Richard P. Mirin, Sae Woo Nam, National Institute of Standards and Technology (United States)

We report on a detector system employing superconducting nanowire single photon detectors (SNSPDs) based on amorphous tungsten silicide (WSi) nanowires with system detection efficiency (SDE) of ≈ 93 % at of 1550 nm wavelength (λ); system dark count rate of ~ 1 kcps (due to the room temperature blackbody radiation); device dark count rate (measured with the device shielded from room-temperature blackbody radiation) of ≈ 1 cps, timing jitter of ≈ 150 ps FWHM; and reset time of 40 ns. Because our WSi superconducting films were amorphous and had a factor of ~ 3 lower energy gap than the materials traditionally used to fabricate SNSPDs (NbN or NbTiN), we could easily fabricate 15 µm x 15 µm -active-area SNSPDs based on 150 - 200 nm (width) nanowires on Si substrates and embed the devices in an optical stack to enhance the detector absorption. The optical stack was designed to allow front-illumination, and it consisted of a metal mirror beneath the device and a dielectric coating on top of the device. Because the detector stack was fabricated on a silicon substrate, we were able to use silicon micromachining of the detectors to implement a self-aligned packaging scheme with telecommunication single mode optical fibers. This scheme improves the reproducibility, robustness and simplicity of the optical coupling with respect to traditional approaches. The packaged devices could be operated in the temperature range 120 mK to 2 K without degradation of the detector sensitivity.

8727-13, Session 4

Tungsten silicide superconducting nanowire single-photon detector arrays for deep-space optical communication

Matthew D. Shaw, Jeffrey A. Stern, Andrew D. Beyer, Jet Propulsion Lab. (United States); Francesco Marsili, Varun B. Verma, Richard P. Mirin, Sae Woo Nam, National Institute of Standards and Technology (United States); William H. Farr, Jet Propulsion Lab. (United States)

We present progress in the development of arrays of tungsten silicide superconducting nanowire superconducting single photon detectors (SNSPDs) for deep-space optical communication. We present results from two array architectures, a fiber-coupled 12-pixel array with an active diameter of 66 µm, and a free-space coupled 64-pixel array with a 160 x 160 µm active area. We will discuss measurements of detection efficiency, achievable count rate, dark counts, timing jitter, and crosstalk. We will discuss progress in the development of custom SiGe ROIC circuitry to perform cryogenic analog-to-digital conversion and signal processing. We will discuss the use of 8-channel signal combiner ROICs with integrated amplifiers to form 16:1 channel combiner boards. We will also discuss the details of the cryogenic platform and wiring required to realize a practical deep-space optical communication ground terminal based on WSi SNSPDs.

8727-14, Session 4

Vertically-stacked superconducting nanowire avalanche photodetectors based on amorphous tungsten silicide *(Invited Paper)*

Varun B. Verma, Francesco Marsili, Sean Harrington, Richard P. Mirin, Sae Woo Nam, National Institute of Standards and Technology (United States)

In conventional superconducting nanowire single photon detectors (SNSPDs) the device detection efficiency depends on the polarization of the light. This polarization dependence ultimately limits the detection efficiency of SNSPDs in single photon applications. By vertically stacking the two sections of a superconducting nanowire avalanche photodetector (SNAP), it is possible to enhance the detection efficiency and reduce the polarization dependence by using orthogonal nanowire orientations in

each layer.

Here we report on the fabrication and electrical characterization of vertically-stacked 2-SNAPs based on tungsten silicide (WSi) nanowires. Our devices consist of two vertically-stacked WSi nanowire meanders separated by a patterned electrical insulator (hydrogen silsesquioxane, HSQ) and connected in parallel. This geometry is made possible by the amorphous nature of WSi which can be deposited on a wide range of substrates without affecting the superconducting properties of the nanowires.

Fabricated devices demonstrated an increase in switching current by a factor of two (~8 μA) compared to a single-layer device (~4 μA). The critical temperature (Tc ~ 3.2 K) of each layer was identical to the Tc of a single layer device, indicating that stacking did not degrade the superconducting properties of the WSi nanowires. We measured a system detection efficiency of 86 % at 1550 nm.

8727-15, Session 5

GHz-gated InGaAs SPAD system with avalanche charge sensitivity approaching the fundamental limit *(Invited Paper)*

Alessandro Restelli, Joint Quantum Institute (United States); Joshua C. Bienfang, Alan L. Migdall, National Institute of Standards and Technology (United States)

It is well known that the count rate of InGaAs single-photon avalanche diodes (SPADs) is critically limited by afterpulsing, and that high-speed periodic gating systems ameliorate this problem by reducing the total avalanche charge, thereby populating fewer traps, reducing the afterpulse probability, and maintaining useful signal to noise ratios at higher count rates. In practice, the degree to which this approach is successful is determined by three factors: the duration of the bias gates, the rejection of the gating waveform, and the preservation of the avalanche signal. We present an approach to GHz periodic gating designed to optimize these three critical factors. The threshold for avalanche discrimination in our system is less than 1 mV referenced to the SPAD anode, which approaches the Johnson noise limit for low-noise avalanche discrimination over a 50 Ohm load. With this approach applied to an InGaAs/InP SPAD operating at a gate frequency of 1.25 GHz and detection efficiency greater than 40 % at 1310 nm, we measure a discrimination threshold below 10 fC per avalanche, and we observe per-gate afterpulse probabilities below 0.002 only 7 ns after an avalanche. With the detection efficiency reduced to 20 % the per-gate afterpulse probability at 7 ns drops below 0.0004. We present design and performance of our approach, and discuss tradeoffs between detection efficiency, afterpulse probability, and maximum count rate.

8727-16, Session 5

Advantages of silicon single-photon detectors in gated mode

Damien Stucki, Matthieu Legré, id Quantique SA (Switzerland); Tommaso Lunghi, Hugo Zbinden, Univ. of Geneva (Switzerland)

More and more quantum optics experiments are based on or study interaction between light and matter. In general, a preparation of this matter system, which is performed with intense light pulses, is required. Hence, strong optical pulses can precede single-photon level signal, which is one of the possible results of this interaction. This intense light can strongly reduce the performance of the single-photon detector at the time of detection of the weak signal if this detector is active when strong optical pulses reach it. Indeed, the detector can either be blinded or experience additional noise (afterpulsing) when single-photon level signal reaches the detector. For APD-based single photon detectors, the best known strategy to mitigate this effect is to use the detector in the so called gated mode. In this working mode, the detector is activated in the Geiger mode only for short periods of time when an electric gate is applied on the APD. In most of the cases, the single-photon light resulting from the interaction with the matter is in the visible spectral range. Hence, Si-based single-photon detectors are more likely used for light-matter interaction experiments. Si-APDs are normally used in free-running and not in gated mode. In this work, we present results of a Si-APD single photon detection module working in pulsed mode. We show that the noise performance of this module just after that the intense light pulse reaches the detector is better by orders of

8727-17, Session 5

Balanced detection in single-photon counting

Zhiwen Lu, Joe C. Campbell, Univ. of Virginia (United States); Xudong Jiang, Mark A. Itzler, Princeton Lightwave, Inc. (United States)

We demonstrate balanced InGaAs/InP single photon avalanche diodes (SPADs) operated in both gated mode and sinusoidal gating mode for data transmission rate up to 20 MHz. The photodiode pair is biased in a balanced configuration with only one of the SPADs illuminated. The common-mode signal cancellation realized with the balanced configuration enables detection of small avalanche pulses. The afterpulse effect is significantly suppressed due to the capability of detecting small avalanche pulses at high laser repetition rate. For gated mode operation and laser repletion rate of 20 MHz at 240 K, the dark count probability for photon detection efficiency of 13% is 1.9x10-5. The afterpulse probability is 0.3% for 2 ns pulse width, hold off time of 20 ns, and 10% PDE, at 240K. For sinusoidal gating mode, using a phase shifter to achieve better synchronization between signals, at laser rate of 20 MHz and 240 K, the dark count probability and photon detection efficiency are 2.8x10-5and 10.8%, respectively.

8727-18, Session 5

Near-IR photon number resolving detector design

Jan Bogdanski, Elanor H. Huntington, The Univ. of New South Wales (Australia)

Photon-Number-Resolving-Detection (PNRD) capability is crucial for many Quantum-Information (QI) applications, e.g. for Coherent-State-Quantum-Computing, Linear-Optics-Quantum-Computing. In Quantum-Key-Distribution and Quantum-Secret-Sharing over 1310/1550 nm fiber, two other important, defence and information security related, QI applications, it's crucial for the information transmission security to guarantee that the information carriers (photons) are single. Thus a PNRD can provide an additional security level against eavesdropping. Currently, there are at least a couple of promising PNRD technologies in near-IR, but all of them require cryogenic cooling (e.g. a Transition-Edge-Sensor requires cooling to 100mK). Thus a compact, portable PNRD, based on commercial APDs, could be a very useful instrument for many QI-experiments.

For an APD based PNRD it is crucial to measure the APD-current in the beginning of the avalanche. Thus an efficient cancellation of the APD capacitive spikes is a necessary condition for the very weak APD current measurement.

Our detector's principle is based on two commercial (Princeton Lightwave), pair-matched InGaAs/InP APDs, connected in series, which leads to a great cancelation of the capacitive spikes caused by the narrow 300 ps gate-pulses of max 4Vp-p amplitude. The cancellation scheme could also be used for other APD technologies, e.g. Germanium and Silicon. Thus the detection spectrum from visible to 1550 nm could easily be covered by a simple exchange of the module containing Pair-Matched APDs.

The design distinguishes itself from other PNRD APD-based schemes by its scalability feature providing adjustable Gating-Rate from 1 kHz to 1 GHz and Gate-Width down to 300 ps.

8727-19, Session 5

High-speed photon detectors operated in sinusoidally gated mode

Yan A. Liang, Min Ren, E. Wu, Guang Wu, Heping Zeng, East China Normal Univ. (China)

Recently, the sinusoidal gating technique has been widely used to improve the single-photon detectors based on avalanche photodiodes (APDs), for its obvious convenience in suppressing the APD's capacitive response. However, in the typical sinusoidal gating scheme, the band-elimination filtering unavoidably causes detrimental distortions to the avalanche signals and accordingly results in a relatively large timing jitter. Here, we demonstrated an efficient way to improve the timing jitter of the sinusoidally gated InGaAs/InP APD by combining low-pass filtering and sinusoidally balanced differencing techniques, achieving a 1-GHz gated single-photon detector with the timing jitter of about 60 ps. The detection efficiency could reach 10% at 1550 nm, with afterpulse probability 3% considering the dead time of 10 ns.

Moreover, a high-speed photon-number-resolving detector was exhibited, which was based on a 200-MHz sinusoidally gated multipixel photon counter (MPPC). Two steps of low-pass filters with the attenuation ratio higher than 40 dB at 200 MHz were employed to minimize the MPPC's capacitive response noise, resulting in the efficient detection of weak photon-induced avalanche currents. The quantum efficiency of the MPPC was measured to be about 20% at 709 nm at room temperature. By using the sinusoidal gates, the recovery time for each pixel of the MPPC to detect the next coming photons was shortened, thus improving the detector's photon-number-resolving capability at a high repetition rate.

Both the detectors promise various applications with high-speed single-photon or photon-number-resolving detection, such as quantum cryptography, quantum random-number generators, and photon counting reflectometry.

8727-33, Session 5

Precise Monte Carlo simulation of single-photon detectors

Mario Stipcevic, Rudjer Boskovic Inst. (Croatia) and Duke Univ. (United States); Daniel J. Gauthier, Duke Univ. (United States)

We demonstrate the importance and utility of Monte Carlo simulation of avalanche-photodiode based single-photon detectors. Using a simple yet very demanding example of random number generation via detection of time-wise Poissonian photons exiting a beam splitter we present an ab ovo Monte Carlo simulation that incorporates detector effects like frequency dependent dead time, noise, afterpulsing and twilight events. Furthermore, we have built a beam-splitter random number generator using two detectors made from Perkin Elmer SPCM avalanche diode and a home-made avalanche quenching circuit. Parameters of the detectors (such as afterpulsing probability, afterpulsing lifetime, dead time etc.) are obtained by measurements independent of the simulation. Based on these parameters the simulation (which allows for two physically different detectors) faithfully reproduces experimentaly obtained serial autocorrelation coefficient of random bits as a function of detection frequency over four orders of magnitude of the incident photon flux. We find that our beam-splitter based RNG suffers from pretty large unreducible imperfections in form of autocorrelation. At low bit production rate the imperfections are dominated by afterpulsing whereas dead time dominates at high bit rate. Interestingly, there is a point at which the two effects cancel each other. We also note a surprisingly large role of twilighting - an effect in single photon detectors which is less studied and which, together with other imperfections, may degrade security of quantum cryptographic protocols that use APD based detectors.

8727-20, Session 6

MiSPiA: microelectronic single-photon 3D imaging arrays for low-light high-speed safety and security applications *(Invited Paper)*

Franco Zappa, Alberto Tosi, Politecnico di Milano (Italy)

MiSPiA concept is to provide simultaneously high frame-rates and single-photon sensitivity CMOS chips with monolithic integration of SPAD detectors and in-pixel processing for 2D intensity-data and 3D depth-ranging information. The two 3D ranging applications are short-range (10 – 40 m) phase-resolved ranging for automotive safety systems and long-range (200 m - 1 km) time-of-flight in-pixel time-to-digital conversion for security surveillance. The talk will present the on-going activities on microelectronic design of CMOS chips for both front- and back-side illuminated SPAD imagers and the experimental validation with 2D and 3D movie acquisitions.

8727-21, Session 6

New silicon technologies enable high-performance arrays of single-photon avalanche diodes *(Invited Paper)*

Angelo Gulinatti, Ivan Rech, Politecnico di Milano (Italy); Piera Maccagnani, Istituto per la Microelettronica e Microsistemi (Italy); Sergio D. Cova, Massimo Ghioni, Politecnico di Milano (Italy) and Micro Photon Devices S.r.l. (Italy)

The design of a Single Photon Avalanche Diode (SPAD) is a complex task that requires to trade off between many device parameters including Dark Count Rate (DCR), Photon Detection Efficiency (PDE), photon timing jitter, afterpulsing probability and active area diameter. This has historically led to the development of detectors optimized either for high temporal resolution (thin SPAD) or for high PDE in the red/near infrared region of the spectrum (thick SPAD). In particular, the latter are devices fabricated with a non-planar process that is unsuitable for the fabrication of arrays.

On the other hand, in the last years many applications emerged that require arrays of SPADs with improved PDE in the red region of the spectrum. While for some of those (e.g. Fluorescence Correlation Spectroscopy) a nanosecond-accuracy in photon detection is sufficient, others require a picosecond timing jitter (e.g. spectrally resolved Fluorescence Lifetime Imaging).

In order to fulfill the requirements of those applications, we recently developed a new technology aimed at combining the advantages of thin and thick SPAD. In particular we demonstrated a remarkable improvement in PDE at the longer wavelengths (e.g. 40% at 800nm) while maintaining a timing jitter better than 100ps. Moreover, to make this technology compatible with the fabrication of arrays of SPADs, we introduced some modifications to the device structure such as dielectric isolation by means of deep trenches.

We will present a detailed experimental investigation of the new detectors and we will discuss the effects of dielectric isolation on main device properties.

8727-22, Session 6

Compound semiconductor SPAD arrays *(Invited Paper)*

Eric S. Harmon, James T. Hyland, Mikhail N. Naydenkov, LightSpin Technologies, Inc. (United States)

Single photon avalanche diodes (SPADs) are revolutionizing ultra-sensitive photodetection applications, providing single photon sensitivity, high quantum efficiency and low dark noise at or near room temperature. When aggregated into arrays, these devices have demonstrated the ability to operate as photon number resolving detectors with wide dynamic range, or as imaging detectors. SPAD array performance has reached a point where replacing vacuum tube based MCP and PMT photodetectors for most applications is imminent. Compound semiconductor SPAD arrays can be tailored to match application specific wavelength, speed and radiation hardness requirements. We present a theoretical framework describing performance limits to compound semiconductor SPAD arrays and our latest experimental results detailing the performance of GaAs SPAD arrays. These devices achieve nanosecond rise and fall times, excellent photon number resolving capability, and low dark count rates. Room temperature dark count rates below 10 Mcps have been achieved for a 1 mm x 1 mm device at 10% single photon detection efficiency. Compound semiconductor SPAD arrays have the opportunity to provide orders of magnitude improvement in dark count rate and radiation hardness compared to silicon SPAD arrays, as well as the ability to detect wavelengths where silicon is blind.

8727-23, Session 7

InP-based Geiger-mode avalanche photodiodes for photon-counting *(Invited Paper)*

Erik K. Duerr, MIT Lincoln Lab. (United States)

At MIT Lincoln Laboratory, avalanche photodiodes (APDs) are being developed for detection of photons with wavelengths from 1-um to 2.2-um in the indium-phosphide (InP) material system. While APDs composed of bulk semiconductor crystal layers are used for photon counting at the short end of this wavelength range, detecting photons beyond 1.65 um requires bandgap-engineering techniques in the photon absorption layer of the APD in order to remain in the InP material system. These novel absorber layers allow a proven, high-quality, bulk InP layer to be used for carrier avalanche while extending the wavelength of operation beyond that of a bulk, indium-gallium-arsenide (InGaAs) absorber layer. Both lattice-matched and strain-compensated multiple-quantum-well structures can be used for extended wavelength detection. Geiger-mode operation in APDs with strain-compensated In(x)Ga(1-x)As/In(y)Ga(1-y)As superlattice absorbers designed for detection of 1.8-um photons has been achieved at operating temperatures from 200 K to 295 K. Research is ongoing to extend the detection wavelength.

8727-24, Session 7

Integrated single-photon detectors combining the avalanche, bipolar, and field-effect transistor gain *(Invited Paper)*

Yu-Hwa Lo, Samia Rahman, David Hall, Univ. of California, San Diego (United States)

We discuss the invention of a novel InGaAs/InP photodetector that integrates three amplification mechanisms: avalanche multiplication, bipolar gain, and field-effect transistor gain. The device is capable of detecting optical signals containing thousands of photons to a few photons and produce output signals of increasing intensities with the number of photons in the signal. To our best knowledge, this is the first infrared semiconductor photodetector with an integrated preamplifier to produce high dynamic range (over 60 dB) and ultra-high sensitivity.

8727-25, Session 7

Progress towards APD imagers *(Invited Paper)*

Daniel R. Schuette, Brian F. Aull, MIT Lincoln Lab. (United States)

No abstract available.

8727-26, Session 8

Single-photon detectors in the log-wavelength infrared through sub-millimeter-wave regions *(Invited Paper)*

Susumu Komiyama, The Univ. of Tokyo (Japan)

Long-wavelength infrared through sub-millimeter-wave regions (λ≈ 10μm ~ 1mm) are richest areas of spectroscopy of matters, including the rotationa/vibrational spectra of molecules, liquids and solids, and the electron energy spectra of insulators, semiconductors and metals. Unfortunately, however, extensive measurements in these spectral ranges have been hindered, primarily due to the lack of ultra-highly sensitive and convenient photo-detectors.

Described here are single-electron transistors (SETs) coupled with semiconductor quantum dots as well as charge-sensitive infrared photo-transistors (CSIPs) based on bi-layer semiconductor quantum wells, which are the only sensors capable of counting individual photons at present, with the highest sensitivity (NEP≈10-21 W/Hz1/2), in a wavelength range of 15μm ~ 600μm [1]. In addition to the sensitivity, huge current responsivity (106–1010 A/W) and extremely large dynamic range (106 –108) make those detectors extremely suitable device for application. The mechanism of detection as well as several applications [2,3] of the detectors will be discussed.

[1] S. Komiyama, IEEE Journal of Selected Topics in Quantum Electronics, 17(1), 54-66 (2011)

[2] K. Ikushimaa and S. Komiyama, Comptes Rendus, Physique 11, 444-456 (2010)

[3] Y. Kajihara, K.Kosaka and S. Komiyama, Opt. Express 19, 7695-7704 (2011)

8727-27, Session 8

New single-nanocrystal spectroscopy approaches for investigation of emission efficiency and recombination dynamics of multi-excitons *(Invited Paper)*

Benjamin D. Mangum, Young-Shin Park, Yagnaseni Ghosh, Jennifer A. Hollingsworth, Han Htoon, Los Alamos National Lab. (United States)

Understanding and controlling the emission efficiency and recombination dynamics of bi-excitonic states (i.e. QBX and BX) in semiconductor nanocrystal quantum dots (NQDs) holds the key to many novel technological applications including optical amplification, entangled photon-pair generation and carrier multiplication. Traditionally, QBX and BX are extracted by performing multi-exponential fits on photoluminescence decay curves measured as a function of pump power. Such measurements require many fitting parameters and assumptions on scaling of radiative and non-radiative recombination rates with exciton multiplicity. Here we present novel single particle spectroscopy approaches capable of measuring these parameter directly. Our approaches are based onsecond order photon correlation spectroscopy (g(2)) and can also be applied to small clusters of NQDs to determine the number of NQDs in a cluster together with average value of QBX and BX.

Specifically, first we demonstrate that the ratio of the areas of center and side peaks of the g(2) function of the spectrally integrated PL of a single NQD provide a precise measure of the ratio of the quantum yield of single and bi-exciton states. Next, we present a time gated photon correlation spectroscopy approach that allows separation of the effects of multi-exciton emission and NQD clustering in g(2) measurements. Finally, we present how the emission of bi-excitons can be separated in g(2) measurements and extract decay dynamics of bi-excitons without any ambiguity.

8727-28, Session 9

Performance of a compact position-sensitive photon counting detector with image charge coupling to an air-side anode *(Invited Paper)*

Ottmar Jagutzki, Johann Wolfgang Goethe-Univ. Frankfurt am Main (Germany) and RoentDek GmbH (Germany); Sven Schössler, Achim Czasch, RoentDek GmbH (Germany)

We discuss a novel MCP photo-multiplier with resistive screen as a detection device for space and time correlated single photon counting, illustrated by several applications. The photo-multiplier tube resembles a standard image intensifier model, however the rear phosphor screen is replaced by a ceramic "window" with resistive coating which capacity-couples image charge from an MCP charge could to a read-out electrode outside the tube. This design allows an easy reconfiguration of the read-out electrode (e.g. pixel, charge sharing, cross strip, delay-line) for optimizing the detector performance towards a certain task and also eases the design and manufacturing process of such a multi-purpose photomultiplier tube. Temporal and spatial resolutions well below 100 ps and 100 micron (FWHM) have been reported at event rates as high as 1 MHz, for up to 40 mm effective detection diameter. Among the applications discussed in the presentation are wide-field fluorescence microscopy and dual gamma/fast neutron radiography for air cargo screening.

8727-29, Session 9

Detection of faint moving space objects with a photon counting imager

Phan D. Dao, Air Force Research Lab. (United States)

Photon counting imager (PCI) technology offers large format imaging sensors with sub-nanosecond time resolution, hence provides a unique capability for astronomy, active imaging and passive photometry of artificial satellites. Signal is recorded as arrival times which are used to calculate positional information, with equivalence to 200-2000 resolution elements, and photon arrival times stamped at 250 ps resolution. The PCI sensor head, used in our laboratory, has a 40 mm diameter and 100 micron spatial resolution in both x and y. The ability to time tag each photon results in a clear advantage in detecting objects that move in the field of view at a speed that would result in streaking for conventional frame-based imager such as CCDs and reduced sensitivity. The PCI advantage is attributed to the dramatic difference in photon number densities between a 2-D array and a 3-D cube. We demonstrate in simulations and with actual measurement data on space objects that the limiting magnitude can be improved by up to 6 visual magnitudes. A quasi blind search algorithm that identifies the streak of photons, assuming no prior knowledge of orbital information, will be discussed and results will be shown.

8727-30, Session 9

Study on the detection efficiency of gaseous photomultipliers

Baishali Garai, Indian Institute of Science (India); V. Radhakrishna, ISRO Satellite Ctr. (India); V. Koushal, K. Rakhee, Space Astronomy Group, ISRO Satellite centre (India); K. Rajanna, Indian Institute of Science (India)

Photomultipliers are sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. In gaseous photomultipliers (GPM) operating in the UV spectral range, a thin film of CsI coated over UV transparent quartz window act as the photocathode. UV photons release photoelectrons into the gas volume of the detector; these photoelectrons undergo avalanche multiplications across electron multiplier structures, thus producing large detectable signal. Efficient photon detection in a GPM requires maximum photoelectron yield from the photocathode surface and also high electron multiplication in the electron multiplier. In this work we have investigated the parameters that affect the photoelectron yield from the photocathode surface and methods to improve them thus ensuring high detection efficiency of the GPM. The parameters studied here are the electric field at the photocathode surface, surface properties of the photocathode and pressure of gas mixture inside the GPM. It is observed that photocurrent increases with increase in electric field. But at higher electric field, the probability of focusing the photoelectrons inside the electron multiplier decreases. This conflicting requirement needs to be kept in mind while choosing the electric field to be applied. Investigations on the effect of filled gas pressure on the photoelectron emission show that with increase of pressure, the photocurrent decreases. Investigations are also carried out to see the effect of surface properties of the photocathode on the photoelectron emission. It is observed that longer duration of evacuation before gas filling helps to increase the photoelectron yield.

8727-31, Session 10

Low-noise high-speed single photon detector in gated Geiger mode

Xiuliang Chen, Yan A. Liang, E. Wu, Guang Wu, Heping Zeng, East China Normal Univ. (China)

Single Photon detection is widely used in quantum cryptography, laser ranging, single photon spectrograph and so on. InGaAs/InP avalanche photodiodes (APDs) are the most popular components for the near-infrared single photon detection. InGaAs/InP APDs are normally operated in the gated Geiger mode, in which fast gating pulses are applied to the APDs. Due to the APD capacitive response of the gating pulses, a spike-signal is produced, while most weak photo-excited avalanche signal is buried in the spike-signal, which limits the detection efficiency and operating frequency of the single photon detection. Recently, the self-differencing spike-signal cancellation technique was introduced to suppress the spike-signal, by subtracting the identical signal in the APD response of the two successive gating cycles.

In this paper, we demonstrate the double-self-differencing spike-signal cancellation technique, which is on the basis of the self-differencing spike-signal cancellation. By adding a post-self-differencing circuit to the pre-self-differencing circuit, the average voltage of photo-excited avalanche signal is increased while the background noise is further suppressed. In order to qualify the ratio of the avalanche signal to background noise, a photon-number resolving method is used. Comparing the signal at the outputs of the pre-self-differencing circuit and the post-self-differencing circuit, the signal to noise ratio is improved more than 10 dB. The detection efficiency and error count probability are improved, and the typical error count probability is reduced to less than 2.5% and 6.5% at the detection efficiency of 20% and 30%, respectively.

8727-32, Session 10

High-speed multichannel time-correlated single-photon counting electronics based on SiGe integrated time to digital converters

Michael Wahl, Tino Röhlicke, Hans-Jürgen Rahn, PicoQuant GmbH (Germany); Nick Bertone, PicoQuant Photonics North America, Inc. (Canada); Gerald Kell, Fachhochschule Brandenburg (Germany)

Time Correlated Single Photon counting with picosecond timing has become a key method in many areas of applied physics. One of the most important areas is that of fluorescence lifetime measurement in biophysics and the life sciences. Precisely timed photon counting for the purpose of coincidence correlation is now also emerging as the most common approach to quantum state interpretation in

experimental quantum optics. Therefore, time-correlated single photon counting (TCSPC) electronics, traditionally mostly used in time-resolved fluorescence research are facing new challenges in different emerging areas. Consequently such instruments are undergoing a fresh cycle of innovation, some of which we try to highlight here. The new picosecond TCSPC system we specifically present provides several interesting new features resulting from a high speed monolithic integration in one of the fastest semiconductor technologies available today.

The result is a high timing resolution by direct digital conversion and a very short deadtime. Apart from conventional histogramming over a very long time span, we can implement continouos single photon recording modes hat allow picosecond timing of all photon events with respect both to a sync signal as well as on a virtually infinite time scale. Multiple timing channels can also be operated indpendently and in parallel, e.g. for picosecond correlation analysis between signals from multiple photon detectors. In this paper we describe some implementation details and the results of an evaluation of the new electroncis in synthetic benchmarks and real quantum optical applications

Monday - Tuesday 29–30 April 2013

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8728-37, Session 1A

Power and Energy at DARPA: enabling a paradigm shift for the Warfighter and DoD *(Keynote Presentation)*

Brian C. Holloway, Defense Advanced Research Projects Agency (United States)

No Abstract Available.

8728-1, Session 1

High-rate performing Li-ion batteries for defense applications *(Invited Paper)*

Palani Balaya, Vishwanathan Ramar, Srirama Hariharan, Kuppan Saravanan, Chad Mason, National Univ. of Singapore (Singapore)

The major concern about the existing rechargeable Li-ion battery technology for defense applications is that it takes too long time for recharging and raises safety concerns upon fast charging. My talk provides a battery technology solution for military applications with all the advantages of batteries and supercapacitors in one unit. In other words, the supercap battery proposed here will have energy density comparable to batteries and high power density as that of supercapacitors.

The proposed technology will use non-carbonaceous anode materials to avoid lithium electroplating upon charging at high rate. On the other hand, this technology employs phosphate based high voltage cathode materials to achieve high energy density.

Potential cathode materials such as $LiMnFePO_4$ and $Li_3V_2(PO_4)_3$ and anode materials based on titanates such as $Li_4Ti_5O_{12}$ and TiO_2-bronze or transition metal oxides such as Fe_2O_3 and Fe_3O_4 will be considered for designing Li-ion battery with high energy and high power. Recent development in these electrode materials will be presented.

8728-2, Session 1

New developments in lithium sulfur batteries *(Invited Paper)*

Ilias Belharouak, Xiaofeng Zhang, Argonne National Lab. (United States); Bryant Polzin, Argonne National Lab. (United States); James Li, Univ. of Rochester (United States)

Rechargeable lithium-ion batteries were first commercialized by Sony in early 90's. The high cost of cobalt and relatively low specific capacity of $LiCoO_2$ (140Ah/kg) have been major obstacles against the wide application of these batteries in transportation where the battery energy density should significantly increase to meet the goals for plug-in hybrid vehicles (PHEVs), and essentially for electric vehicles (EVs). Also, despite the abundance of iron and manganese, olivine $LiFePO_4$ and spinel $LiMn_2O_4$ will not likely be adequate candidates since neither of them can provide enough gravimetric and volumetric energy densities for automotive applications. Therefore, research groups have been under the challenge of inventing and developing new advanced positive electrode materials whose main characteristics is to store more and more electricity per mass and volume. Of these materials, advanced composite materials were found to deliver a high reversible capacity (250Ah/kg) while being structurally and electrochemically stable upon charge and discharge. These thermally stable materials are considered as potential candidates to surmount the energy density shortfall of current lithium ion batteries. The journey for materials design and discovery will be unveiled in the light of the most recent developments in lithium-ion batteries. Also, the implementation of the very challenging lithium-sulfur will be discussed.

8728-4, Session 1

Three-dimensional lithium-ion batteries with interdigitated electrodes *(Invited Paper)*

Derek Johnson, Prieto Battery, Inc. (United States); Amy L. Prieto, Colorado State Univ. (United States) and Prieto Battery, Inc. (United States)

Lithium-ion batteries have become the primary energy choice for low power applications, and are now being sought after for high power applications that require long cycle life. These applications range from stationing sources, such as grid stabilization, to more mobile platforms such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and electric vehicles (EV). To meet the performance requirements for high power density applications, the shortcomings that have relegated the use of conventional lithium-ion batteries to low-power applications needs to be addressed. These shortcomings are, in part, a result of two-dimensional planar electrodes that have the inherent trade-off between energy and power density. The use of a three-dimensional (3D) architecture with interdigitated electrodes has been proposed to alleviate the shortcomings because it allows a significant decoupling of energy and power density. While the use of 3D battery architectures promises a significant leap forward in terms of performance, many synthetic challenges must be overcome. Our approach is to use electrodeposition as the main synthetic tool for the fabrication of the 3D solid-state lithium-ion cell. Electrodeposition is used to plate copper antimonide onto a copper foam substrate. Since the anode is highly conducting, it is subsequently used as the substrate to which a solid-state electrolyte is directly electrochemically deposited. A nanoparticle based cathode slurry is then applied to the surface of the solid-state electrolyte to complete the cell. Characterization and performance of the individual components as well as the composite structures will be presented.

8728-5, Session 2

Nanostructured vanadium pentoxides as cathodes for lithium-ion batteries *(Invited Paper)*

Guozhong Cao, Univ. of Washington (United States)

Nanostructured vanadium pentoxide films were fabricated using various wet chemical processes including sol-gel processing, electrodeposition and electrospinning with or without the assistant of organic additives or surfactants. The appropriately controlled nanostructures possess high surface area and short distant for charge and mass transport, and thus lead to much enhanced power density. The higher surface energy also favors the higher lithium intercalation capacity.

Controlled doping of less than 5% manganese and tin in vanadium pentoxides has demonstrated an appreciable enhancement in lithium-ion intercalation properties with the most significant improvement in the cyclic stability. Such enhancement was attributed to increased electrical conductivity and lithium ion diffusivity due to the introduction of oxygen vacancies, and reduced energy barrier for phase transformation with doping.

Further study has revealed the surface defects exert an appreciable impact on the lithium-ion intercalation capacity, allowing the storage capacity exceeding the theoretical capacity of bulk counterpart. Although more research is required to obtain a better understanding, it is believed that the surface defects or coating may alter the surface energy, and thus enable the reversible phase transition to occur at a much higher lithium content.

8728-6, Session 2

New directions on rechargeable nano-batteries: lessons from in-situ electron microscopy *(Invited Paper)*

Reza Shahbazian, Anmin Nie, Michigan Technological Univ. (United States)

Nanostructured anode materials have received considerable attention in energy storage devices due to the enhanced electrochemical reactions at the surface and their unique electrical and mechanical properties. Silicon and titanate nanostructures are promising anode materials because of their energy capacity and safer performance for Li-ion batteries. One of the hurdles in developing better and long lasting batteries is the lack of scientific knowledge on the electrochemical reactions that happen inside a battery under charging and discharging conditions. Using real-time microscopy at atomic resolutions should shed light into some of the fundamental questions in this regard. This presentation focuses on the in-situ observation of lithiation and delithiation in Si nanorods and TiO_2 nanotubes. The electrochemical testing of these low dimensional structures were conducted inside a transmission electron microscope equipped with a novel in-situ electrical probing holder. The intercalation of Li-ions in Si nanorods was monitored during charging and the fracture of nanorods was quantified in terms of size. In addition, the intercalation of crystalline anatase and amorphous TiO_2 was studied and their fracture events were monitored in real time.

8728-7, Session 2

Nanostructured olivine phosphate cathode material for rechargeable lithium ion batteries *(Invited Paper)*

Sevi Murugavel, Raza Shahid, Univ. of Delhi (India)

A different solid state preparation of undoped cathode material $LiFePO_4$ (LFP) olivine compound has been synthesized at low temperatures with different particle sizes with an emphasis towards understanding the size dependent physical and electrochemical properties of LFPs. The phase purity and structural properties of as prepared sample has been characterized by X-ray diffraction (XRD), Raman Spectroscopy, FTIR and Transmission Electron Microscopy (TEM). Based on the obtained results, we confirm that as obtained nano-sized particles are without any parasitic phases. The spectroscopic studies on these samples show that the observed vibrational modes are intrinsic part of LFP samples. The consequences of phonon confinement are noticeable in the vibrational spectra when the particle size becomes less than 200 nm. The measured room temperature electronic conductivity and optical band gap shows the systematic dependence on particle size. We ascribe the variation of the optical band gap and electronic conductivity with particle size is due to the quantum confinement effects. Furthermore, we have extended the temperature and frequency dependent conductivity measurements on these samples and identify the charge transport mechanism responsible in LFPs.

8728-8, Session 3

Transport properties of ordered and disordered spinel $LiMn_{1.5}Ni_{0.5}O_4$ *(Invited Paper)*

Ruhul Amin, Massachusetts Institute of Technology (United States)

$LiMn_{1.5}Ni_{0.5}O_{4-}$ (= 0-0.05) is a high voltage cathode material for lithium ion batteries, which has attracted great attention within the battery community due to its high power density and flat voltage plateau. This material exhibits two different polymorphs - order and disorder - depending on the arrangement of Mn and Ni on the lattice positions in the spinel structure. The degree of disorder varies with sintering conditions, which influence the transport properties and electrochemical performance. The charge-discharge behavior of both structures have been tested by several research groups, however still it is not clear which structural composition is suitable for a high performance batteries. It is also not clearly understood if the rate performance of the material is limited by bulk transport properties or charge transfer reactions. Many of the unknown questions can be resolved if the transport properties of the material are reliably characterized. The transport properties of the material are scarcely known, i.e. only electronic conductivity of the fully lithiated phase has been measured. Here we report the ionic and electronic conductivities as well as ionic diffusivity of ordered and disordered phases separately by using ion and electron blocking cell configurations. The measurements have been performed by direct current polarization technique and impedance spectroscopy on a thick sintered pellet. In order to elucidate the mechanistic understanding we measured the transport properties as a function of lithium content as well as of temperature. We found that the electronic conductivity of the ordered phase increases with a certain amount of lithium removal (electrochemically) after which the conductivity remains almost constant with further lithium removal. Conversely, the disordered phase exhibits a sudden drop of conductivity upon complete delithiation at the 4.1 volt plateau i.e. complete conversion of Mn^{3+} into Mn^{4+}. Hereafter, it exhibits similar conductivity behavior as the ordered structure. Comparing ionic conductivities and diffusivities between ordered and disordered fully lithiated phases shows them to be the same order of magnitude. Initial measurements of partially delithiated phases indicate decrease of ionic conductivities and diffusivities in comparison with lithiated phases.

8728-10, Session 3

Lithium intercalation into $Li_{1+x}V_{1-x}O_2$ a low voltage anode for lithium batteries *(Invited Paper)*

Pooja Panchmatia, Univ. of Huddersfield (United Kingdom) and Univ. of Bath (United Kingdom); Robert Armstrong, Univ. of St. Andrews (United Kingdom); M. Saitul Islam, Univ. of Bath (United Kingdom); Peter G. Bruce, Univ. of St. Andrews (United Kingdom)

Graphite remains the dominant anode for rechargeable lithium batteries. Oxides represent an attractive alternative because of their significantly greater density, leading to higher volumetric energy densities; essential for future applications in portable electronics and electric vehicles. Lithium can be reversibly intercalated into layered $Li_{1+x}V_{1-x}O_2$ ($LiCoO_2$ structure) at ~0.1V, but only if $x > 0$. Here we have investigated the intercalation process focusing on the crucial role of stoichiometry in switching on intercalation. Atomistic simulation and DFT studies show that intercalated Li^+ occupying tetrahedral sites are energetically more stable for Li-rich compositions, since they share a face with a Li^+ on the V site in the transition metal layers [1]. The unprecedented low intercalation voltage in an oxide renders the material of interest as an anode for lithium batteries.

[1] Armstrong A R, Lyness C, Panchmatia P, Islam M S, Bruce P G, Nature. Mater. 10, 223-229 (2011).

8728-11, Session 3

Water-based sodium battery for energy storage *(Invited Paper)*

Manickam Minakshi, Murdoch Univ. (Australia)

The global drive for the electrification of road transport for fuel supply and environmental reasons has put rechargeable batteries at the forefront of new energy technologies. Lithium-ion batteries have been considered one of the most attractive rechargeable technologies suitable for electric vehicles (EVs) due to their high energy density and multiple cycling characteristics. EVs with extended range powered by lithium-ion storage batteries already exist in the consumer market.

The high cost of lithium is concerning, having roughly doubled from the first practical application in 1991 to the present. The cost of lithium is expected to dramatically increase as demand for it increases in response to demand for large-scale industrial, household and EV energy storage. Alternative energy storage mechanisms using abundant and environmentally friendly materials are critical for the development of energy storage technology. In contrast to lithium resources, sodium sources are plentiful and cheap. Next to lithium, the electrochemical properties of sodium are the most attractive for battery applications. This proposed project paves the way for an alternative energy future by removing global reliance on fossil fuels, replacing them with sustainable sodium-based energy storage technology, reducing our environmental impact and ensuring short and long term energy supply. At the conference, our recent work on water-based sodium-ion battery will be presented.

In one of the author's earlier works, the commercial alkaline Zn-MnO2 primary battery has been transformed into a secondary battery using LiOH electrolyte. In the current study, a novel Zn-MnO2 battery using NaOH (aqueous) electrolyte is demonstrated. The sodium battery is fully reversible with an improved energy density of 300 Wh/Kg. The aqueous cell showed an excellent efficiency exhibiting reversible electrochemical intercalation and extraction of sodium from the host MnO2 that make the battery suitable for energy storage applications. Longer term stability is yet to be proved.

8728-12, Session 3

From lithium to sodium: the case of olivine materials *(Invited Paper)*

Pierre Kubiak, Montse Casas-Cabanas, Vladimir Roddatis, Damien Saurel, Teofilo Rojo, CIC Energigune (Spain)

There is a rising interest in the development of new low cost energy storage technologies for grid storage. Sodium-ion batteries are a particularly attractive alternative because they could potentially be much less expensive, safer and environmentally benign than Li-ion batteries. However, the choice of electrode materials available for the sodium technology is significantly smaller than for lithium technology. Additionally, fundamental differences between lithium and sodium insertion mechanisms in the same host structure have been observed. Na insertion/extraction can induce successive phase transitions that are less common on the lithium counterparts. This is the case of the NaFePO4 material with olivine structure. While Li extraction/insertion from/into LiFePO4 olivine occurs via a biphasic mechanism, the mechanism of the electrochemical Na extraction/insertion from/into NaFePO4 involves the formation of an intermediate Na0.7FePO4 phase. This intermediate phase can be isolated on battery charging or prepared by chemical delithiation of LiFePO4 followed by partial chemical sodiation of the obtained FePO4 material. X-rays and electron diffraction techniques revealed the existence of an ordering of Na+ and vacancies resulting in a large associated supercell. In this study, we have investigated the structural and electrochemical properties of various NaxFePO4 ($0 \leq x \leq 1$) materials. The NaxFePO4 materials show remarkable electrochemical properties in the sodium cell, such as long charge–discharge cycle life and good capacity. Preliminary results on NaxFe1-yMnyPO4 will also be presented and discussed during the meeting.

8728-13, Session 4

In situ studies of synthesis and lithium reaction of high-energy electrodes for lithium-ion batteries *(Invited Paper)*

Feng Wang, Brookhaven National Lab. (United States)

Lithium-ion batteries are the preferred energy storage devices for portable electronics and may become the main power sources for electrical vehicles and grid storage. The development of improved high-energy electrodes for a new generation of lithium-ion batteries requires better understanding of the physical and chemical processes that occur during cycling and the ability to predict and ultimately control the key properties of the electrode materials. We developed and utilized specialized in situ reactors to investigate hydrothermal synthesis reactions in real-time using synchrotron x-ray diffraction. This unique capability allows us to track the chemical reaction in real time, and help us better understand how reaction conditions affect phase nucleation, crystallization, particle size, morphology and defects. Those new insights can be used to develop novel high-energy electrodes. I will show our in-situ studies of hydrothermal synthesis high-capacity Cu-V-O cathodes. In situ synchrotron x-ray diffraction, absorption spectroscopy (XRD, XAS), and transmission electron microscopy (TEM) were also used to investigate the chemical and structural changes that take place during the lithium displacement/intercalation reaction process in Cu-V-O and provide new insights into the lithium reaction mechanisms in this system.

8728-14, Session 4

Heat generation in Li-ion cells during charge and discharge *(Invited Paper)*

Rengaswamy Srinivasan, Johns Hopkins Univ. Applied Physics Lab. (United States)

The conventional dialogues on the reasons for thermal runaway, venting and fire during fast charging and discharging, and during overcharging of Li-ion cells point to temperature increase and gas formation. There is, however, no consensus on which of these events occurs first, thereby enabling research to correctly target the root cause. The recent work conducted at the Johns Hopkins University Applied Physics Laboratory (JHU/APL) demonstrates that neither the temperature increase nor gas formation may be the primary reason for the venting or fire. Instead, the primary reason could potentially be a thermodynamic parameter that is often associated with both anode and cathode, namely entropy. Typically, a decrease in entropy, and a concomitant increase in the electrode temperature have been observed in the anode during charging, and in the cathode during discharging. We find that under ambient operating conditions (0 to 30 ºC), entropy-driven thermal energy accounts for more than 2/3rd of the heat. More importantly, sudden changes in the entropy increases the electrode temperature by an order-of-magnitude that if left unchecked could drive the electrode temperatures sufficiently high to disrupt the SEI layer, bringing the active materials in the electrodes in direct contact with the electrolyte, enabling exothermic reactions. Battery internal temperature sensor (BITS), a technique that we recently developed at JHU/APL enables one to follow the anode and cathode temperatures in real time, while the cell is under charge and discharge. We will discuss the application of BITS in estimating the entropy changes that define the limits of safety in Li-ion cells.

8728-15, Session 4

Lithium ion diffusion kinetics in lithium metal phosphates (LiMPO4, M= Fe, Mn and Ni) in presence of 2 M Li2SO4 aqueous electrolyte *(Invited Paper)*

Gurukar Shivappa Suresh, NMKRV College for Women (India)

Here we report a comparative study of kinetics of lithium ion insertion process at LiMPO4 (M = Fe, Mn & Ni) electrodes in 2 M L2SO4 electrolyte using cyclic voltammetry, potentiostatic intermittent titration technique (PITT), Galvanostatic intermittent titration technique and electrochemical impedance spectroscopy technique (EIS) for calculating the kinetic parameters of the lithium insertion processes at these cathode materials. The dimensionless kinetic parameter, Λ, whose magnitude determines the deviation of the electrode process from pure diffusion, is found to be 108.1, 2.3 & 0.78 for LiFePO4, LiMnPO4 & LiNiPO4 respectively in 2

M Li2SO4 solution. Higher the value of Λ, smaller is the deviation from pure diffusion and vice verse. The diffusion of lithium ion in LiMnPO4 and LiNiPO4 is found to be retarded by kinetic limitations like ohmic potential drops, resistance due to charge transfer and resistance due to phase transition and are the intrinsic properties of these materials neglecting the limitation of current by the SEI layer formed in case of these two materials. LiFePO4 is found to be the best among the olivine family to use as cathode material for aqueous rechargeable lithium batteries.

8728-16, Session 5

The future of high-efficiency photovoltaics from materials and applications perspective *(Invited Paper)*

Robert J. Walters, U.S. Naval Research Lab. (United States)

This talk will begin with a discussion of next generation, high efficiency photovoltaic (PV) concepts, including nano-structures cells for hot carrier and intermediate band solar cells as well as multijunction solar cell materials such as the inverted metamorphic (IMM) technology and novel, alternative concepts using Sb-containing, InP-based materials. In the talk, material scarcity issues will be touched on and emphasized, as material abundance combined with the amount of material needed must be a driving factor in PV technology development. The talk will then shift to a discussion of PV applications with a focus on portable power for military and commercial use, and building integrated PV (BIPV) such as the new Dow roofing shingle, and space applications. This section of the talk will cover thin film technologies and highlight their efficiency limitations and potential paths for eliminating the limitations, concluding with a discussion of future prospects.

8728-17, Session 5

Enhanced radiation tolerance of InGaN/silicon hybrid solar cell

Naresh C. Das, Meridith Reed, Anand V. Sampath, U.S. Army Research Lab. (United States)

InGaN solar cells can be used to extend the short wavelength performance of Si solar cells, leading to greater efficiency in energy harvesting. Thus, broad solar spectrum absorption and energy conversion can be achieved by combining InGaN solar cell(s) (UV-visible part) with silicon cells (visible-IR part) in a vertical structure using voltage matching [1]. It has also been reported [2] that InGaN material has superior radiation resistance and hence will be helpful in protecting the silicon solar cells when used as the window material in a radiation environment. Recently we reported [1] enhanced solar energy harvesting by using a hybrid voltage matched solar cell with an InGaN solar cell on top and 4 silicon solar cells on bottom. We report here increased radiation tolerance of the silicon solar cells in the hybrid solar cell structure compared to silicon solar cells only.

InGaN/GaN multiple quantum well (MQW) solar cell structures were grown on double-side-polished 50 mm (0001) sapphire substrates by metal-organic chemical-vapor deposition (MOCVD) technique. The InGaN solar cell structures consist of a 1 m unintentionally doped GaN template layer, a 2 m Si-doped n-GaN layer ([Si]=6x1018/cm3), a 10 nm highly Si-doped n+-GaN layer ([Si]=2x1019/cm3), a 30 period undoped MQW active region with 2.6 nm In0.2Ga0.8N QWs and 6.7 nm GaN barriers, a 40 nm highly Mg-doped smooth p+-GaN layer ([Mg]=5x1019/cm3), a 30 nm Mg-doped smooth p-GaN layer ([Mg]=2x1019/cm3), and a 15 nm highly Mg-doped p+-GaN contact layer. An unfiltered Newport solar simulator provided broadband illumination with an equivalent AM1.5G illumination intensity of approximately 1.0 sun (100 mW/cm2). We used a Varian Linac model 200A 2 MeV gamma radiation source with the dose rate of 2 kRad/min to determine the radiation hardness of the silicon solar cells in the hybrid structure.

As shown in figure 1 (a), the I-V curves of the silicon solar cell before and after irradiation shifted on voltage axis. Though we did not observe any significant change in Isc, the I-V curves shift shows reduction in Voc. We observed about 15 % decreases in Voc for irradiated devices compared to an unirradiated device, which will result in similar degradation in solar cell efficiency. However, when the radiation experiment was performed with the InGaN solar cell structure on top of the silicon solar cells, we did not observe any degradation as shown in figure 1 (b). In this experiment the sapphire substrate from InGaN solar cell was first removed by laser liftoff technique and then we performed the irradiation experiment with only the thin layer (about 3 microns) of InGaN solar cell structure on top of the silicon solar cells. Hence, it is concluded that by using hybrid solar cell structure with InGaN solar cell on top of the silicon solar cell the damage due to high-energy irradiation can be reduced. We will discuss in detail the results of irradiation experiments with different energies and doses for the hybrid solar cell and the InGaN solar cell compared with that of the bare silicon solar cells in the full paper.

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[2] J. Wu et al, “Superior radiation resistance of InGaN alloys: Full-solar-spectrum photovoltaic material system,” J. Appl. Phys., 94, pp. 6477, (2003)

8728-18, Session 5

A maximum power point tracking algorithm for photovoltaic applications

Sudarshan R. Nelatury, Penn State Erie, The Behrend College (United States); Robert Gray, Penn State Harrisburg (United States)

The voltage and current characteristic of a photovoltaic (PV) cell is highly nonlinear and operating a PV cell for maximum power transfer has been a design challenge for a long time. Several techniques have been proposed to estimate and track the maximum power point (MPP) in order to improve the overall efficiency of a PV panel. Hitherto, MPP is analytically found only to within a certain neighborhood, but an exact solution in closed form is not yet published. This problem can be formulated analytically as a constrained optimization for which recursive algorithms could yield a reasonably good solution. Suppose the voltage current characteristic and the constant power contours are plotted on the same voltage current plane, we need to identify the point of tangency between the device characteristic and the power curves. This point is the sought for MPP and is subject to change with the incident irradiation and temperature and hence the algorithm that attempts to maintain the MPP should be adaptive in nature and is supposed to have fast convergence and the least misadjustment. Analytically, the equations to be solved happen to be a system of nonlinear equations. An iterative algorithm is proposed and the existence of solution, its uniqueness, and convergence are dealt in this paper. Based on the steps involved in its implementation, a novel MPP tracker is proposed. The actual circuitry for the MPP tracker requires selection of various power electronics stages, but the scope of the present work is restricted only to MATLAB simulations.

8728-19, Session 5

Flexible high-efficiency solar cells: approaches and advanced design concepts

Roger E. Welser, Gopal G. Pethuraja, Magnolia Solar, Inc. (United States); Adam W. Sood, Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States)

Photovoltaic (PV) devices can provide a mobile source of electrical power for a wide variety of defense applications in both space and terrestrial environments. Many of these mobile and portable power applications can directly benefit from the development of flexible, lightweight, high-efficiency solar cells. Emerging technical approaches for achieving flexible photovoltaic power include the growth of copper indium gallium diselenide (CIGS) cells on flexible substrates and the epitaxial liftoff (ELO) of III-V devices onto thin metal film handles. With both approaches, advanced designs are needed which can further increase power generating performance, lower module weight, enhance robustness, and reduce costs.

In this paper, we review recent demonstrations of flexible, high-efficiency solar cells. Solar electric conversion efficiency in excess of 12% has been achieved on CIGS cells deposited on ultra lightweight titanium substrates. Higher conversion efficiency approaching 30% has been obtained from multiple junction III-V devices fabricated using ELO processes. In both cases, the current output can be further increased by including nanostructured coatings on the front surface of the thin-film solar cells to minimize reflection losses. Nanostructured coatings with a reduced refractive index can also be incorporated into omnidirectional reflector (ODR) structures capable of achieving high internal reflectivity over a broad spectrum of wavelengths and a wide range of angles. Such conductive, high-performance ODR structures on the back surface of a thin-film solar cell can potentially increase both the current and voltage output by scattering unabsorbed and emitted photons back into the active region of the device.

8728-20, Session 5

Photonic and plasmonic solar energy conversion *(Invited Paper)*

Jeremy N. Munday, Univ. of Maryland, College Park (United States)

The main driving force in current photovoltaic research is the desire for cheaper and more efficient devices. We have taken two approaches to this problem by considering the photonic aspects of light absorption in thin layers and the thermodynamic requirements of such devices. We find that the use of photonic and plasmonic waveguiding and light localization can greatly improve the absorption characteristics of thin film solar cells and lead to absorption enhancements in excess of the traditional light trapping limit of 4n2, where n is the index of refraction of the absorber. Further, by considering the photonic aspects of the detailed balance formulation of solar converters, we find several interesting directions to improve solar cell efficiencies, e.g. by modifying the radiative recombination rate. In this talk, I will overview our recent results and on-going experiments aimed at next generation photovoltaics.

8728-21, Session 6

Solar cell with charged quantum dots: optimization for high efficiency *(Invited Paper)*

Kimberly A. Sablon, U.S. Army Research Lab. (United States); Vladimir V. Mitin, Nizami Z. Vagidov, Andrei V. Sergeev, Univ. at Buffalo (United States)

Charging of quantum dots (QDs) significantly improves the performance of QDs solar cells due to the following factors. First, it increases electron coupling to sub-bandgap photons and provides effective harvesting of IR energy. Second, QD charging is also an effective tool for managing the potential profile at micro- and nanoscales. QDs are always charged since electrons from the dopants fill QDs. Under solar radiation QDs are also filled by photocarriers. In the last case the filling of QDs is determined by the condition of equality of electron and hole capture rates. Because of strong difference in effective masses of electrons and holes, an electron level spacing in QDs substantially exceeds a level spacing for holes. Therefore, QDs play a role of deep traps for electrons, but they are just shallow traps for holes. Thus, the holes trapped in QDs may be excited by thermal phonons, while excitation of localized electrons requires IR radiation. Therefore, n-doping of QD structures is strongly preferable for photovoltaic applications. Moreover, without adequate electron doping of QD medium, QDs are filled by electrons from the n-doped junction area and deteriorate the solar cell performance. Corresponding selective n-doping of QD medium provides micro- and nanoscale potential profiles favorable for effective photovoltaic conversion. Potential barriers around charged QDs decrease the photoelectron capture and suppress recombination processes via QDs. Filling QDs predominantly from dopants in QD medium allows one to maintain the macroscale potential profile analogous to that in the best conventional single-junction solar cells.

8728-22, Session 6

Flexible copper indium gallium diselenide photovoltaics for unmanned aircraft systems

Jesse A. Frantz, Jason D. Myers, U.S. Naval Research Lab. (United States); Robel Y. Bekele, Univ. Research Foundation (United States); Vinh Q. Nguyen, U.S. Naval Research Lab. (United States); Allan J. Bruce, Sergey V. Frolov, Michael Cyrus, Sunlight Photonics (United States); Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

The availability of electrical power frequently limits mission lifetime and scope for unmanned aircraft Systems (UASs). Photovoltaic (PV) panels have been proposed as an appealing alternative or supplement to traditional power sources for these platforms. Silicon and III-V material based PVs, however, employ thick substrates that add significant weight to UAS platforms. Furthermore, their rigidity limits design options, requiring large, flat surfaces. Thin film PVs offer one potential solution with specific power (measured in W/kg) significantly higher than that of traditional PV and the potential for flexible devices. Among the thin film PV materials, copper indium gallium diselenide (CIGS) has produced the best laboratory results on rigid glass substrates. Typically, CIGS is deposited by co-evaporation or, alternately, by deposition of the metals with, or followed by, treatment in a selenium environment. We present results from an alternative deposition method that instead uses RF magnetron sputtering from a single quaternary target without additional selenization. This technique has already produced devices with conversion efficiencies over 11%. The novel fabrication methods are especially well suited to fabrication on flexible polyimide substrates and have the potential to result in performance improvements over evaporated CIGS devices. This will ultimately result in SWAP advantages over existing technology, longer mission lifetimes, and may potentially lead to continuous operation of UASs.

8728-23, Session 6

Evaluation of the temperature dependence of thermoelectric properties of materials under steady-state isothermal conditions

Jay R. Maddux, U.S. Army Research Lab. (United States)

A rapid, simple, and highly accurate method for characterizing the temperature dependence of thermoelectric properties of materials is presented. In this special method, two well-controlled heat flows into/out of a sample are balanced. The two heat flows are non-contact radiative-input heat and Peltier heat caused by electrical current passed through a sample. [1] Radiative-output heat loss from the sample to the surroundings would normally cause error. However, in this method that is eliminated by performing the measurements within a small copper chamber whose temperature exactly matches the sample. By exactly balancing Peltier and radiative-input heat flows, the temperature difference across a sample can be forced to converge to exactly zero: the isothermal condition. Under isothermal conditions, all steady-state heat flows can be uniquely determined because all parasitic heat flows that could cause error become negligible and that enables accurate measurements. In this presentation, we employ this method at increasing temperature to evaluate the temperature dependence of three principal thermoelectric properties of (Bi,Sb)2(Se,Te)3 alloys [2]: Seebeck coefficient, electrical resistivity and thermal conductivity. Determination of

Z (or ZT) from these data is therefore straightforward.

[1] J. Maddux, P. Taylor, Proc. SPIE 8035, Energy Harvesting and Storage: Materials, Devices, and Applications II, 803511 (2011).

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8728-24, Session 6

Piezoelectric-based electrical energy harvesting and storage methods and electronics for munitions

Carlos M. Pereira, U.S. Army Armament Research, Development and Engineering Ctr. (United States); Jahangir S. Rastegar, Dake Feng, Omnitek Partners, LLC (United States)

The Armament Research development Center (ARDEC) and the Army Research Laboratories in Adelphi, Maryland, and their small business collaborator (Omnitek Partners, LLC) have been developing energy systems that can serve as alternatives to current reserve batteries in certain applications in gun-fired munitions. These energy systems rely on electrical energy that is harvested during the launch and the flight. Harvested energy from the launch and the flight of gun–launched munitions is used to charge a storage device such as a capacitor or an ultra-capacitor. The work to be presented focuses on the coupling of the energy harvester and the appropriate matching of the harvester output parameters with the storage medium in order to achieve optimum efficiency considering the strict requirements of munitions applications. It is shown that using a novel passive method, efficiencies of over 70 percent could be achieved in the transfer of the generated electrical charges to appropriately selected storage medium.

The paper also describes the development of test-beds that simulate electrical charge generation of the energy harvesting power sources during the firing and the flight. These test-beds provide the means to test the conversion electronics in realistic conditions and to conduct further studies of the internal structure and design of storage medium. Results of tests with the energy conversion electronic circuitry developed for different applications using the above firing and flight simulation test-beds are presented. A discussion is also presented on the methods to improve energy conversion efficiency and high-G survivability for operation in harsh gun-launch environment.

8728-25, Session 7

System-level solar module optimization

Monica Rivera, Grahm C. Roach, Joseph N. Mitchell, Jeffrey L. Boehme, Southwest Research Institute (United States)

Concentrated photovoltaic (CPV) systems achieve the highest level of solar conversion efficiency of all photovoltaic (PV) technologies by combining solar concentration, sun tracking, and high-efficiency multi-junction PV cells. Although these design features increase the overall efficiency of the device, they also dramatically increase the cost and physical volume of the system and make the system fragile and unwieldy.

In this paper, we present recent progress towards the development of a robust, reduced form-factor CPV system. The CPV system is designed for portable applications and utilizes a series of low profile optical and optomechanical components to concentrate the solar spectrum, enhance energy absorption, and track the sun throughout the diurnal cycle. Based on commercial off-the-shelf (COTS) single-junction PV cells, the system exploits the efficiency gains associated with tuning the wavelength of the incoming light to the band-gap of a PV material. This is accomplished by spectrally splitting the concentrated incident beam into multiple wavelength bands via a series of custom optical elements. Additional energy is harvested by the system through the use of scavenger PV cells, thermoelectric generators, and biologically inspired anti-reflective materials. The system's compact, low-profile active solar tracking module minimizes the effects of wind-induced loads and reduces the overall size of the system, thus enabling future ruggedization of the system for defense applications. Designed from a systems engineering approach, the CPV system has been optimized to maximize efficiency while reducing system size and cost per kilowatt-hour. Results from system tests will be presented and design trade-offs will be discussed.

8728-26, Session 7

High-efficiency boost convertor for remote sensors

Mark R. Morgenstern, David M. Mackie, U.S. Army Research Lab. (United States)

Unattended remote sensors (URSs) are a critical asset to enable threat monitoring, border and perimeter security, and situation awareness. Currently, many URSs have a large portion of their size and weight attributed to large battery packs required to support their operation. This limits missions to a few months, even with state-of-the-art batteries. Battery replacement after deployment is expensive, is hazardous in hostile areas, and reveals the URS's location. Many alternative power sources have been proposed, such as windmills, solar panels, and fuel cells. However, large installations are often undesirable because the URSs must remain inconspicuous. Unfortunately, small alternative power sources typically produce voltage and current outputs that are unusable by the radio, data, and sensory electronics in URSs. We have tailored existing boost convertor technology in order to raise low-voltage / low-current power to voltage levels appropriate to trickle-charge capacitor banks or small battery packs. To maximize efficiency and utility, switching losses (e.g. drain to source current during coil charging, inductor core losses, and switching energies) are minimized. Component values are tailored with SPICE modeling to the available source and intended load. Components used are inexpensive and commercially available. We have demonstrated that power sources as low as 200mV and 30mA can be converted to useable voltage levels of 5 – 12 volts, with occasional bursts of hundreds of milliamps of current. The overall measured efficiency of the boost converter is >65%. This new high-efficiency boost converter will enable completely new mission profiles and increased persistence of surveillance.

8728-27, Session 7

Energy harvesting and energy scavenging approaches to power micro-instruments for on-site use

Gurjit Dulai, Donghyun Lee, Vassili Karanassios, Univ. of Waterloo (Canada)

In classical plasma-based elemental analysis, plasmas can consume as much as 25 L/min of Ar gas and require 1-2 kW of power. But when plasmas are scaled down to become microplasmas, power and gas consumption also scale down. Thus, size sets power and gas consumption requirements. For power, how does one either harvest energy or scavenge energy to power postage stamp-size or sugar-cube size devices (for example, for elemental analysis of metallo-proteins)? In this presentation [1], energy harvesting and energy scavenging approaches will be discussed.

1. V, Karanassios, Powering mobile micro- and nano-instruments, Materials Research Society (MRS) conference, Boston, MA, USA, November 28-December 2, 2011 (Invited)

8728-28, Session 7

Vehicle to grid: electric vehicles as an energy storage solution

Nicole Wells, Nicholas Waite, Rodney McGee, Fouad E. Kiamilev, Willett M. Kempton, Univ. of Delaware (United States)

With increased focus on intermittent renewable energy sources such as wind turbines and photovoltaics, there comes a rising need for large-scale energy storage. The vehicle to grid (V2G) project seeks to meet this need using electric vehicles, whose high power capacity and existing power electronics make them a promising energy storage solution. This paper will describe a charging system designed by the V2G team that facilitates selective charging and backfeeding by electric vehicles. The system consists of a custom circuit board attached to an embedded linux computer that is installed both in the EVSE (electric vehicle supply equipment) and in the power electronics unit of the vehicle. The boards establish an in-band communication link between the EVSE and the vehicle, giving the vehicle internet connectivity and the ability to make intelligent decisions about when to charge and discharge. This is done while maintaining compliance with existing charging protocols (SAEJ1772, IEC62196) and compatibility with standard “non-intelligent” cars and chargers. Through this system, the vehicles in a test fleet have been able to successfully serve as portable temporary grid storage, which has implications for regulating the electrical grid, providing emergency power, or supplying power to forward military bases.

8728-29, Session 7

Performance of a bending mode energy harvester using Fe-Ga alloy (Galfenol)

Robert Haynes, JinHyeong Yoo, U.S. Army Research Lab. (United States); Alison B. Flatau, Univ. of Maryland, College Park (United States)

Magnetostrictive materials are distinguished by the phenomenon of dimensional changes in response to changes in the magnetization of a ferromagnetic material. Magnetostrictive materials also experience an inverse effect whereby magnetization changes occur in response to changes in applied stress fields. Iron-Gallium alloys (Galfenol, Fe_(100-x)Ga_x, 12 < x < 30) are promising transducer materials that combine desirable mechanical properties with advantageous magnetostrictive properties. These characteristics make it possible to design robust structural sensors and energy harvesters which exhibit temperature insensitivity and high strength under mechanical loads.

In this work, an investigation will be performed into the power potential of a magnetostrictive energy harvester constructed from a cantilevered Galfenol-Aluminum unimorph beam subject to vibratory loads. The Galfenol strip is offset from the neutral axis. As the beam alternates between tension and compression during bending, strain-induced changes in magnetic permeability occur. A pickup coil wound around the beam harvests the power produced as a result of the time rate of change of the magnetic flux within the Galfenol strip. Through optimization of the beam configuration, the permeability change during bending can be maximized. This paper will show an optimal design for a bending mode energy harvester based on base excitation level. Power generation and efficiency data are presented for a given size limitation of the device.

8728-30, Session 7

Scintillator-based beta-batteries

Noa M. Rensing, Timothy C. Tiernan, Urmila Shirwadkar, Patrick O’Dougherty, Sara Freed, Rastgo H. Hawrami, Michael R. Squillante, Radiation Monitoring Devices, Inc. (United States)

Some long-term, remote sensor installations do not have access to conventional harvestable energy in the form of solar radiation (or other ambient light), wind, environmental vibration, or wave motion. Radiation Monitoring Devices, Inc. (RMD) is carrying out research to address the most challenging applications, inaccessible sensors that must operate for many months or years and which have undependable or no access to environmental energy. Radioisotopes are an attractive candidate for this energy source, as they can offer a very high energy density combined with a long lifetime. Both large scale nuclear power plants and radiothermal generators are based on converting nuclear energy to heat, but do not scale well to small sizes. Furthermore, thermomechanical power plants depend on moving parts, and RTG’s suffer from low efficiency. To address the need for compact nuclear power devices, RMD is developing a novel beta battery, in which the beta emissions from a radioisotope are converted to visible light in a scintillator and then the visible light is converted to electrical power in a photodiode. By incorporating strontium-90 into the scintillator SrI¬2 and coupling the material to a wavelength-matched solar cell, we will create a scalable, compact power source capable of supplying milliwatts to several watts of power over a period of up to 30 years. We will present the latest results of radiation damage studies and materials processing development efforts, and discuss how these factors interact to set the operating life and energy density of the device.

8728-31, Session 7

Review of the energy harvesting systems for munitions and firing platforms

Carlos M. Pereira, U.S. Army Armament Research, Development and Engineering Ctr. (United States); Jahangir S. Rastegar, Dake Feng, Omnitek Partners, LLC (United States)

A review is presented of energy harvesting systems developed at the U. S. Army Armament Research Development Engineering Center (ARDEC) and its small business partners for munitions. The efforts include the development of a number of novel piezoelectric-based energy harvesting power sources for gun-fired munitions and weapon platforms and the development of Thermophotovoltaic (TPV) based energy harvesting power sources for supersonic rounds. The piezoelectric devices use mass-spring elements. Firing shock loading is used to store mechanical energy in the device springs. Vibration of the device mass-spring following firing provides a cyclic load on the piezoelectric element, which converts it to electrical energy. The power source spring-mass units are designed to harvest additional energy from vibratory motions during the flight. The developed piezoelectric-based power sources provide safe sources for initial powering of munitions electronics since they have no stored electrical energy before firing. They are designed to survive launch accelerations in the range of 10-200 KGs and depending on application and available volume, power requirements in the range of 5 mJ to 150 mJ can be met.

The Thermophotovoltaic (TPV) based energy harvesting power sources are designed to generate electrical energy from heating of the leading edges of supersonic munitions during the flight. Prototypes of such TPV-based power sources were constructed and successfully tested in supersonic munitions.

In this paper, a number of developed piezoelectric-based and TPV-based energy harvesting power sources are presented and their operation and characteristics as well as their potential applications in munitions and weapon platforms are described.

8728-32, Session 7

Tritium power source for long-lived sensors

Marc S. Litz, U.S. Army Research Lab. (United States); Dimosthenis C. Katsis, Athena Energy Corp. (United States); John A. Russo, David A. Burns, James J. Carroll, U.S. Army Research Lab. (United States)

The first report of charge storage from isotopes was documented in 1913. [1] In the experiment, Moseley showed that in an evacuated chamber surrounding 20 mCi of radium, he could develop 100s of kV of voltage potential due to the charge emitted (beta decay) from the radium. Charge collection using isotope emission showed just how versatile were Moseley’s experimental talents. It was particularly challenging at that time because few materials were available to sustain high-voltage. This result was simply described and had great impact.

Low-power applications are well suited to using micro-grams of isotope. Long-lived applications are particularly well suited to isotope power sources. These include sensors located in remote locations, buried sensors in infrastructure/building/bridge, compact devices for tracking animals, self-powered MEMS and Micro-robots. Flight recorders using 60Co providing 100uW power [2] have been proposed for commercial use. Protections of electronics controlled by field programmable gate arrays (FPGAs) can be inhibited/destroyed for applications requiring anti-tamper (AT) circuits. The most compelling applications are those requiring energy sources for long-lived sensor elements for space, oceanographic exploration, bio-medical engineering & structural engineering.

Isotope power sources provide a continuous flow of energy from decaying isotopes. When isotopes decay they emit alpha, beta or gamma particles. The energy from the emitted particles can be converted to electrical current without intermediate thermalization. Avoiding heat signatures is accomplished by energy conversion efficient practices and keeping the devices low power. Isotopes decay in five possible modes, 1) alpha decay, 2)beta decay, 3)positron emission, 4)electron capture, and 5) isomeric transitions. Combinations of particles (α, β, positron, and ?) are commonly emitted during a given type of decay. Alpha particles (5 MeV) typically carry more energy than β or γ emitters but few materials can stand-up to the α-bombardment without significant deterioration.

Tritium encapsulated in glass vials, lined with phosphor, has met all the levels of examination that have earned a general license for commercial lighting systems. These devices are used in emergency exit signs in airplanes and public buildings. Extending their use to provide power as a long-lived battery is a step that should be achievable in the near future. The commercial companies that package light sources for exit signs and emergency lighting can provide the cells, which we propose to use as a light emitter for a power source. By adding photovoltaic conversion of the light to electrical current, a small (100uW) power source has been designed. The device is inexpensive compared to other approaches that may offer more efficient conversion techniques, higher energy-density and more compact packaging. While iterative steps can be taken to make a tritium power source more efficient, (encapsulation techniques, more efficient phosphors, tuned PV) these rudimentary sources offer a practical first step. These long-lived power sources can have impact on sensors and network arrays now.

8728-38, Session 7

Betavoltaic power sources for ultra-low power electronics

Christopher Thomas, Samuel Portnoff, Widetronix, Inc. (United States); Michael G. Spencer, Cornell Univ. (United States)

Betavoltaic power sources enable remote sensing devices that can run unattended in the field for decades. They use the electron voltaic effect in semiconductor junctions to harvest the energy of beta particles, producing a direct current output. Betavoltaics have key advantages due to their long lifetimes, ability to operate in harsh environments, and high energy density. Widetronix is developing silicon carbide (SiC) betavoltaics, which, due to its wide bandgap, enables the design of betavoltaic devices with high conversion efficiencies (> 20%) and a high open circuit voltage (2.0 V). The current line of planar SiC devices, when connected in series and parallel like traditional batteries, can generate up to 0.38 μW/cc continuously for over a decade. With wafer thinning, the output of a planar betavoltaic stack can be increased to over 1.0 μW/cc. Widetronix has also begun to fabricate textured betavoltaics that will increase the power density of a 1 cc betavoltaic stack by a factor of 100. In addition, Widetronix has built ultra low power microcontroller driven electronics that alternate between sleep and active modes on a given duty cycle to perform real time clock functions for a power budget of 150 nW. Charge from the betavoltaic is accumulated in either capacitors or thin film rechargeable batteries and is burst out when drawn by the circuit. The next generation of Widetronix electronics are designed to take and store sensor measurements in the active portion of the duty cycle, and Widetronix has demonstrated betavoltaic enabled transmission over 100 yards.

8728-39, Session 7

Controlling the interplay of photonics, electronics, and thermodynamics in solar upconversion *(Invited Paper)*

Jennifer A. Dionne, Stanford Univ. (United States)

Upconversion of sub-bandgap photons is a promising approach to exceed the Shockley-Queisser limit in solar technologies. Calculations have indicated that ideal upconverter-enhanced cell efficiencies can exceed 44% for non-concentrated sunlight, but such improvements have yet to be observed experimentally. In this presentation, we develop both theoretical and experimental methods to understand and improve solar upconversion, considering photonic, electronic, and thermodynamic design constraints.

First, we develop a thermodynamic model of an upconverter-cell considering a highly realistic narrow-band, non-unity-quantum-yield upconverter. As expected, solar cell efficiencies increase with increasing upconverter bandwidth and quantum yield, with maximum efficiency enhancements found for near-infrared upconverter absorption bands. Our model indicates that existing bimolecular and lanthanide-based upconverters will not improve cell efficiencies more than 1%, consistent with recent experiments. However, our calculations show that these upconverters can significantly increase cell efficiencies from 28% to over 34% with improved quantum yield, despite their narrow bandwidths. Then, we develop the experimental techniques to enhance upconversion efficiencies, tailoring both the optical density of states via plasmonics and the electronic density of states via pressure measurements.

Our results highlight the interplay of absorption and quantum-yield in upconversion, and provide a platform for optimizing future solar upconverter designs.

8728-33, Session PSTUE

Design and modeling of the trapezoidal electrodes array for electrets energy harvester

Mohamad Radzi Ahmad, Mohd Haris Md Khir, Univ. Teknologi Petronas (Malaysia); John Ojur Dennis, Universiti Teknologi Petronas (Malaysia)

Electret-based electrostatic energy harvester technique to harvest electrical energy from ambient vibration is introduced in this paper. Specifically, a new design of the electrode structure called trapezoidal electrodes is developed, modeled, simulated and then fabricated into a miniaturized silicon device. The trapezoidal electrodes and electrets designs are thoroughly analyzed to evaluate its performance. Theoretical analysis is first modeled with Matlab/Simulink tool and later simulated with Finite Element Analysis (FEA) tool. Analysis result shows that the trapezoidal electrodes is able to harvest an average output power of approximately 1 mW from a 20 Hz frequency and 1 g acceleration input vibrations. Further mechanical and electrostatic analyses conducted with FEA, indicates that the trapezoidal electrodes structure vibrates at 113 Hz resonance frequency and induced 1895 pC of charge from 450 VDC electrets surface potential. The optimized parameters derive from the analysis and the simulation are used to fabricate the physical device on a standard 0.35 micron CMOS-MEMS (Micro Electro-Mechanical System) process technology.

8728-34, Session PSTUE

Pseudocapacitive and hierarchically ordered porous electrode materials supercapacitors

Bilge Saruhan-Brings, Yakup Gönüllü, Benedikt Arndt, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Batteries require long time to charge but store greater charges, while capacitors can be charged very rapidly within seconds, but suffer from lower energy densities. With new electrodes which introduce pseudo-capacitance and higher surface area, super-capacitors charge rapidly and also have higher electrical energy densities and supply this longer. These features are desirable for a range of applications, in electric vehicles and for storage of energy from renewable energy supplies such as solar and wind power which can come in short bursts. Other applications of super-capacitors and more specifically pseudo-capacitors that combine features of both rechargeable battery and standard capacitor are in mobile digital technologies and flash photography.

This work demonstrates the fabrication of pseudocapacitive films grown by electrochemical deposition and nano-tubular layers achieved by anodisation of metallic plates. The electrochemical testing of the electrodes in half-cells indicates improvement of charge storage behaviour relying on combination of atomic- and nano-scale structures in films. The redox pseudo-capacitive behaviour of the films is analysed by means of cyclic voltammeter measurements. Capacitive charge-storage properties of mesoporous films made of complex metal-oxides in core + shell architecture are superior to those of non-porous and crystalline metal-oxides. Cation intercalated, aligned nano-structured (titania) combined with redox capable oxides (such as Mn, Co, Ni, Li etc.) introduces enhanced capacitance and storage capabilities. Mn-based mixed redox oxides yield higher cyclic charge/discharge stability.

8728-35, Session PSTUE

Modeling of high-efficiency ITO/ZnO quantum wire photovoltaic

Fahad A. Althowibi, Kimberly Kaltenecker, Yevhen Rutovytskyy, Eric Donkor, Univ. of Connecticut (United States)

This paper presents a new nanofiber ITO/ZnO/ITO photovoltaic cell designed to have higher efficiency of solar energy conversion. The ZnO is the active medium and it also serves as the core of the fiber. It is sandwiched between ITO cladding layers. The thickness of ZnO film ranges between 20-30nm while ITO thickness is between 200-300 µm. By virtue of the higher refractive index of the ZnO and its higher bandgap relative to ITO, the incident light is impinging on ITO cladding couples to ZnO core. The resultant photogenerated carriers in the ZnO are then transferred across ITO/ZnO heterointerfaces to the ITO due to bandgap discontinuity between ITO and ZnO. As a result, the optical and electrical paths of the solar cell are effectively separated.

A model of light absorption and propagation for the energy conversion will be presented. The optical model will be based on guided-wave theory and the energy conversion model will be based on energy-band theory for the ITO-ZnO heterojunction. Results will be presented for high efficiency generated photocurrents (cell short-circuit current) and high voltage across cell terminals (cell open-circuit voltage) as function of material parameters and device geometry.

8728-36, Session PSTUE

Performance study of glucose-yeast-ethanol bio-hybrid fuel cell

David M. Mackie, Sanchao Liu, Marcus S. Benyamin, U.S. Army Research Lab. (United States); Rahul Ganguli, Teledyne Scientific Co. (United States); James J. Sumner, U.S. Army Research Lab. (United States)

Renewable alternatives to fossil hydrocarbons for energy generation are of great interest, for a variety of political, economic, environmental, and practical reasons. These alternatives must also be environmentally sustainable and convenient to implement. Proton exchange membrane (PEM) fuel cells provide clean, quiet power from hydrogen or alcohol, but these fuels are inflammable and/or toxic. These hazards impose additional logistics burdens and safety issues. Sugar as a fuel has many positives: energy density, safety, sustainability, and the ability to be scavenged from native ecosystems or from waste streams. While microbial fuel cells (MFCs) can efficiently use various sugars as fuel, they suffer from low power densities. Here we investigate a bio-hybrid fuel cell: yeast ferments glucose to ethanol; the filtered fermentate fuels a direct alcohol fuel cell (DAFC) in batch mode. There are no additional measures such as pumping. We use small, commercial-off-the-shelf DAFCs, both as-bought and slightly modified to enlarge the fuel reservoir. Shifting the DAFC from purified aqueous alcohol to fermented media raises many questions. These include how the starting materials, byproducts of the fermentations, and DAFC waste products affect the long-term performance of the catalytic oxidation of ethanol at metal catalysts in batch mode. This study examines the effects of ionic strength, cation size, buffering strength, alcohol concentration, fermentation / fuel cell byproducts, interfering organics, and load resistance. The performance obtained is comparable to that of a DAFC with purified aqueous ethanol. The modified DAFC can provide useable amounts of power for weeks.

Conference 8729: Scanning Microscopies 2013: Advanced Microscopy Technologies for Defense, Homeland Security, Forensic, Life, Environmental, and Industrial Sciences

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8729-1, Session 1

SEM/EDS fixed-beam or overscan analysis of particles can miss the real structure: x-ray spectrum image mapping reveals the true nature *(Keynote Presentation)*

Dale E. Newbury, Nicholas W. M. Ritchie, National Institute of Standards and Technology (United States)

The typical strategy for analysis of a microscopic particle by scanning electron microscopy/ energy dispersive spectrometry (SEM/EDS) x-ray microanalysis is to use a fixed beam placed at the particle center or to continuously overscan to gather an "averaged" x-ray spectrum. While useful, such strategies inevitably concede any possibility of recognizing microstructure within the particle, and such fine scale structure is often critical for understanding the origins, behavior, and fate of particles. Elemental imaging by x-ray mapping has been a mainstay of SEM/EDS analytical practice for many years, but the time penalty associated with mapping has discouraged its general use and reserved it more for detailed studies that justified the time investment. The emergence of the high throughput, high peak stability silicon drift detector (SDD-EDS) has enabled a more effective particle mapping strategy: "flash" x-ray spectrum image maps can now be recorded in seconds that capture the spatial distribution of major (concentration, $C > 0.1$ mass fraction) and minor ($0.01 \leq C \leq 0.1$) constituents. The NIST DTSA-II software engine is a powerful aid for quantitatively analyzing this mapping information (available free at: http://www.cstl.nist.gov/div837/837.02/epq/dtsa2/index.html).

8729-2, Session 1

Does your SEM really tell the truth: How would you know? Part 2 *(Keynote Presentation)*

Michael T. Postek, András E. Vladár , National Institute of Standards and Technology (United States)

The first paper in this series, discussed some of the issues related to signal generation in the SEM, instrument calibration, electron beam interactions and the need for modelling to understand the actual image formation process. All these were summed together in a discussion of how these issues effect measurements made with the instrument. This second paper, discusses two other major issues confronting the microscopist, specimen contamination and instrument vibration/motion. NIST has done a great deal of research into both of these issues especially sample contamination and its removal and elimination and some of this work is reviewed here. Today, given the proper accessory equipment, such as oxygen or hydrogen plasma cleaner, attached to the instrument, contamination can be eliminated. The second topic discussed is instrument/sample instability, vibration and drift. SEMs need to be highly stable especially at high magnification and resolution. The motion of a sample either through vibration or stage drift modifies the image being viewed and compromises any measurement made with that instrument. NIST has developed approaches to solving this problem and this presentation discusses both of these issues and their effects on imaging and measurements made with the SEM that every user should know, and understand before any critical quantitative work is attempted.

8729-3, Session 1

Electron microscopy and forensic practice *(Invited Paper)*

Marek Kotrly, Ivana Turková, Institute of Criminalistics Prague (Czech Republic)

Electron microscopy is one of the essential techniques of forensic inorganic microanalysis. The use is facilitated by versatility, availability, rapidity of analysis and routinely by unequivocal interpretation of results. SEM and EDS/WDS systems are predominately applied due to versatility and simplicity in sample preparation. Systems enable the processing of a vast spectrum of samples and materials - classic micro traces - glass fragments, gunshot residues, post-blast residues (PBR), explosives and propellants, pigments and paint systems, colour layers of art works, soils phases, mineralogical and petrologic samples, unknown samples (including extortionate letters), fillers and additives of paper and plastics,building materials, fillers of safety boxes, bulb filaments from road accidents, gemmological objects., etc. Another field of the use is surface characteristics, grain size and analysis of inorganic phases in organic matrices - cosmetic and pharmaceutical products, narcotics, etc. The potential use can be found in forensic defectoscopy when analysing fracture areas and other defects. Next field comprises biological and anthropological disciplines - analysis of hair and hairs, determination of insect eggs, etc. Less traditional areas include analysis and comparisons of nanoparticles and nanocomposites, analysis of intersecting lines in documents, analysis of holograms and other protecting elements. From successive techniques, cathode luminescence is widely used not only in forensic mineralogy and gemmology. Ion microscopy (FIB) - has been gaining ground recently, particularly for analyses and comparisons of nanocomposite structures, micro-and nanoparticles, functional glass layers and the like, coupled with 3D reconstruction and particle documentation. TOF-SIMS technique in FIB systems will probably provide further future development as well.

8729-4, Session 2

A Large range metrological atomic force microscope and its uncertainty analysis

Sitian Gao, Qi Li, Wei Li, Mingzhen Lu, Yushu Shi, National Institute of Metrology (China)

The Scanning probe microscopes (SPMs) are widely used in nanotechnology research and industry. To ensure the quantity consistency, metrological instruments are developed to calibrate the standard artifacts. The grating pitch artifacts are used to calibrate the lateral magnification of instrument as SEM and SPM.

A large range metrological atomic force microscope (AFM) with 50mm?50mm?4mm scan range has been designed and constructed. In this paper, the structure and the performance of the instrument are briefly introduced. The AFM is a sample scanning instrument and the displacement is traced to SI unit with multi-pass interferometer. One dimensional grating pitch specimens are measured and the pitch values are investigated with gravity center method. The mean pitch values are estimated by fitting the gravity canter positions. The error sources are analyzed and the errors caused by sample oblique due to sample arrangement are corrected. The measured standard deviation of 400 nm grating pitch is 0.2 nm.

8729-5, Session 2

Performance improvement of a large-range metrological AFM through parasitic interference feedback artifacts removing by using laser multimode modulation method

Qi Li, Sitian Gao, National Institute of Metrology (China); Zheng Ming Lu, Wei Li, Shu Yu Shi, national institute of metrology P.R China (China)

A large range multi-functional metrological atomic force microscope has been set up at NIM, which is based on optical beam deflection method to make traceable measurement of standard samples, this machine is deliberately designed to use three axes stacked piezoceramics actuators, homodyne interferometer framework associated with eight times optical path multiplier interferometer mirror and compact AFM head with special track and convergence lens. However in practical a parasitic interferences by sample surface and cantilever influence calibration results quite well, so in paper a laser multimode modulation method is mentioned to remove the effect.

8729-6, Session 2

Development of atomic force microscope (AFM) tip width calibration standards

Ronald G. Dixson, National Institute of Standards and Technology (United States); Boon Ping Ng, A*STAR Singapore Institute of Manufacturing Technology (Singapore); Craig McGray, Ndubuisi Orji, Jon Geist, 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. A major component of this program is the use and traceable calibration of critical dimension atomic force microscopy (CD-AFM) – which uses flared tips and two-dimensional surface sensing to scan the sidewalls of near-vertical and reentrant features. [1]

Since the calibration of tip width is an essential element of traceable CD-AFM metrology, a closely related effort is the development of a new generation of the NIST single crystal critical dimension reference material (SCCDRM) project, using a novel self-aligned selective etching process. [2] This effort is pushing toward feature widths below 10 nm, with the prospect of CD-AFM tip width calibration having expanded uncertainty (k = 2) below 1 nm.

Line width roughness is an important contributor to the uncertainty, so we are working to improve feature uniformity through refinement of the etch process. We will report the results of etching experiments on Si(111) surfaces to minimize the surface roughness.

1. R. Dixson, N. G. Orji, C. D. McGray, J. Bonevich, J. Geist, “Traceable Calibration of a Critical Dimension Atomic Force Microscope,” J. Micro/Nanolith. MEMS MOEMS Vol. 11, 011006 (2012).

2. C. McGray, R. Kasica, N. G. Orji, R. Dixson, M. Cresswell, R. Allen, and J. Geist, “Robust Auto-Alignment Technique for Orientation-Dependent Etching of Nanostructures,” J. Micro/Nanolith. MEMS MOEMS Vol. 11, 023005 (2012).

8729-7, Session 2

Automatic tuning of proportional-integral controller for atomic force microscopy based on graphics

Daixie Chen, Institute of Electrical Engineering (China); Bohua Yin, Institute of Electrical Engineering (China); Li Han, Yunsheng Lin, Mingzhang Chu, Institute of Electrical Engineering (China)

The control of a typical Atomic Force Microscope (AFM) is through some variant on a Proportional-Integral (PI) controller. As the well known tedious and complicated parameters tuning procedure, this paper shows a novel automatic tuning method for PI parameters based on graphics. It maps the four main indices about step response such as rise time, overshoot, resolving time and steady-state error to one cost function. Then it generates 3-D plot using P, I and value of the cost function with objective to search for maximum value. Grain analysis algorithm is used to select the optimal parameter group. Experimental results in AFM show that this approach offers system with optimal step response and better feedback control while getting less error signal in line scan.

8729-8, Session 2

Hybrid metrology for critical dimensions data to enable 1X node production

Johann Foucher, CEA-LETI (France)

To fulfil advanced process control requirements for 1X node production, the semiconductor industry must cope with multiple parallel metrology requirements such as resolution, precision and accuracy enhancement in all directions to answer to new 3D integrated circuit fabrication methods. Current limitations of conventional techniques (i.e., CD-SEM and Scatterometry) tend to complicate global process control configuration in the semiconductor industry. Recently, a new approach, so-called hybrid metrology, has been proposed that consists of using in tandem multiple techniques that collectively reduce global measurement uncertainty. To successfully integrate data from multiple measurements, data fusion algorithms are employed in hybrid metrology to reduce measurement uncertainty. Through this approach, various topologies can be used—for example parallel, serial or tree topologies—to satisfy ITRS recommendations.

In this paper, we will discuss various configurations of hybrid metrology dedicated to critical dimensions data. Our objective is to study and propose the best real-time multiple data analysis dedicated to the semiconductor industry. To do so, we propose the development of a universal platform dedicated to the main techniques such as CD-SEM, Scatterometry, TEM and CD-AFM. The added value on the global uncertainty of the fleet of tools we want to control is a function of the individual data quality that comes from various tools. Therefore we also focus our study on the constraints to impose on data set quality and data format. Finally, we will propose potential manufacturing solution that will enable better advanced process control for 1X nodes production.

8729-9, Session 2

Physical-chemical measurement methods for self-assembled core-shell nanostructures

Natalia Farkas, National Institute of Standards and Technology (United States); Puthupparampil V. Scaria, Martin C. Woodle, Aparna Biosciences (United States); John A. Dagata, National Institute of Standards and Technology (United States)

Improvements in dimensional metrology and innovations in physical-chemical characterization of functionalized nanoparticles are critically important for the realization of enhanced performance and benefits of nanomaterials. Toward this goal, we propose a multi-technique measurement approach, in which correlated atomic force microscopy (AFM), dynamic light scattering (DLS), high performance liquid chromatography and mass spectroscopy measurements are used to assess molecular and structural properties of self-assembled polyelectrolyte nanoparticles with a core-shell structure. In this approach, measurement methods are first validated with a model system consisting of gold nanoparticles functionalized with synthetic polycationic branched polyamide macromolecules. Shell thickness is measured by AFM and DLS, and the polyelectrolyte uptake determined by chromatographic

separation and mass spectrometric analysis. Statistical correlation between size, structure and stability provide a basis for extending the methods to more complex self-assembly of nucleic acids and macromolecules via a condensation reaction. From these size and analytical chemical measurements, we obtain a comprehensive spatial description of these assemblies, obtain a detailed interpretation of the core-shell evolution, and identify regions of the parameter space where stable, discrete particle formation occurs.

*Work performed under a NIST-Aparna cooperative research and development agreement (CRADA) CN-11-0014.

8729-10, Session 3

HTA educational outreach program and change the equation participation

Robert Gordon, Hitachi High Technologies America, Inc. (United States)

In this talk, Hitachi High Technologies America (HTA) introduces its Educational Outreach Program and explains it's involvement with Change The Equation (CTEq), a nonprofit, nonpartisan, CEO-led initiative that is mobilizing the business community to improve the quality of science, technology, engineering and mathematics (STEM) learning in the United States.

Change the Equation was started by five Chief Operating Officers from some of the largest companies in the U. S. along with the Carnegie Corporation of New York and the Bill and Melinda Gates Foundation in September 2010. In that time, CTEq has helped its more than 100 members connect and align their philanthropic and advocacy efforts so that they add up to more than the sum of their parts. CTEq is meant to answer President Obama's Educate to Innovate Campaign to move the U.S. to the top of the pack in science and math education over the next decade.

CTEq is interested in improving STEM education for every child, with a particular focus on girls and students of color which have long been underrepresented in STEM fields. Some of the key focuses of CTEq are on scalability, sustainability, an emphasis on long term impact, support of teachers in the STEM field and encouragement of hands-on-learning. With some of the long term goals of CTEq being improving corporate member philanthropy, inspiring and capturing the imagination of America's youth, providing insight to students into STEM postsecondary and career options, and advocating change at the state and national level for STEM education, the CTEq coalition will look to speak and act as a unified voice for change in STEM education in the years to come.

8729-11, Session 3

Bringing students to the mountain: a model for developing partnerships to introduce students to cutting-edge research

AnneLynn Gillian-Daniel, Univ. of Wisconsin-Madison (United States); Robert Gordon, Hitachi High Technologies America, Inc. (United States); Benjamin L. Taylor, Jon J. McCarthy, Univ. of Wisconsin-Madison (United States)

Many materials science education and outreach activities are designed to be easy and cost-effective to implement in K-12 classrooms. While these activities are extremely effective at teaching broad materials science concepts such as size and scale, materials properties, and the use of tools in science, they do not connect very closely to the work being done in materials science research laboratories. In an effort to more closely connect our outreach efforts to the work being done by our researchers, the University of Wisconsin–Madison's Materials Research Science and Engineering Center (UW-MRSEC) has developed a partnership with Hitachi High Technologies America, Inc. This partnership allows us to introduce public audiences to a state-of-the-art tabletop scanning electron microscope (SEM) that is being used by UW researchers. In this presentation, we will describe the partnership including the use of the SEM in our Research Experience for Teachers (RET) program and in our community outreach programs. Our experiences will also serve as a template for similar partnerships at other institutions.

8729-12, Session 3

Using the Hitachi TMS 3000 in a middle school classroom

Mary Ellen Wolfinger, Takoma Park Middle School (United States)

A middle school science teacher in Montgomery County, Maryland had the opportunity to have a tabletop scanning electron microscope, the Hitachi TMS 3000, in her classroom for one week. During the week the sixth grade science students used the microscope to learn about how measurements are made at the nanometer scale through measuring objects of their choice. Students compared scanning electron microscopes to optical microscopes, learned uses of nanotechnology, and practiced converting metric measurements from the measurements made with the SEM to measurements on a scale to which they are more accustomed, for example, from nanometers to micrometers. In an Open House for parents and students one evening that same week the microscope was used to teach students and their families about microscopy, nanotechnology, electrons and the electromagnetic spectrum. The Hitachi TMS 3000 was a useful instrument to integrate science, technology, engineering and mathematics in the classroom.

8729-13, Session 3

Use of a tabletop scanning electron microscope in the classroom

Carolyn Holcomb, Western Heights Middle School (United States)

It often happens in academic settings that gifted opportunities are reserved for those students marked as gifted. STEM funds and technological equipment are often earmarked for special programs and charter schools. Hitachi's school loan program for their TMS 3000 allowed a Title 1 school to offer an opportunity to its students whose math and reading scores are well below state and national levels. Each class of 7th grade students was split into two learning groups of approximately 10-15 students. One group used computers to investigate a virtual electron microscope, examining samples and generating a written response regarding interesting facts discovered. Meanwhile, the other group was given an introductory lesson on how an SEM works in relation to a light microscope. Students were given a manufactured scenario of a bioterrorist attack in which they were forensic scientists who had to make a positive identity of a neurotoxin, comparing three plant samples. Using the TMS 3000, students learned how to load samples, scan, take pictures and focus the TEM. After 45 minutes, learning groups were switched, all of them taking turns having hands-on exposure with the equipment. This experience was an eye opener to students, who otherwise would never have had such a learning opportunity. As a result many verbalized interest in pursuing careers in STEM related fields, if only to be able to use such fun equipment!

8729-14, Session 3

Integrating independent research into science curricula to foster STEM leadership

Craig Queenan, Alyssa Calabro, David L. Becker, Bergen County Academies (United States)

The Bergen County Academies (BCA) is a public magnet high school in New Jersey focused on science, technology, engineering and mathematics (STEM) education. The research program offered at the school offers students the opportunity to conduct, present and defend their own scientific research using advanced tools and techniques, including scientific equipment unavailable in most high schools.

One of the highlights of STEM education at the school is the integration of advanced microscopy into the curriculum and research programs. The school is home to the Nano-Structural Imaging Lab (NSIL) where students have access to a scanning electron microscope (SEM), a transmission electron microscope (TEM), and a laser scanning confocal microscope (LSCM).

Through their journey into research, students are given a skill set that can be transferred to future education and their careers, and will help shape the next generation of leaders in the fields of science, technology, engineering and math. By serving as an educational model for reformed STEM education, BCA is at the forefront of what STEM education in the United States will look like in the years ahead.

8729-15, Session 5

Metrological scanning electron microscope and imaging method

Bohua Yin, Daixie Chen, Li Han, Institute of Electrical Engineering (China); Sitian Gao, Mingzhen Lu, National Institute of Metrology (China)

Generally, as one of the strong and popular microstructure imaging and analysis tools, scanning electron microscope (SEM) is used to watch the surface micro or nanometer scale structure of conductor or semiconductor materials. The SEM has great magnification ability up to several hundred thousand multiple with resolution of 1~2 nanometer. Although the SEM has above advantage characters, it normally could not be considered as a standard metrology tool with trace to standard meter. There are several factors which can influence SEM metrological accuracy, such as aperture size, acceleration voltage, work distance, and so on.

In this paper, a metrological SEM based on precision stage moving is presented. In ordinary SEM mode, the image is acquired by e-beam scanning action in x and y direction. In our metrological SEM system, the image is obtained by the x-y stage scanning motion while the e-beam is stationed at somewhere. The dual axis flexure stage is used to realize step-by-step nano scale moving during obtaining two dimension SEM image. In order to getting large range moving, the flexure stage is fixed on the surface of the large displace stage which is driven by piezoelectricity motors. This double stages structure can realize both sample positioning in 50mm?50mm range and accuracy imaging in several tens of micron scale. In order to trace to the define of the standard meter, the interferometer is used to measure the stage displacement during acquiring SEM secondary electron image or back-scatter electron image.

In order to acquiring scanning image with above SEM system, the control system is indispensability. The control system based on digital signal processing (DSP) is constructed, including TMS320-6713 DSP, precision AD/DA modules, Galil motion controller, high speed data bus interface, and so on.

In this paper, the measuring accuracy is discussed in several aspects: image resolution, e-beam floating, mechanical assembling error, x-y axis orthogonality error, etc.

8729-16, Session 5

Advances in photo-thermal infrared imaging microspectroscopy

Robert Furstenberg, Christopher A. Kendziora, Michael R. Papantonakis, Viet Q. Nguyen, R. Andrew McGill, U.S. Naval Research Lab. (United States)

There is a growing need for chemical imaging techniques with spatial resolution in the range of 1-10 microns. While FTIR micro-spectroscopy is commonly used, its practical resolution limit of about 20 microns (which is twice the diffraction limit due to the weak IR sources) is often insufficient. Raman micro-spectroscopy provides adequate spatial resolution (~1 micron), but is not always practical because of its low throughput and for samples exhibiting strong fluorescence. We are developing a non-contact and non-destructive technique we call photo-thermal infrared imaging spectroscopy (PT-IRIS). It provides similar information to FTIR or Raman spectroscopy and can be applied in both stand-off and microscopy configurations. It involves photo-thermal heating of the sample with a (focused) tunable quantum cascade laser (or other suitable infrared laser) and measuring the resulting increase in thermal emission by either an infrared detector or a laser probe in the visible spectral range. The latter case allows for a further increase of the spatial resolution from the diffraction limit (~10 microns for mid-IR wavelengths with a NA=0.5 objective) to ~1 micron, under the right experimental conditions. Since the thermal emission signal from the surface is directly proportional to the absorption coefficient, by tuning the laser wavelength we directly measure the IR absorption spectrum of the sample. With minor modifications, we can also measure the IR reflectance spectrum. By raster-scanning over the surface of the sample we can obtain chemical composition maps. We demonstrate this technique by imaging different materials with structures on the microscale.

8729-17, Session 5

Surface optical properties for copper based on surface Kramers-Kroning analysis

Tao Tang, Zengming Zhang, Zejun J. Ding, Univ. of Science and Technology of China (China); Karoly Tokesi, Hungarian Academy of Sciences (Hungary); K. Goto, Nagoya Institute of Technology (Japan)

The differential surface excitation probability (DSEP) for medium energy electrons traveling in Cu is extracted by using the Werner's elimination-retrieved algorithm acting on different reflection electron energy loss spectroscopy (REELS) spectra including from thin film and bulk materials and by applying different theoretical methods. Other than a conventional treatment of the contributions to DSEP from surface and bulk excitations by simply using the bulk optical data under an implicit assumption that the dielectric function at the surface is the same as that in the bulk, we use in this work a surface Kramers-Kronig dispersion relationship for the surface energy loss function to derive the complex dielectric function . In all cases, the present results display that the optical property curves between surface layer and bulk are similar in shape, while deviate quantitatively for energies below 60 eV, which may be caused by the different electronic structures at surface and in bulk. The optical data from different theoretical methods are similar which stand on the surface optical constant of bulk material from Cu. There is some deviation among the surface optical constant from different theoretical methods and the Werner's experimental method acting on the film material's REELS spectrum which approximately represents the surface optical constant of Cu's film material. The obtained optical data is dependent on the shape and intensities of DSEP. These present data would be good approximations to the dielectric function of surface layer of different materials.

8729-18, Session 6

Monte Carlo simulation for realistic beam-sample interaction in SEM: application to evaluation of sharpness measurement methods

Zhu Ruan, S. F. Mao, Peng Zhang, Univ. of Science and Technology of China (China); H.M. Li, University of Science and Technology of China (China); Zejun J. Ding, Univ. of Science and Technology of China (China)

Simulated SEM images by Monte Carlo method under realistic instrumental conditions are used for evaluation of sharpness measurement methods. The Monte Carlo simulation of the SEM image is based on a physical model for electron-solid interaction with Mott elastic cross section and dielectric functional approach, a finite element triangle model for delicate complex sample topography and a model for description of SEM instrumental conditions (focus, astigmatism, drift and vibration). A series of simulated SEM images of a realistic sample structure, golden particles on a carbon film, under different instrumental condition parameters are generated, which can be considered as experimental results where all instrumental conditions are precisely known and controlled. An estimation of three SEM image sharpness measurement methods, i.e. FT, CG and DR method, has been performed for the simulated images. The responses of image sharpness measurement methods to various instrumental conditions are studied. All three methods show reasonable response on focus situation. For astigmatism, the variations of measured sharpness are complicated. For drift and vibration, FT method responses reasonably but CG and DR methods are not satisfied.

8729-19, Session 6

Monte Carlo Study of the Influence of Electron Beam Focusing to SEM Linewidth Measurement

Peng Zhang, Shifeng Mao, Zengming Zhang, Zejun J. Ding, Univ. of Science and Technology of China (China)

In critical dimension scanning electron microscopy (CD-SEM), the measurement error resulted from a finite electron beam spot size can not be neglected for nanoscale structure. In this work, an analysis on the influence of electron beam focusing to linewidth measurement for silicon (Si) trapezoid lines by scanning electron microscopy image has been carried out based on a Monte Carlo simulation method. The electron probe focusing with finite width due to aberration for simulating incident electron trajectories is taken into account by two different models. The simulation has been verified through a comparison with experiment. The research result shows that: 1. For a certain trapezoidal line, the larger of aperture angle and the extent of focusing position away from the just focusing plane, the bigger bias of linewidth is. 2. The focus point should be placed between the trapezoidal top surface and substrate surface for a precise measurement of the linewidth. 3. On the specimen surface the electron beam profile is deviated from the Gaussian probe shape and changes with the surface topography due to the beam focusing state especially when the vertical size of the specimen is over submicron order. The results will benefit further researches on linewidth measurement.

8729-20, Session 6

Monte Carlo simulation of x-ray photoemission electron microscopic image

Zengming Zhang, Tao Tang, Univ. of Science and Technology of China (China); Shifeng Mao, University of Science and Technology of China (China); Zejun J. Ding, Univ. of Science and Technology of China (China)

A new Monte Carlo method is built to describe the photoelectrons excited by incident X-ray generation processes and the transport process of photoelectron in solid and XPEEM image is also obtained. For contrast with experimental result, XPEEM images for Ag dot array on Si are simulated in TEY mode in the X-ray energy region upon and below Ag L3-edge and Al . The image of dots of Au on Si substrate is also simulated with the x-ray energy at M-shell absorption edge. And the trajectories of electrons scattered among dot sides and substrate surface were given to visualize the penetrating processes. Silicon substrate was substituted by the polymer PMMA for imaging, which was usually used in photon etching. The simulated XPEEM images in TEY mode are very close to the experimental pictures.

8730-1, Session 1

Technology horizons: the U.S. Air Force Headquarters level science and technology vision for 2010-2030 *(Invited Paper)*

Werner J. A. Dahm, Arizona State Univ. (United States)

Roughly once every decade since its inception as a separate Service, the U.S. Air Force has undertaken a Headquarters-level assessment identifying the scientific and technological areas it must focus on over the following decade to gain the capabilities it needs to perform its mission. Six such Headquarters-level visions have guided Air Force S&T from 1945-2010, beginning with “Toward New Horizons” led by Theodore von Kármán for General Hap Arnold, through “New World Vistas” conducted in 1995. In 2009, the Secretary of the Air Force and the Air Force Chief of Staff called on the Chief Scientist of the U.S. Air Force to conduct “Technology Horizons” as the next major Air Force S&T vision. The resulting effort received inputs ranging from the MAJCOM and Air Staff level to the operational unit level, from other DoD Services and agencies, other Federal entities, FFRDCs, national laboratories, industry, and academia. Released in 2010, the first volume of “Technology Horizons” is publicly accessible. It provides an overview of the strategic context that defines technologies likely to be “disproportionately valuable” over the 2010-2030 time frame. From this it identifies twelve overarching themes highlighting technology characteristics that are consistent with this strategic context. Technology Horizons then used a “10+10 Technology-to-Capability” process to identify a set of potential capability areas and a further set of key supporting technology areas that the Air Force must focus on to meet the strategic, technology, and budget challenges it faces over the next two decades. This paper gives an overview of “Technology Horizons” and key insights gained from it, and their implications for technology development efforts relevant to defense, security, and sensing.

8730-2, Session 1

High-performance logic circuits using solution-based, low-temperature semiconductors for flexible electronics

Israel Mejia, Ana L. Salas-Villasenor, John W. Murphy, The Univ. of Texas at Dallas (United States); George R. Kunnen, Arizona State Univ. (United States); Kurtis D. Cantley, The Univ. of Texas at Dallas (United States); David R. Allee, Arizona State Univ. (United States); Bruce E. Gnade, Manuel A. Quevedo-Lopez, The Univ. of Texas at Dallas (United States)

In this work we demonstrate high performance and low-power n-type inverters using solution-based CdS as the semiconductor in thin film transistors. Our fabrication process consists of five mask levels and a maximum temperature of 150 °C. The CdS is deposited using chemical bath deposition at 70 °C to provide full compatibility with flexible substrates. Isolated TFTs showed mobilities ~10 cm2/V-s and threshold voltages ~0.5V. Inverters were biased at 1, 3 and 5 V, resulting in maximum gains in the range of 60. The devices and circuits are fully patterned using standard photolithographic techniques that can be used to design more complex circuitry for flexible and large area electronic applications. In addition we used an extraction parameter method for our TFTs that allows the use of regular SPICE simulation software to design and test the circuits. Our simulations are in good agreement with the experimental data for isolated devices and inverters. Other circuits such as NAND gates are also demonstrated.

8730-3, Session 1

Flexible packaging and integration of CMOS IC with elastomeric microfluidics

Bowei Zhang, Quan Dong, Can E. Korman, Mona Zaghloul, Zhenyu Li, The George Washington Univ. (United States)

Significant progress has been made in flexible electronics in the past few years. However, current flexible electronic systems have not yet matched the high performance, low power consumption, low cost and scalability offered by traditional CMOS technology. In addition, current flexible electronic systems rely on either organic molecules which often have low carrier mobilities, or ultrathin inorganic semiconductor membranes which require delicate fabrication processes and are prone to mechanical damages. Another constraint on current flexible electronic systems is that they often provide only electronic functionalities with little or no fluidic functions. Here we demonstrate, to our knowledge, the first flexible packaging and integration of a CMOS die with polydimethylsiloxane (PDMS) elastomeric microfluidics. Microfluidic channels are used to deliver both liquid samples and room temperature liquid metals to the CMOS integrated circuits (ICs). The liquid metals are used to realize electrical interconnects to the CMOS chip. This avoids the traditional IC packaging challenges, such as wire-bonding and flip-chip bonding, which are not compatible with current microfluidic technologies. As a demonstration we integrated a CMOS magnetic sensor chip and associate microfluidic channels on a flexible PDMS substrate that allows precise delivery of small liquid samples to the sensor area. Furthermore, the packaged system is fully functional under bending curvature radius of three centimeters. The flexible integration of CMOS ICs with microfluidics enables compact and low-cost flexible electronic and lab-on-a-chip systems, which hold great potential for wearable health monitoring, handheld point-of-care diagnostics and environmental sensing among many other applications.

8730-4, Session 1

Biomimetic functionalization of graphene for flexible sensing platform

Steve S. N. Kim, Yen H. Ngo, Zhifeng Kuang, Sharon E. Jones, Barry L. Farmer, Rajesh R. Naik, Air Force Research Lab. (United States)

Miniaturized, energy efficient and biocompatible sensors, actuators, and batteries are expected to play key roles in advancing the human-device interface. Nanosized graphene-based electronics have been recognized as a platform for creating flexible sensing devices due to their excellent electronic and mechanical properties. Biomolecules such as peptides and DNAs offer exquisite sensitivity and selectivity towards analytes. Nanomaterials such as graphene can serve to transduce the binding activity of the biomolecules into an electronic output. Our work has focused on developing designer biomolecules that interact with nanomaterials and be used in the development of sensors. In this paper, we discuss the nature of the interaction, structural conformation of the biomolecules that interact with graphene, the binding reaction kinetics, and sensing performance.

8730-5, Session 1

Nanobio manufacturing of flex devices for aerospace *(Invited Paper)*

Richard Vaia, Michael F. Durstock, Rajesh R. Naik, Air Force Research Lab. (United States)

Nano-bio manufacturing is the construction of macroscopic devices that integrate multiple functions, such as sensing, communication, logic and/or power into a single compliant package. The sub-component function relies on the unique properties provided by nanostructures or nanomaterials and on the unique specificity provided by biomacromolecules or biomaterials. Through an open architecture, modular manufacturing framework that builds off current flexible and printed electronics manufacturing, multifunctional devices packaged into a pliable form factor could be efficiently fabricated from concept-to-product for both high and low volume markets. For the future warfighter, flexible manufacturing of such conformal nano-bio devices will deliver technologies, including ultralight conformal RF antennas, energy harvesting appliqués, and wireless human cognition monitors, that are critical path enablers for a vast array of DoD capabilities, including persistent ISR, human augmentation, autonomy, and sustainment through prognostics. Commercially, the integration of these material and manufacturing technologies underpin future point-of-care concepts and ubiquitous sensing. This presentation will highlight the status of government –industry partnership and associated technologies toward these goals.

8730-6, Session 2

Flexible electronics for Army applications *(Invited Paper)*

Eric Forsythe, U.S. Army Research Lab. (United States); David R. Allee, Arizona State Univ. (United States); Jianmin Shi, David C. Morton, U.S. Army Research Lab. (United States); Nicholas Colaneri, Arizona State Univ. (United States)

The talk will present the Army's advancements in flexible displays at the Flexible Display and Electronics Center. Reflective electrophoretic flexible displays have made significant advances towards commercialization and system integration. The electronics requirements for flexible displays will be presented to include manufacturing approaches. Based on the display technology platform, we will present future Army applications and the underlying electronics performance necessary to achieve these concepts.

The paper will present the thin film transistor performance necessary for flexible displays and the current commercial trends towards manufacturing flexible and glass-based organic light emitting diodes and reflective electrophoretic displays. Based on these performance demands, emerging Army applications will be discussed for large-area sensors and imaging arrays. The paper will highlight the underlying electronics requirements and possible manufacturing solutions for large-area arrays through high performance flexible electronics for analog and digital processing.

8730-9, Session 2

Flexible microstrip antennas

Camilo A. Cano, Univ. EAFIT (Colombia)

Actually the technological community has an interest in developing flexible circuits and antennas with particular characteristics e.g. robust, flexible, lightweight load-bearing, economical and efficient antennas for integrated millimeter wave systems. Microstrip antennas are an excellent solution because those have all the characteristics before mentioned, but they have the problem of being rigid antennas and this makes impossible that those antennas can be use in portable devices.A practical solution is developing flexible microstrip antennas that can be integrated to different devices. one axis of work is the analysis of the electromagnetic field to the microstrip antennas using Bessel function and after generalize for application in flexible microstrip antennas.

8730-11, Session 3

FlexTech Alliance: partnering for progress in flexible, printed electronics *(Invited Paper)*

Michael F. Ciesinski, FlexTech Alliance (United States)

The flexible, printed electronics (FPE) industry has been recognized by diverse publications such as CNN Tech to EE Times as among the top 10 future technologies. Applications have been identified in both defense and commercial market sectors.

In order to move from "lab to fab", FPE requires a robust supply chain, reliable manufacturing facilities and, most importantly, a collaborative effort amongst industry, academia and government in order to thrive. FlexTech Alliance's formula for collaboration is to identify technology gaps, develop underlying elements of the supply chain, and partner to provide pilot manufacturing sites. We also offer a suite of valued business services.

This presentation will review the compelling interest in FPE, projects recently funded by FlexTech, and provide some perspective on the future of the FPE industry.

8730-12, Session 3

Hybrid electrospinning casting method to produce multifunctional flexible transparent conductive films

Miko Cakmak, The Univ. of Akron (United States)

There is a strong need to develop new transparent electrodes that are robust enough to take the flexing requirements in a wide range of developing flexible electronics markets. In the past few years, we have been working on a patent pending process that can produce nanowire embedded polymer films with electrical conductivities in 250 -1000 ohm/sq with optical transmittances from 60% to over 95% in the visible range. With special testing equipment we developed, we found that the cyclic bending of these films to small radii of curvatures down to 1/3 mm-1(e.g. 1/4" radius rod) has little or no effect on their electrical conductivities whereas the industry standard ITO coated films rapidly degrade their electrical conductivities through crack formation mechanism An added benefit of these films is their unprecedented thermoformability as they can be stretched as much as 2 times the original length with moderate loss in conductivities as revealed by real time tracking of mechano-electric properties during deformation. This property makes them ideal for future flexible electronics including displays that require double curvature surfaces.

8730-13, Session 3

Flexible Amorphous Silicon PIN Diode X-Ray Detectors

Michael Marrs, Edward J Bawolek, Joseph T Smith, Gregory B Raupp, Arizona State Univ. (United States); David Morton, US Army Research Laboratory (United States)

A low temperature amorphous indium gallium zinc oxide (IGZO) thin film transistor (TFT) and amorphous silicon PIN diode backplane technology for flexible passive pixel detector arrays has been developed using active matrix display technology. The flexible detector arrays can be mounted to non-planar surfaces with the potential to detect x-rays or other radiation with an appropriate conversion layer. The thin, lightweight, and robust backplanes may enable the use of highly portable x-ray detectors for use

in the battlefield or in remote locations.

Mixed metal oxides, such as IGZO, have been extensively researched due to their improved stability under electrical bias stress and higher mobility compared to amorphous silicon. We have fabricated detector arrays up to 200 millimeters along the diagonal on a Gen II (370 mm x 470 mm rectangular substrate) flat panel scale pilot line using IGZO as the active layer and plasma enhanced chemical vapor deposition (PECVD) silicon oxide as the gate dielectric and passivation. The IGZO based TFTs exhibited an effective saturation mobility of 11.7 cm2/V-s. The PIN diode material was fabricated using a low stress amorphous silicon (a-Si) PECVD process. The PIN diode dark current 1.7 pA/mm2, the diode ideality factor was 1.36, and the diode fill factor was 0.73. We report on the critical steps in the evolution of the backplane process from qualification of the low temperature (180°C) IGZO TFT and a-Si PIN process on the 150 mm pilot line, the transfer of the process to flexible plastic substrates, the stability of the devices under forward bias stress, and finally a discussion and demonstration of the scale-up to the Gen II (370 x 470 mm) panel scale pilot line.

8730-14, Session 3

Functional electronic and optical devices via additive driven self-sssembly and nanoimprint lithography: towards solution-based R2R fabrication *(Invited Paper)*

James Watkins, Univ. of Massachusetts Amherst (United States)

The NSF Center for Hierarchical Manufacturing (CHM) at University of Massachusetts Amherst, a National Science Foundation supported nanotechnology center, is developing materials and processing approaches to enable the fabrication of nanotechnology enabled devices on a R2R platform. Specifically we employ additive-driven self-assembly to produce well-ordered polymer/nanoparticle hybrid materials that can serve as active device layers, we use highly filled nanoparticle/polymer hybrids for applications in high k dielectrics and light/EM management and we employ R2R nanoimprint lithography for device scale patterning. Our newly constructed R2R processing facility includes a custom designed, precision R2R UV-assisted nanoimprint lithography (NIL) system and hybrid nanostructured materials coaters.

Here we illustrate the capabilities of these approaches by the fabrication of floating gate field effect transistor memory devices (FGM) and the production of large area patterned films for light/EM management. For the FGM devices the charge trapping layer is comprised of well-ordered polymer/gold NP composites. This layer is sandwiched between a dielectric layer and a poly(3-hexylthiophene) semiconductor layer. We can achieve facile control of the memory windows by changing the density of gold nanoparticles. The devices show high carrier mobility (> 0.1 cm2/Vs), high on/off ratio (>105) between memory states and long retention times. Strategies for patterning of the device using NIL and incorporation of solution coat-able high k dielectric layers will be discussed. The optical/EM films are comprised of patterned polymer/NP films with tunable refractive indices.

8730-15, Session 4

Epidermal electronics *(Invited Paper)*

John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

We summarize recent advances in classes of electronic systems that achieve thicknesses, effective elastic moduli, bending stiffnesses and areal mass densities matched to the epidermis. Laminating such devices onto the skin leads to conformal contact, and adequate adhesion based on van der Waals interactions alone, in a manner that is mechanically invisible to the user. We describe systems incorporating electrophysiological, temperature and strain sensors, as well as transistors, light emitting diodes, photodetectors and radio frequency inductors, capacitors, oscillators and rectifying diodes. Solar cells and wireless coils provide options for power supply. We use this type of technology to measure electrical activity produced by the heart, brain and skeletal muscles and we show that the resulting data contain sufficient information for an unusual type of computer game controller and a human/machine interface.

8730-16, Session 4

Flexible digital x-ray technology for far-forward remote diagnostic and conformal x-ray imaging applications

Joseph T. Smith, Michael Marrs, Mark Strnad, Arizona State Univ. (United States); Raj B. Apte, Palo Alto Research Center, Inc. (United States); Julie Bert, Palo Alto Research Center (United States); David R. Allee, Nicholas Colaneri, Arizona State Univ. (United States); Eric Forsythe, David C. Morton, U.S. Army Research Lab. (United States)

Today's digital x-ray image sensors, which have been in production since the mid-1990s, are produced exclusively on glass substrates. While acceptable for use in a hospital or doctor's office, conventional glass substrate digital x-ray sensors are simply too fragile for use outside of these controlled environments without extensive reinforcement. Reinforcement, however, significantly increases weight, bulk, and cost, making them impractical for far-forward remote diagnostic applications, which demand thin, portable, and lightweight x-ray detectors. Additionally, glass substrate x-ray detectors are inherently rigid. This limits their use in curved or bendable conformal x-ray imaging applications such as NDT (non destructive testing) of pipelines.

However, by extending low temperature thin film transistor technology (TFT) previously demonstrated on plastic-substrate-based electrophoretic and OLED flexible displays, it is now possible to manufacture a very thin, lightweight, and flexible digital x-ray detectors. In this paper, we discuss the principal technical challenges and approaches used in extending flexible display technology into two new large-area flexible digital x-ray sensors for defense, security, and industrial applications and will demonstrate their imaging capabilities.

Our results include a 4.8" diagonal, 353 x 463 resolution, flexible digital x-ray, fabricated on a 6" polyethylene naphthalate (PEN) plastic substrate; and a larger, 7.9" diagonal, 720 x 640 resolution flexible digital x-ray detector also fabricated on PEN and manufactured on a Gen 2 substrate.

8730-17, Session 4

Sol gel ZnO films doped with Mg and Li evaluated for charged particle detectors

John W. Murphy, Alexander Eddy, The Univ. of Texas at Dallas (United States); George R. Kunnen, Arizona State Univ. (United States); Israel Mejia, Kurtis D. Cantley, The Univ. of Texas at Dallas (United States); David R. Allee, Arizona State Univ. (United States); Manuel A. Quevedo-Lopez, Bruce E. Gnade, The Univ. of Texas at Dallas (United States)

In this work we assess the feasibility of ZnO films deposited from a sol gel precursor as a material for thin film charged particle detectors. There are many reports of polycrystalline ZnO thin film transistors (TFTs) in the literature, deposited by sputtering, pulsed laser deposition, and sol gel. There are also reports of sol gel derived ZnO doped with Li or Mg to increase the resistivity, however, these works only measure resistivity of the films, without determining the effect of doping on the carrier concentration. We study the effects of doping the ZnO with Mg and Li as well as the effects of thickness on the films' resistivity, mobility, and carrier concentration, since these material parameters are critical for a charged particle sensor. Carrier concentration is particularly important because it must be kept low in order for the intrinsic region of a p-i-n diode to be depleted. In order to accomplish this we fabricate and electrically characterize test structures for resistivity, test structures for hall measurement, common back-gate TFTs, and metal-insulator-semiconductor (MIS) capacitors. We also conduct physical characterization techniques such as x-ray diffraction, atomic force microscopy, electron microscopy, UV-Vis spectroscopy, and ellipsometry to determine the effect of doping and film thickness on the microstructure and optical properties of the ZnO.

8730-18, Session 4

Development of a Testbed for Flexible a-Si:H Photodiode Sensing Arrays

Alfonso Dominguez, George R. Kunnen, Michael Vetrano, Joseph T. Smith, Michael Marrs, David R. Allee, Arizona State Univ. (United States)

Large area, flexible sensing arrays for imaging, biochemical sensing and radiation detection are now possible with the development of flexible active matrix display technology. In particular, large-area flexible imaging arrays can provide considerable advancement in defense and security industries because of their inherent low manufacturing costs and physical plasticity that allows for increased adaptability to non-planar mounting surfaces. For example, a flexible array of photodetectors and lenslets formed into a cylinder could image simultaneously with a 360 degree view without the need for expensive bulky optics or a gimbaled mount.

Here we report the design and development of a scalable 16x16 pixel testbed for flexible sensor arrays using commercial-off-the-shelf (COTS) parts and demonstrate the capture of a shadow image with an array of photodiodes and active pixel sensors on a plastic substrate. In addition, the image is transferred via a Bluetooth link to a cell phone. The image capture system makes use of an array of low-noise, InGaZnO active pixel amplfiers to detect changes in current in 2.4 µm-thick reverse-biased a-Si:H PIN diodes. At the back end, analog capture circuitry progressively scans the array and constructs an image based on the electrical activity in each pixel. The use of correlated-double-sampling to remove fixed pattern noise is shown to significantly improve spatial resolution due to process variations. The testbed can be readily adapted for the development of neutron, alpha-particle, or X-ray detection arrays given an appropriate conversion layer.

8730-19, Session 4

Towards a flexible electronic flying carpet *(Invited Paper)*

James C. Sturm, Noah T. Jafferis, Princeton Univ. (United States)

Electronic devices (e.g. TFT's) and sensors (e.g. for light, X-rays, etc) are well known in flexible electronics. Research in actuators in flexible electronics is less common. In this talk, we will discuss progress towards the creation of a flexible electronic "flying carpet" – a flexible sheet which can propel itself forward and lift itself off the ground by the application of electrical inputs. The device consists of a thin sheet of a piezoelectric polymer, which is electrically driven to move in a travelling wave shape. This causes air beneath the sheet to be propelled along with the wave, and thus a propulsive force in response to move the sheet in the opposite direction. This effect is one well-known in biology (to move in water), but has only recently been explored in air, theoretically [1] or experimentally [2,3]. This talk will first describe the fundamental physical requirements for the travelling wave, and then describe the physical implementation of our experiments. A critical enabling technology was integrated sensors to measure the real-time shape of the travelling wave. Finally, the observed propulsive forces and forward motion, and requirements for lift will be described.

1. M. Argentina, J. Skotheim, and L. Mahadevan, Phys. Rev. Lett. 99, 224503 (2007).

2. N.T. Jafferis, H.A. Stone, and J.C. Sturm, Appl. Phys. Lett. 99, 114102 (2011).

8731-1, Session 1

Extraction and classification of vehicles in ladar imagery

Hans C. Palm, Trym V. Haavardsholm, Halvor R. Ajer, Cathrine V. Jensen, Forsvarets Forsknings Institute (Norway)

The work presented in this paper is based on a dataset recorded with the CMRTR-sensor from NAVAIR (CMRTR = Cruise Missile Real Time Retargeting). It comprises targets like M-60, M-47, M-113, bridge layers, tank retrievers, in various types of scenes.

The segmentation consists of first estimating the ground level everywhere in the scene, and then for each sample simply subtracting the measured height and ground level height. No assumptions concerning flat terrain etc. are made.

Samples with height above ground level higher than a certain threshold are clustered by utilizing a straightforward agglomerative clustering algorithm. Around each cluster the bounding box with minimum volume is determined. Based on these bounding boxes, too small as well as too large clusters can easily be removed.

However, vehicle-sized clutter will not be removed. Clutter detection is based on estimating the normal vector for a plane approximation around each sample. This approach is based on the fact that the surface normals of a vehicle is more “modulo 90o” distributed than clutter.

The aim of the classification has been to classify main battle tanks (MBTs). Two types of algorithms have been studied, one model based, and one based on Dempster Shafer fusion theory.

Our dataset comprises clusters of 269 vehicles (among them 131 MBTs), and 253 clutters (i.e. in practice vehicle-sized bushes). The experiments we have carried out show that the segmentation extracts all vehicles, the clutter detection removes 90% of the clutter, and the classification finds more than 95% of the MBTs.

8731-2, Session 1

Methods for lidar point-cloud classification using local neighborhood statistics

Angela M. Kim, Richard C. Olsen, Fred A. Kruse, Naval Postgraduate School (United States)

LiDAR data are available in a variety of publicly-accessible forums, providing high-resolution, accurate 3-dimensional information about objects at the Earth’s surface. Automatic extraction of information from LiDAR point clouds, however, remains a challenging problem. The focus of this research is to develop methods for point cloud classification and object detection which can be customized for specific applications. The methods presented rely on analysis of statistics of local neighborhoods of LiDAR points. A multi-dimensional vector composed of these statistics can be classified using traditional data classification routines. Local neighborhood statistics are defined, the impacts of local neighborhood size and point cloud density are analyzed, and examples are given of the methods for specific applications such as building extraction and vegetation classification. Results indicate the feasibility of the local neighborhood statistics approach and provide a framework for the design of customized classification or object detection routines for LiDAR point clouds.

8731-3, Session 1

Enhancing online waveform processing by adding new point attributes

Martin Pfennigbauer, Andreas Ullrich, RIEGL Laser Measurement Systems GmbH (Austria)

Besides the basic spatial information, RIEGL LIDAR instruments based on echo digitization and on-line waveform processing or subsequent full waveform analysis provide additional valuable information to every detected target: calibrated amplitude, calibrated estimated target reflectance, and echo pulse width or deviation of the echo pulse shape from the expected one. These attributes significantly improve the interpretation of the point cloud and add much to its usability for various applications in airborne, terrestrial and mobile laser scanning.

By introducing new and extended algorithms to RIEGL’s reliable and proven on-line waveform processing it is possible to provide even further attributes. For example in hydrography an estimate for the backscattering coefficient of a water column is determined, allowing to determine its turbidity and thus also the reflectance of the ground. For topographic laser scanning it is possible to estimate the width of a slanted solid flat target’s backscatter cross-section and subsequently to provide an estimate of the angle of incidence of the laser beam on that target from a single point without the necessity to analyze surrounding targets.

We present data sets based on on-line waveform processing with the additional attributes of RIEGL’s V-Line and compare these with the results from off-line full waveform analysis demonstrating the potential of the technique. Additionally we provide insight into the underlying concepts and algorithms.

8731-4, Session 1

Classification and extraction of trees and buildings from urban scenes using discrete return lidar and aerial color imagery

Madhurima Bandyopadhyay, Jan van Aardt, Kerry Cawse-Nicholson, Rochester Institute of Technology (United States)

Airborne Light Detection and Ranging (LiDAR) is used in many 3D applications such as urban planning, city modeling, facility management, and environmental assessments. LiDAR systems generate dense 3D point clouds, which provide a distinct and comprehensive geometrical description of object surfaces. However, the challenge is that most of the applications require correct identification and extraction of objects from LiDAR point clouds. This paper presents a feature-level fusion approach between LiDAR and aerial color (RGB) imagery to detect urban vegetation and buildings from other urban classes/cover types. The classification method used structural and spectral features derived from LiDAR and RGB imagery. Features such as flatness, horizontality and distribution of normal vectors were estimated from LiDAR data, while the normalized difference vegetation index (NDVI) was calculated by combining LiDAR intensity at 1064 nm with the red channel from the RGB imagery. For example, building roof tops have regular surfaces with smaller variation in surface normal, whereas tree points generate irregular surfaces. Tree points, on the other hand, exhibit higher NDVI values when compared to returns from other classes. Accuracy was assessed by comparing the extraction result with manually digitized reference data generated from the RGB image. Preliminary results of a region growing algorithm, based on smoothness constraints, gave good separation between smooth and irregular surfaces and exhibited greater than 80% accuracy. Inclusion of NDVI in the algorithm is expected to improve the accuracy of classification. Final results will be presented at the conference.

8731-5, Session 1

Reconstruction of 3D tree stem models from low-cost terrestrial laser scanner data

David Kelbe, Paul Romanczyk, Jan van Aardt, Kerry Cawse-Nicholson, Rochester Institute of Technology (United States)

The Digital Imaging and Remote Sensing (DIRS) Laboratory at Rochester Institute of Technology (RIT) conducted a data collection campaign in September 2012 to collect coincident multi-modal imagery of the

greater Rochester area. The SpecTIR Hyperspectral Airborne Rochester Experiment (SHARE) 2012 was conducted in conjunction with several ground-based experiments. Here we introduce one such experiment using airborne and terrestrial laser ranging. In particular, we focus on using coincident terrestrial LiDAR for 3-D scene reconstruction of a 0.025 ha subset of the SHARE collection area.

The study area is a section of Avon Sports Park with mixed canopy cover. Three large cubes (side length 5-10 ft.), were constructed from PVC piping and fabric, and placed beneath the canopy. Terrestrial LiDAR was used to sample below-canopy object structure. The objective of this paper is to evaluate the feasibility of 3-D scene reconstruction of a mixed natural and built environment using terrestrial LiDAR.

We use a topology-based approach to reconstruct object surfaces based on the sampled points. Objects are characterized by approximating the structure tensor of point cloud cover sets, using principal component analysis. Objects are then modeled based on simple geometric constraints (e.g., cylinder, plane, etc.)

Because of the complementary perspective of terrestrial LiDAR systems, this below-canopy structural characterization provides a unique potential for future airborne target detection and below-canopy studies.

8731-49, Session 1

Lidar data processing for scalable compression

Ruben D. Nieves, ITT Exelis Inc. (United States)

Compression of LIDAR point cloud offers many challenges to the signal processing community. Compression schemes must preserve both the numerical and geometrical aspects of the data, while dealing with the sparsely distributed three-dimensional nature of it. Very few effective compression methods have been developed for this type of data, and only a handful of those methods offer the advantages of scalability. The focus of this research and development activity was to design and implement a series of preprocessing techniques that address the common obstacles found when pursuing scalable LIDAR point cloud compression. Three main areas being addressed are: spatial scalability by means of effective indexing techniques; range reduction and redundancy exploitation; and resolution scalability by means of sub-band decomposition and sampling. These techniques will be combined with two different entropy encoding schemes –namely LZW and MQ encoding, yielding scalable 12:1 compression rates.

8731-6, Session 2

Registration of multiple texel images (fused ladar/digital imagery) for 3D image creation

Scott E. Budge, Neeraj Badamikar, Utah State Univ. (United States)

Creation of 3D images through remote sensing is a topic of interest in many applications such as terrain/building modeling and automatic target recognition. Several photogrammetry-based methods have been proposed that derive 3D information from digital images from different perspectives, and ladar-based methods have been proposed that merge ladar point clouds and texture the merged point clouds with digital imagery. Image registration alone has difficulty with smooth regions with low contrast, whereas point cloud merging alone has difficulty with outliers and lack of proper convergence in the merging process.

This paper presents a method to create 3D images that uses the unique properties of texel images (pixel-fused ladar and digital imagery) to improve the quality and robustness of fused 3D images. The proposed method uses both image processing and point-cloud merging to combine texel images in an iterative technique. Since the digital image pixels and the ladar 3D points are fused at the sensor level, more accurate 3D images are generated since registration of image data automatically improves the merging of the point clouds, and vice versa. Examples illustrate the value of this method over other methods.

8731-7, Session 2

3D graph segmentation for target detection in FOPEN lidar data

Nicholas S. Shorter, Judson Locke, Anthony O. Smith, Emma Keating, Philip W. Smith, Harris Corp. (United States)

A novel use of Felzenszwalb's graph based efficient image segmentation algorithm* is proposed for segmenting 3D volumetric foliage penetrating (FOPEN) Light Detection and Ranging (LiDAR) data for automated target detection. The authors propose using an approximate nearest neighbor's algorithm to establish neighbors of points in 3D and thus form the graph for segmentation. Following graph formation, the angular difference in the points' estimated normal vectors is proposed for the graph edge weight. Then the LiDAR data is segmented, in 3D, and metrics are calculated from the segments to determine their geometrical characteristics and thus likelihood of being a target. Finally, the bare earth within the scene is automatically identified to avoid confusion of flat bare earth with flat targets. The segmentation, the calculated metrics, and the bare earth all culminate in a target detection system deployed for FOPEN LiDAR. General purpose graphics processing units (GPGPUs) are leveraged to reduce processing times for the approximate nearest neighbors and point normal estimation algorithms such that the application can be run in near real time. Results are presented on several data sets.

8731-8, Session 2

Fusing lidar-based voxel geometry with multi-angle visible imagery

Shea Hagstrom, David W. Messinger, Rochester Institute of Technology (United States)

Modern airborne LIDAR instruments are capable of accurately measuring fine detail, making them ideal for producing 3D models. A closely related problem is how best to map passive aerial imagery to the LIDAR-derived models. Typical solutions to this problem involve first constructing a surface representation from the LIDAR, then projecting imagery onto this surface. Unfortunately, a surface model can introduce errors into the process because it is not a good representation of the underlying scene geometry in areas containing overlapping or complex surfaces. A voxel-based 3D model of the LIDAR geometry is one alternative to the surface representation, and we show how this achieves more accurate results in complex areas when compared to existing approaches. Additional information we derive for the voxel model can also be used to assist with fusing the aerial imagery by driving quality metrics, and we demonstrate how this gives improved results. Multiple images covering the same area are required in order to capture details occluded in any single aerial photograph. We show how this occlusion affects fusion with the 3D model, and how any redundant color information can be filtered further to produce better products. Results are presented from our voxel-based fusion technique using LIDAR and coincident visible aerial imagery collected in the summer of 2011 over downtown Rochester, NY.

8731-9, Session 2

Point spread function (PSF) noise filter strategy for Geiger-mode lidar

Anthony O. Smith, Robert Stark, Philip W. Smith, Randall St Romain, Steven G. Blask, Harris Corp. (United States)

LiDAR is an efficient optical remote sensing technology that has application in geography, forestry, and defense. The effectiveness is often limited by signal-to-noise ratio (SNR). Geiger mode avalanche photodiode (APD) detectors are able to operate above critical voltage, and a single photoelectron can initiate the current surge, making the device very sensitive. These advantages come at the expense of requiring computationally intensive noise filtering techniques. Noise is a

problem which affects the imaging system and reduces the capability. Common noise-reduction algorithms have drawbacks such as over aggressive filtering, or decimating in order to improve quality and performance. In recent years, there has been growing interest on GPUs (Graphics Processing Units) for their ability to perform powerful massive parallel processing. In this paper, we leverage this capability to reduce the processing latency. The Point Spread Function (PSF) filter algorithm is a local spatial measure that has been GPGPU accelerated. The idea is to use a kernel density estimation technique for point clustering. We associate a local likelihood measure with every point of the input data capturing the probability that a 3D point is true target-return photons or noise (background photons, dark-current). This process suppresses noise and allows for detection of outliers. We apply this approach to the LiDAR noise filtering problem for which we have recognized a speed-up factor of 30-50 times compared to traditional sequential CPU implementation.

8731-12, Session 3

Foliage-penetration optimization for Geiger-mode avalanche photodiode lidar

Steven E. Johnson, OG Systems (United States)

Geiger-mode avalanche photodiode (GMAPD) Lidar systems can be used to image targets that are partially concealed by foliage.

This application is challenging because most GMAPDs report only one range-to-target value per transmitted laser pulse.

If a GMAPD makes a foliage range measurement, it cannot make a target range measurement.

When too much laser energy is received, the vast majority of range measurements are from the foliage and few are from the target.

GMAPD Lidar systems often report their average detection probability during operation.

The average detection probability is calculated over an array of GAMPDs, over multiple laser pulses, or over both.

However, the detection probability does not distinguish between target and foliage measurements.

In this paper, it is shown that the probability of detecting a target obscured by foliage can be maximized by varying the detection probability.

It is shown that for many foliage penetration scenarios, operating with a detection probability of about 70% produces a near-maximum target detection probability.

8731-13, Session 3

3D image formation by maximum likelihood estimation of Geiger-mode lidar data

Gary W. Kamerman, Philip E. Johnson, FastMetrix, Inc. (United States)

No Abstract Available.

8731-14, Session 3

A comparison of two embedded programming techniques for high-rep-rate coherent Doppler lidar

Mark F. Arend, Sameh Abdelazim, Miguel Lopez, Fred Moshary, The City College of New York (United States)

Two FPGA embedded programming approaches are considered and compared for a 20 kHz pulse repetition rate coherent Doppler lidar system which acquires return signals at 400 Msamples/second and operates with signal to noise ratios as low as -20 dB. In the first approach, the acquired return signal is gated in time and the square modulus of the fast Fourier transform is accumulated for each of the range gates, producing a series of power spectra as a function of range. Wind speed decisions based on numerical estimators can then be made after transferring the range gated accumulated power spectra to a host computer, enabling the line of sight wind speed as a function of range gate to be calculated and stored for additional processing. In the second FPGA approach, a digital IQ demodulator and down sampler reduces the data flow requirements so that an auto-correlation matrix representing a preselected number of lags can be accumulated, allowing for the process of range gating to be explored on the host computer. The added feature of the second approach is that it allows for an additional capability to adjust the range gate period dynamically as the state of the atmospheric boundary layer (e.g. backscatter coefficient and stability condition) changes. A simple beam scanning technique is used to calculate the wind field vector which is graphically displayed on time-height cross section plots. A comparison to other observed wind information is presented suggesting the usefulness for the characterization of microscale meteorology.

8731-15, Session 4

Adapting a Ground-Based Laser Ranging System at NASA-GSFC for Identification and Tracking of Orbital Debris

Donald B. Coyle, Paul Stysley, Romae Young, Kenneth Getzandanner, Jan F. McGarry, NASA Goddard Space Flight Ctr. (United States); Scott Hull, NASA Goddard Space Flight Center (United States)

We propose to demonstrate laser ranging and optical tracking capabilities on selected orbital debris targets from the Goddard Geophysical and Astronomical Observatory (GGAO) laser ranging facility. We expect to show an up to 85% improvement over current RF and passive debris orbit prediction methods by achieving meter-level ranging precision on these optically passive targets. These experiments will determine our initial ranging link boundary conditions in debris size and orbit altitude, and will quantify many ranging system improvements that will be needed to maximize this much-needed capability. Our proposed tracking plan will describe a near term effort by employing the GGAO's 48" (1.2m) diameter laser ranging telescope and station. With this facility we will rapidly achieve meter-level laser range returns on cooperative targets. This will create a new capability in ground-based laser ranging as both a proof-of-concept demonstration and as a critical experimental baseline for further developing an optimized system for laser ranging to the smallest targets possible. The long-term plan will start with tracking large uncooperative orbital debris, focusing on first identifying the target then tracking it so that a more accurate trajectory can be calculated. From there we will enhance both laser and detector technology which will increase GSFC's ability to track smaller targets on the order of 10 cm. Long term goals also include forming partnerships with other RF and SLR facilities to create a global capability for tracking orbital debris at a high precision level.

8731-16, Session 4

Doppler lidar sensor for precision navigation in GPS-deprived environment

Farzin Amzajerdian, NASA Langley Research Ctr. (United States); Diego F. Pierrottet, Coherent Applications, Inc. (United States); Glenn D. Hines, Larry B. Petway, Bruce W. Barnes, NASA Langley Research Ctr. (United States)

Future robotic and manned exploration missions to the Moon, Mars, and other planetary bodies demand accurate knowledge of ground relative velocity and altitude in order to ensure soft landing at the designated landing location with high degree of precision. To meet this requirement, a Doppler lidar is being developed by NASA Langley Research Center under the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project. The range and velocity measurements provided by this lidar sensor will be used by an autonomous Guidance, Navigation, and Control (GN&C) system to accurately navigate the vehicle to the designated location and achieve soft landing. Compared with radars, such as the ones used by previous Mars landres, this sensor offers several benefits including much lower mass and smaller size, higher precision and data rate, and lower false alarm rates. The Doppler lidar will begin its operation during the powered descent phase from an altitude of a few kilometers above the ground. The lidar data enables the GN&C system to improve its position and attitude data and accurately update the vehicle trajectory toward the landing point. The lidar data will also allow for controlling the vehicle velocity during terminal descent to avoid the risk of tipping over and ensure a gentle touchdown. In addition to its space application, this Doppler lidar can benefit military aircraft and UAVs that require operation in GPS-deprived environment. A prototype version of this lidar sensor has been completed for a closed-loop demonstration onboard a rocket-powered terrestrial free-flyer vehicle.

8731-17, Session 4

Helicopter flight test of 3D imaging flash LIDAR technology for safe, autonomous, and precise planetary landing

Vincent E. Roback, NASA Langley Research Ctr. (United States); Alexander Bulyshev, Analytical Mechanics Associates, Inc. (United States); Farzin Amzajerdian, Robert A. Reisse, NASA Langley Research Ctr. (United States)

Two flash lidars, integrated from a number of cutting-edge components from industry and NASA, are lab characterized and flight tested for determination of maximum operational range under the Autonomous Landing and Hazard Avoidance (ALHAT) project (in its fourth development and field test cycle) which is seeking to develop a guidance, navigation, and control (GNC) and sensing system based on lidar technology capable of enabling safe, precise human-crewed or robotic landings in challenging terrain on planetary bodies under any ambient lighting conditions. The flash lidars incorporate pioneering 3-D imaging cameras based on Indium-Gallium-Arsenide Avalanche Photo Diode (InGaAs APD) and novel micro-electronic technology for a 128 x 128 pixel array operating at 30 Hz, high pulse-energy 1.06 µm Nd:YAG lasers, and high performance transmitter and receiver fixed and zoom optics. The two flash lidars are characterized on the NASA-Langley Research Center (LaRC) Sensor Test Range, integrated with other portions of the ALHAT GNC system from partner organizations into an instrument pod at NASA-JPL, integrated onto an Erickson Aircrane Helicopter at NASA-Dryden, and flight tested at the Edwards AFB Rogers dry lakebed over a field of human-made geometric hazards. Results show that the maximum operational range goal of 1000m is met and exceeded up to a value of 1200m. Several hazards are imaged at medium ranges to provide three-dimensional Digital Elevation Map (DEM) information.

8731-39, Session PTues

Planetary boundary layer detection with fractal dimension of three-wavelength lidar signals

Liqiao Lei, Hampton Univ. (United States) and Hefei Univ. Technology (China); M. Patrick McCormick, Jia Su, Hampton Univ. (United States)

Lidar backscatter signal resulting from laser light scattering from the aerosol and molecular in the atmosphere contains various information about the geometrical and physical properties of aerosol and molecular. The lidar backscatter signal can provide information about the PBL stratification by using aerosol as a tracer for convective and mixing processes. A PBL height and structure detecting technique based on the fractal dimension of three-wavelength backscatter signals is advanced. In this PBL height detecting technique, the three-wavelength backscatter signals are obtained by the Hampton University (HU, 37.02° N, 76.33° W) Lidar. The fractal dimension was calculated using the three-wavelength Lidar signals. The PBL heights obtained from fractal dimension of three-wavelength Lidar signals was compared with PBL heights obtained from the potential temperature profiles which are provided by NASA Langely Research Center (10 miles from HU). And results of the two methods agree well. Moreover, fractal dimension method can reduce the influence of the geometrical form factor on the PBL detecting to expand the detecting range of PBL and remove the effect of plume. Also, the fractal dimension method can show the PBL dynamics and the PBL evolution clearly.

8731-18, Session 5

Frequency locking and control technologies for remote lidar systems

Sarah R. Bickman, Scott R. Davis, Benjamin Luey, Scott D. Rommel, Michael H. Anderson, Vescent Photonics Inc. (United States)

The ASCENDS mission will be the first to utilize active laser sensing from space; using LIDAR or laser sounding it will provide a part-per-million sensitive global map of CO2 sources and sinks as required for future global climate science. To realize this, an absolute frequency reference on board the satellite is necessary to precisely control the probe laser detuning from line center for both CO2 and O2. Since the transitions are necessarily weak (atmosphere of path length) new technologies for the reference laser lock and detuning are required. In this effort we utilize a combination of: i) frequency-modulation (FM) spectroscopy for noise suppression, ii) high-finesse cavity-enhanced sampling to compress a large path-length (can be km's) into a few cm's, and iii) frequency offset locking for precise laser detunings. This is all in a very compact, rugged, and versatile package as required for space deployment. These technologies will be generally applicable and potentially enabling to the nascent arena of space based laser spectroscopy. The wavelength reference technology has broad application to laser-sounding measurements and could be used for CO2, H2O, O2, CO, CH3 and other molecules of interest for Earth and planetary science. While particularly suited for weak transitions, the technology can be used for stronger transitions simply by reducing the finesse of the optical cavity to the required level.

8731-19, Session 5

A new method to retrieve aerosol extinction coefficients from elastic-Raman lidar data

Jia Su, Patrick McCormick, Liqiao Lei, Hampton Univ. (United States)

Atmospheric aerosols have a significant impact on climate change through the scattering and absorption of incoming solar and outgoing thermal radiation. The aerosol optical properties can be directly measured using an elastic-Raman lidar. However, extraction of the extinction coefficient from the optical depth profile requires the use of numerical differentiation with these lidars, which suffers the random and systematic noises limitation and thereby reducing the detection sensitivity and accuracy. A new method to improve the quality of Raman lidar data processing is presented. Compared to the conventional method, the proposed method has the advantage, which can directly retrieve the aerosol extinction coefficients without numerical differentiation. Trial values of lidar ratio (from 10 to 90 sr with an increment of 1 sr) are applied to Fernald solution of the elastic lidar signals at 354.7 nm and all aerosol backscatter coefficients are obtained. The exact aerosol backscatter coefficients retrieved by combing elastic and Raman signals are used as

constrain of these results of Fernald method to determine aerosol true lidar ratios as well as extinction coefficients. The numerical simulations demonstrated that the proposed method provides good accuracy and resolution of aerosol profile retrievals. And the method is also applied to elastic-Raman lidar measurements at the Hampton University, Hampton, Virginia.

8731-20, Session 5

Airborne wind profiling algorithms for the pulsed 2-micron coherent Doppler lidar at NASA Langley Research Center

Jeffrey Y. Beyon, Grady J. Koch, Michael J. Kavaya, NASA Langley Research Ctr. (United States); Taylor J. Ray, Colorado School of Mines (United States)

Two versions of airborne wind profiling algorithms for the pulsed 2-micron coherent Doppler lidar system at NASA Langley Research Center in Virginia are presented. Each algorithm utilizes different number of line-of-sight (LOS) lidar returns while compensating the adverse effects of different coordinate systems between the aircraft and the Earth. One of the two algorithms APOLO (Airborne Wind Profiling Algorithm for Doppler Wind Lidar) estimates wind products using two LOSs. The other algorithm utilizes five LOSs. The airborne lidar data were acquired during the NASA's Genesis and Rapid Intensification Processes (GRIP) campaign in 2010. The wind profile products from the two algorithms are compared with the dropsonde data to validate their results.

8731-21, Session 5

Semi-empirical validation of the cross-band relative absorption technique for the measurement of molecular mixing ratios

Denis V. Pliutau, Narasimha S. Prasad, NASA Langley Research Ctr. (United States)

Studies were performed to carry out semi-empirical validation of a new measurement approach we propose for molecular mixing ratios determination. The approach is based on relative measurements in bands of O_2 and other molecules and as such may be best described as cross band relative absorption (CoBRA). The current validation studies rely upon well verified and established theoretical and experimental databases, satellite data assimilations and modeling codes such as HITRAN, line-by-line radiative transfer model (LBLRTM), and the modern-era retrospective analysis for research and applications (MERRA). The approach holds promise for atmospheric mixing ratio measurements of CO_2 and a variety of other molecules currently under investigation for several future satellite lidar missions. One of the advantages of the method is a significant reduction of the temperature sensitivity uncertainties which is illustrated with application to the ASCENDS mission for the measurement of CO_2 mixing ratios (XCO_2). Additional advantages of the method include the possibility to closely match cross-band weighting function combinations which is harder to achieve using conventional differential absorption techniques and the potential for additional corrections for water vapor and other interferences without using the data from numerical weather prediction (NWP) models.

8731-22, Session 5

Understanding lidar returns from complex dust mixtures

D. A. Hook, Garrett E. Pangle, North Carolina State Univ. (United States); Brandon J. N. Long, Physics Dept. North Carolina State Univ (United States); C. R. Philbrick, Hans D. Hallen, North Carolina State Univ. (United States)

Lidar is a powerful tool for measuring the vertical profiles of aerosols in the atmosphere using Rayleigh and Raman lidar techniques. Most of the aerosol studies have been done in the wavelength regions with nearly constant values of refractive index; however, dust aerosol examined in the LWIR wavelengths provide a formidable challenge. Dusts tend to be irregularly-shaped particles with varied composition. In order to simulate the lidar returns from dust aerosols, the optical properties of the dust itself must be well characterized and understood. The indices of refraction are combined with scattering calculations to simulate atmospheric dust profiles using Lorentz-Mie and MODTRAN calculations to represent the atmospheric extinction. Previous measurements of dust indices of refraction have varied widely. We approach the characterization of the dust indices from two directions, one using ellipsometry measurements of pressed dust pellets and the other measuring direct transmission of dust suspended in a potassium bromide matrix pellets. We find that ball milling of the dust is required to minimize scattering effects. Milling makes the ellipsometry data independent of incidence angle, and causes the values obtained from ellipsometry to converge with those from transmission measurements followed by Kramers-Kronig analysis. The spectra of a milled quartz bearing dust approach that of pure quartz, indicating a decrease of absorption efficiency for particles larger than the absorption length. These laboratory measured indices of refraction are used to simulate the extinction expected for a lidar operating in the LWIR region using a CO_2 laser transmitter.

8731-23, Session 5

Optical extinction dependence on wavelength and size distribution of airborne dust

Garrett E. Pangle, D. A. Hook, North Carolina State Univ. (United States); Brandon J Long, North Carolina State Univ (United States); Hans D. Hallen, C. R. Philbrick, North Carolina State Univ. (United States)

Optical properties of Arizona Road Dust (ARD) have been measured in a chamber that disperses particles to simulate the atmospheric environment of dust aerosols. Particle size distribution and extinction measurements were made during several minutes as the larger dust particles settled to the floor of the chamber. Examining the extinction on the beam paths of horizontal laser beams at wavelengths of 532 nm, 1064 nm, and 10.6 μm shows the dependence of the combination of wavelength and the particle size. The lofting and circulation of the dust within the chamber allows a study of the change of the particle size distribution over time. Larger particles relative to wavelength increase the overall scattering, but settle out of the volume quickly. Optical extinction of the beams at visible and near infrared wavelength is dominated by scattering. Optical extinction at long wave infrared is dominated by absorption when the wavelength corresponds with the molecular absorption of the chemical species composing the dust; however scattering is observed when large particles are present. The relative scattering in the visible and near infrared provides general information about the particle size distribution. These findings are discussed in terms of the measured data from the chamber and Lorentz-Mie calculations of scattering.

8731-24, Session 5

Using a laser aureole to study aerosols

Brandon J. Long, D. A. Hook, Garrett E. Pangle, Hans D. Hallen, C. R. Philbrick, North Carolina State Univ. (United States)

Aerosol scattering experiments are often large, expensive, and provide poor control of dust uniformity and size distribution. Solar aureole experiments, where measurements are taken by observing the near-forward scattering of sunlight by aerosols, are especially effected. The size distribution is difficult to control in atmospheric suspension measurements since particles larger than 10 microns settle quickly. In the

lab-scale experiment, particles are suspended in a mineral oil colloidal solution. Pellets with different concentrations or size distributions enable control of these variations. Images of laser aureole scattering from mineral oil colloidal solution containing a few percent Arizona Road Dust (ARD) by volume with blue (400 nm), green (532 nm) and red (650 nm) lasers are compared to data from a 44.5 m3, open-air chamber containing 70 grams of ARD. Although the densities differed by several orders of magnitude, the volume fractions of dust multiplied by the length of the scattering region are similar. The measured extinctions are also similar. We discuss aureole analysis, the differences expected in scattering due to the index of refraction of the mineral oil medium versus air, and effects of scattering by a KBr pellet. In summary, the use of scatters suspended in a mineral oil medium simulates aerosol scattering in air, while offering reproducibility and ease of parameter variation to study dust properties.

8731-25, Session 5

Multistatic lidar measurements of nonspherical aerosols

Hans D. Hallen, Brandon J Long, D. A. Hook, Garrett E. Pangle, C. R. Philbrick, North Carolina State Univ. (United States)

Lidar is a powerful tool for measuring the vertical profiles of aerosols in the atmosphere using Rayleigh and Raman lidar techniques. Bistatic lidar can be used to obtain the angular structure of the scattered light. When the aerosols are uniformly distributed, this information can be analyzed to provide particle size distribution information. However, dusts tend to be irregularly-shaped particles with varied composition. We investigate the impact of the irregular shape with optical scattering at several wavelengths, scanning electron microscopy, and T-matrix calculations. In particular, we study the rapid loss of Mie scattering resonances as the particle shape departs from spherical. Different size distributions produced by different size-cuts of Arizona Road Dust (ARD) are studied.

8731-26, Session 5

Optical signatures of dust

Andrea M. Brown, Shadrian B. Strong, David M. Brown, Johns Hopkins Univ. Applied Physics Lab. (United States)

Elastic backscatter lidar has become a popular approach for remote sensing of the environment, whether the primary interest is stand-off detection and identification of aerosol clouds or the characterization of the atmosphere for removal from passive ground-based, airborne, or satellite data. The Johns Hopkins University Applied Physics Laboratory has simultaneously operated two micro-pulse lidar (MPL) systems in multiple dusty locations throughout the United States: a 527 nm Sigma Space depolarization system and a 1047nm depolarization system from Science and Engineering Services, Inc. (SESI). Oftentimes, these MPL collects will be coordinated with observations by a Cimel sunphotometer, Stellarnet spectroradiometer, or a tethered balloon carrying a TSI, Inc. Aerodynamic Particle Sizer (APS). The MPL systems were also used to collect backscatter and extinction data during a controlled experiment focused on understanding the optical properties of Arizona road dust. Backscatter-to-extinction measurements from the controlled experiment are presented, as well as the two-wavelength extinction profiles extracted from dusty atmospheric profiles collected by the MPLs. This collection of data from multiple field campaigns and laboratory tests is assembled for the purpose of better understanding the active and passive signatures of dust across the optical spectrum.

8731-27, Session 6

Difference modeling enhancement of topographic superresolution

Jeremy Straub, The Univ. of North Dakota (United States)

Super resolution techniques have been previously used enhance topographic data directly (instead of via enhancement of imagery). However, system performance degrades as the pattern database's size increases. To keep system performance at an acceptable level, a smaller-than-optimal database must be utilized. This results in error being introduced due to differences in feature and average region height between the training and presented data.

With the proposed approach, an area-average height value (AAHV) is computed. Each grid element is then compared to the AAHV and the difference is computed. The difference value is stored for each pattern-cell. High, medium and low-resolution versions of the pattern area stored; the relative size of these patterns are application-configurable.

The work presented compares the average-height-and-difference-pattern-based topographic approach to the previous actual-height-based version. It also compares the utility of incorporating an overlap of pattern areas (designed to have a smoothing effect on the resulting data) with a non-overlapping approach, for both approaches. These comparisons are made both quantitatively (in terms of the average difference value) and qualitatively (in terms of the apparent smoothness of the resulting topographic map compared to the original source data). The paper concludes by discussing possible applications for the proposed approach including reducing collection costs (through reducing the required collection accuracy), increasing map accuracy and decreasing map storage requirements (via storing an average value and differences in stead of numerous grid location height values).

8731-28, Session 6

A study on the calibration of pitch-angle deviation for airborne lidar system

Xiangyang Hao, Lixing Jiang, Songlin Liu, Zhengzhou Institute of Surveying and Mapping (China)

Airborne Lidar measurement technology, as an efficient way of acquiring three-dimensional geographic information, plays an important role in building DSM and DEM rapidly. Because the airborne Lidar measurement system usually integrates multiple devices including GPS receiver, INS, laser rangefinder and CCD camera, the relative geometric position and attitude relationships among these devices must be accurately measured in order to get the points with high precision and thereby satisfy the accuracy requirements of produced DSM and DEM. It is proved that the misalignment of airborne Lidar system, which is represented by angle deviations of yaw, pitch and roll, is the most significant source of systematic error in airborne Lidar measurement. In this paper, the effect of pitch angle error on the 3D coordinates of measured point is firstly analyzed. On this basis, a calibration method of the pitch angle deviation for airborne Lidar system by using the geometric characteristics of spire houses is put forward. The proposed pitch angle deviation calibration method consists of four key steps: (1) Initial pitch angle calculation. In the light of the offset distance between the ridge lines of the same house acquired by airborne Lidar system flying in opposite directions, an initial pitch angle deviation can be calculated. After separating the effect of pitch angle deviation, the rectified laser point cloud data are obtained. (2) Roof plane equation determination. The plane equations of both roof slopes are determined by fitting algorithms with the 3D coordinates of points located in the same spire roof. (3) Distance standard error calculation. The distance of each point to the roof plane is computed and applied to the calculation of distance standard error. (4) Final pitch angle deviation calculation. Taking the distance standard error as the overlapping criterion, the pitch angle deviation correction is iteratively calculated according to the aforesaid procedure until the distance standard error is less than a given value. The final pitch angle deviation is the sum of all the pitch angle deviation corrections. Experiments show that the proposed calibration method is correct and effective.

8731-30, Session 6

Information density and 3D image quality

Gary W. Kamerman, FastMetrix, Inc. (United States)

No Abstract Available.

8731-31, Session 7

Simulation of the performance of laser imaging and range profiling of small-surface vessels

Ove K. Steinvall, Magnus Elmqvist, Tomas R. Chevalier, Swedish Defence Research Agency (Sweden)

The detection and classification of small surface targets at long ranges is a growing need for naval security.

This paper will discuss simulations of a laser radar at 1.5 µm aimed for search, detect and recognition of small maritime targets. Example of supporting measurements will be given. The data for the laser radar system will be based on existing technology.

The simulations will incorporate typical target movements at different sea states, the vessel course, the effect of the atmosphere and the laser system parameters such as beam size, beam jitter, pulse energy, repetition rates as well as detector sensitivity and bandwidth.

A discussion of the classification accuracy based on information in 1D, 2D and 3D data separate and in combination will be made vs. different environmental conditions and system parameters. System issues when combining the laser radar with range-Doppler radar will also be discussed.

8731-32, Session 7

Scintillation effects on round-trip ladar imaging through turbulence with finite-sized objects and collecting apertures: modeling advances

Douglas G. Youmans, SPARTA, Inc. (United States)

Atmospheric scintillation affects laser radar imaging through atmospheric turbulence both on the outward path and the return path, as is well known. Quantitative previous studies have used tiny flat mirrors and corner-cube-retro-reflectors as their objects. In actuality, the real world finite sized object creates scintillation averaging on the outgoing path and the finite sized telescope aperture produces scintillation averaging on the return path. We will quantify these effects and compare them to the tiny mirror and to the corner-cube retro-reflector quantitative data from the literature. Methods for modeling the scintillation effects and modeling the ladar signal-to-noise ratio (SNRp), or mean squared over a variance, will be discussed.

8731-48, Session 7

Comparison of LIDAR system performance for alternative single-mode receiver architectures: modeling and experimental validation

Paul Toliver, Applied Communication Sciences (United States); Ibrahim T Ozdur, Anjali Agarwal, Ted K Woodward, Applied Communications Sciences (United States)

In this paper, we describe a detailed performance comparison of alternative single-pixel, single-mode LIDAR architectures including (i) linear-mode APD-based direct-detection, (ii) Geiger-mode APD photon-counting, (iii) PIN-based coherent-detection, and (iv) optically-preamplified receivers. Such a comparison is useful when considering next-generation LIDAR on a chip, which would allow one to leverage extensive waveguide-based structures and processing elements developed for telecom and apply them to small form-factor sensing applications.

Models of four LIDAR transmit and receive systems are described in detail, which include not only the dominant sources of receiver noise commonly assumed in each of the four detection limits, but also additional noise terms present in realistic implementations. These receiver models are validated through the analysis of detection statistics collected from an experimental LIDAR testbed. The receiver is reconfigurable into four modes of operation, while transmit waveforms and channel characteristics are held constant. The use of a diffuse hard target highlights the importance of including speckle noise terms in the overall system analysis. All measurements are done at 1550 nm, which offers multiple system advantages including less stringent eye safety requirements and compatibility with available telecom components, optical amplification, and photonic integration. Ultimately, the experimentally-validated detection statistics can be used as part of an end-to-end system model for projecting rate, range, and resolution performance limits and tradeoffs of alternative integrated LIDAR architectures.

8731-33, Session 8

Large-format Geiger-mode ladar camera

Ping Yuan, Rengarajan Sudharsanan, Xiaogang Bai, Paul McDonald, Eduardo L. Labios, Spectrolab, Inc. (United States); Bryan Morris, John P. Nicholson, Gary M. Stuart, Harrison Danny, Boeing-SVS, Inc. (United States)

Recently Spectrolab has successfully demonstrated a compact 32x32 Laser Detection and Range (LADAR) camera with single photo-level sensitivity with small size, weight, and power (SWAP) budget for three-dimensional (3D) topographic imaging at 1064 nm on various platforms. With 20-kHz frame rate and 7.5-cm range resolution, this LADAR system provides coverage down to inch-level fidelity and allows for effective wide-area terrain mapping. At a 10 mph forward speed and 1000 feet above ground level (AGL), it covers 0.5 square-mile per hour with 5-in ground sample distance (GSD). In order to increase the forward speed to fit for more platforms and survey a large area more effectively, Spectrolab developed 32x128 Geiger-mode LADAR camera with 50-kHz frame rate. With the increase in both frame rate and array size, the data collection rate is improved by 10 times. With a programmable bin size from 0.3 ps to 1 ns and 14-bit timing dynamic range, LADAR developers will have more freedom in system integration for various applications. Most of the special features of Spectrolab 32x32 LADAR camera, such as non-uniform bias correction, variable range gate width, windowing for smaller arrays, and short pixel protection, are implemented in this camera.

8731-34, Session 8

Highly sensitive lidar with a thumb-sized sensor-head built using an optical fiber preamplifier (3)

Daisuke Inoue, Tadashi Ichikawa, Hiroyuki Matsubara, Manabu Kagami, Toyota Central R&D Labs., Inc. (Japan)

We have developed a LIDAR system with a sensor head which, although it includes a scanning mechanism, is less than 20 cc in size. The system is not only small, but is also highly sensitive.

Our LIDAR system is based on time-of-flight measurements, and incorporates an optical fiber. The main feature of our system is the utilization of optical amplifiers for both the transmitter and the receiver, and the optical amplifiers enable us to exceed the detection limit set by

thermal noise. In conventional automotive LIDAR systems the detection limit is determined by the thermal noise, because the avalanche photodiodes (APD) and trans-impedance amplifiers (TIA) that they use detect the received signals directly. In the case of our LIDAR system, the received signal is amplified by an optical fiber amplifier before reaching the photo diode and the TIA. Therefore, our LIDAR system boosts the signal level before the weak incoming signal is depleted by thermal noise.

We have previously demonstrated scanning up to a range of 80 m with this LIDAR system with a 2 mm diameter of receiving lens. We improved the optical amplifier and the peak output power of LIDAR was over 10KW. We re-designed the sensor-head and improved coupling efficiency. As a result, we succeeded in scanning over a range of 100 m.

This small and highly sensitive measurement technology shows great potential for use in LIDAR.

8731-36, Session 8

Development of a scanning polarimetric laser detection and ranging system

Renu Tripathi, Yuri Markushin, Nicholas P. Calvano, Gour S. Pati, Delaware State Univ. (United States)

Laser Detection and Ranging (LADAR) is an established optical sensing technology for creating three-dimensional image of a target object using the time-of-flight (TOF) information.

In this presentation, we will present the development of a scanning LADAR (Scan-LADAR) prototype system with polarimetric imaging capability. The basic system consists of two parts: a transmitter and a receiver. Transmitter arm employs a Q- switched Nd:YAG laser operating at 1064 nm and a fast-scanning two-axis galvanometer mirror which is synchronized with the pulsed laser. The receiver arm employs a large aperture telescope, focusing optics, a light-sensitive discrete amplification photon detector (DAPD) with a fast rise time (1ns), and a multiple-event time-to-digital converter (TDC). The system scans the target object using galvanometer mirrors and multiple laser pulses. Fraction of the scattered/reflected light is collected by using the telescope for measuring the TOF and the intensity of the detected signal to create a 3-D image of the target scene. The system also includes an in-line polarimeter to generate Stokes images of the target scene. The polarimetric scan-LADAR will have the ability to see parts of the scene that are not visible under intensity-only-imaging, such as object hidden behind highly reflective surfaces.

8731-37, Session 8

Handheld laser imaging for military forensic use

Håkan Larsson, Dietmar Letalick, Swedish Defence Research Agency (Sweden)

One of the main threats for armed forces in conflict areas are attacks by improvised explosive devices (IED). After an IED attack a forensic investigation of the site is undertaken. In many ways military forensic work is similar to the civilian counterpart. There are the same needs to acquire evidence in the crime scene, such as fingerprints, DNA, and samples of the remains of the IED. Photos have to be taken and the geometry of the location shall be measured, preferably in 3D. A main difference between the military and the civilian forensic work is the time slot available for the scene investigation. The military must work very fast and under the threat of fire assault, e.g. snipers. The short time slot puts great demands on the forensic team and the equipment they use. We have done performance measurements of the Mantis-Vision F5 sensor and evaluated the usefulness in military forensic applications. This presentation will describe some applications and show possibilities and also limitations of using a handheld laser imaging sensor for military forensic investigations.

8731-40, Session 8

Ice sheet surface elevation retrieval from CALIPSO lidar measurements

Xiaomei Lu, Yongxiang Hu, NASA Langley Research Ctr. (United States)

Since launching in April 2006 the main objective of the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission has been studying the climate impact of clouds and aerosols in the atmosphere. However, CALIPSO also collects information about other components of the Earth's ecosystem, such as lands, oceans and polar ice sheets. The objective of this study is to propose a new technique to provide high resolution of polar ice sheet surface elevation from CALIPSO single shot lidar measurements (70 m spot size). The new technique relies on an empirical relationship between the peak signal ratio and the distance between the surface and the peak signal range bin center to achieve high altimetry resolution. The ice sheet surface results in the region of Greenland and Antarctic compare very well with the Ice, Cloud and land Elevation Satellite (ICESat) laser altimetry measurements. The comparisons suggest that the obtained CALIPSO ice sheet surface elevation by the new technique is accurate to within 1 m. Based on the new technique, the preliminary data product of along-track topography retrieved from the CALIPSO lidar measurements is available to the altimetry community for evaluation.

8732-20, Session PTues

USAF high energy laser (HEL) systems: multi-spectral algorithm efficiencies susceptibilities during missile staging (Case: GHADR 110 MOD 2 (SEJIL-2)

Clifford A. Paiva, BSM Research Associates (United States)

This comprises continued research addressing missile exhaust plume ionization adverse effects; such HEL ionization processes occurring as a function of altitude, exhaust and attitude control systems (DACS) plume expansion and reverse (Prandtl-Meyer) exhaust flows, applied to Iranian Sejil-2. It is demonstrated that these processes adversely affect the USAF/Navy multi-wavelength Discriminating Interceptor Technology Program (DIT)'s infrared and millimeter wave fused system. Boost-phase and Early Midcourse (Ascent) missile exhaust and DACS plumes have been shown to generate a variety of very challenging plasma and electromagnetic HEL extinction effects.

8732-7, Session 1

Atmospheric transmission from an instrument measuring scatter at 1550 nm

Michael J. Vilcheck, Christopher I. Moore, Rita S. Mahon, James L. Murphy, Harris R. Burris Jr., Linda M. Thomas, William S. Rabinovich, U.S. Naval Research Lab. (United States)

The Naval Research Laboratory (NRL) has extensively investigated atmospheric effects on maritime lasercomm in both long term research studies and short term system demonstrations. A current effort is underway in the ONR Tactical Line-of-Sight Optical Communications (TALON) program to better characterize atmospheric transmission at 1550 nm in multiple climates to enable prediction of communication link performance. In order to allow long term unmanned measurements in these multiple climates, NRL developed a scatter-based 1550 nm transmission sensor similar in function to commercial visible wavelength visibility monitors. After the system was built and calibrated, it was deployed to numerous sites with various climate types to collect data over a 1-month period for each site. This paper describes the development of the instrument and the software. It also presents some of the data collected.

8732-8, Session 1

Characterization of, and imaging through, horizontal-path turbulence

Szymon Gladysz, Gabriele Marchi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

We have performed a series of experiments aiming at understanding the statistics of deep turbulence. That data were collected over a 2.5 km horizontal path, at a height of approximately 20 m. The experimental setup consisted of a Shack-Hartmann wavefront sensor and an imaging camera that simultaneously recorded wavefront-, and focal-plane data. Various objects, of sizes ranging from 1 cm (quasi point-source) to 10 cm (isokinetic patch), were used as targets.

The observations constitute a rich source of information: from the wavefront-sensor we have measured temporal power spectra of the phase and of the Zernike polynomials. From the images we have estimated power spectra and auto-correlations of image motion. Using double sources we have estimated the magnitude of the isokinetic patch.

Calibration of the measurements was done with a novel method of estimating turbulence strength directly from the target images: a suitable transformation of the images makes the objects "disappear", in principle leaving only the turbulence effects. The method visualizes the size (and for anisotropic turbulence also the shape) of Fried's parameter. The results were compared to those from the image motion analysis.

The spatial and temporal characteristics of deep-turbulence-induced optical aberrations were compared to predictions resulting from the Kolmogorov model. Performance of a theoretical adaptive-optics system was modeled based on the measurements. Finally, we show the usefulness of semi-automatic image deconvolution from speckle images.

8732-10, Session 1

Multi-wavelength operation of a control algorithm for mobile FSO node alignment

Peter G. LoPresti, The Univ. of Tulsa (United States); Dayong Zhou, Hazem Refai, The Univ. of Oklahoma - Tulsa (United States)

This paper investigates the performance of a recently proposed pointing, acquisition and tracking algorithm for mobile FSO node alignment through experimental methods that include multi-wavelength operation. The performance is evaluated on key parameters including power availability at the receiver, switching time, link recapturing time, and coverage area at the receiver plane. Optical sources operating at 850 nm, 1310 nm and 1550 nm are coupled to the transmitter through one of three possible distribution fabrics. The fabrics used are a 1x4 splitter that illuminates all four output fibers, a 1x4 switch fabric that selects one output fiber at a time, and a hybrid switch-splitter fabric that allows switching between pairs of illuminated fibers. The receiver is moved through a plane illuminated by the transmitter, and the collected power is monitored by the control system. Based on the collected power and varying levels of information about the receiver motion, the control system searches for a new connection when the current connection fails. The dependence of performance on the fiber-lens distance at the transmitter, the wavelength, and the transmitter fabric was examined. The results show that the alignment control system successfully recovered and maintained the link while the receiver was in motion, and each wavelength operation has one optimal transmitter fiber-lens distance that provides largest coverage.

8732-1, Session 2

Cloud-free line-of-sight estimation for free space optical communications *(Invited Paper)*

Radha A. Venkat, David W. Young, Johns Hopkins Univ. Applied Physics Lab. (United States)

No Abstract Available.

8732-2, Session 2

Effectiveness of using gridded forecast data in hyperspectral radiative transfer analyses and high energy laser research and mission planning

Steven T. Fiorino, Michelle F. Via, Kevin J. Keefer, Stephen Shirey, Justin T. Engel, Brannon J. Elmore, Air Force Institute of Technology (United States)

This study demonstrates the effectiveness of using gridded numerical weather prediction (NWP) data from the NOMADS (NOAA National Operational Model Archive & Distribution System) website in hyperspectral radiative transfer analyses and high energy laser (HEL)

research and mission planning software. The radiative transfer analysis code utilized is the Laser Environmental Effects Definition and Reference (LEEDR) model, the HEL research model is the high energy laser end-to-end operational simulation (HELEEOS), and the HEL mission planning software is the high energy laser tactical decision aid (HELTDA). Analyses of example simulated HEL mission engagements are described based on: (1) geographic location and associated atmospheric effects, defined through the LEEDR model, and (2) laser performance and engagement dynamics via HELEEOS or HELTDA. These models enable development of climatologically- or NWP-derived vertical profiles of temperature, pressure, water vapor content, optical turbulence, and atmospheric particulates and hydrometeors as they relate to line-by-line or band-averaged layer extinction coefficient magnitude at any wavelength from 350 nm to 8.6 m. Output derived from NWP data are compared to seasonal, generalized boundary layer, and time of day variations for a range of relative humidity percentile conditions to determine optimum efficiency in a specific environment. Results using 4-dimensional past reanalysis NWP in analyses of long-path HEL or other laser field testing in HELEEOS simulations indicate horizontal variations in atmospheric effects can be important. Coupling forecast/nowcast weather data with climatological properties for aerosols and turbulence offers significant advantages in HELTDA that optimize potential laser weapon engagements, whether air-to-air, air-to-surface, or surface-to-air scenarios.

8732-3, Session 2

Sparse spectrum model for the turbulent phase simulations

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

Monte-Carlo simulation of the phase front perturbations by atmospheric turbulence finds numerous applications for design and modeling of the adaptive optics systems, laser beams propagation simulations and evaluating the performance of the various optical systems operating in the open air environment. Accurate generation of the two-dimensional random fields of the turbulent phase is complicated by the enormous diversity of scales that can reach five orders in magnitude in each coordinate. In addition there is a need for generation of the long "ribbons" of the turbulent phase that are used to represent the time evolution of the wave front. This makes it unfeasible to use the standard discrete Fourier transform-based technique as a basis for the Monte-Carlo simulation algorithm. We propose a novel concept for the turbulent phase – Sparse Spectrum (SS) random field. The principal assumption of the SS model is that each realization of the random field is has a discrete random spectral support. Statistics of the random amplitudes and wave vectors of the SS model is arranged to provide the required spectral and correlation properties of the random field. SS-based Monte-Carlo model offers substantial reduction of computer costs for simulation of the wide-band random fields and processes, and is capable of generating long aperiodic phase "ribbons". We report the results of the model trials that determine the number of the sparse components, and the range of wavenumbers that are necessary to accurately reproduce the random field with power-law spectrum.

8732-4, Session 2

Simulation of stochastic signals for FSO communication systems through spectral representation

Jose Paulo G. de Oliveira, Univ. de Pernambuco (Brazil) and FITec (Brazil)

Recent studies have been carried out, in which the statistical properties of the received signal of free space communication systems are assessed by means of simulations. The obtained results, however, have brought no information about the temporal behavior of the generated photocurrent. This work describes how this can be accomplished through stochastic processes simulations. Although most of the theory on stochastic field simulation has been developed for application in mechanics and fluids engineering, it is well suited for signal analysis in wireless optical systems. If it is possible to artificially create signals with characteristics of a real one that is transmitted over the atmospheric channel, it can be used for system analysis and design without mounting a real transceiver. This dramatically reduces development costs and time. A technique that has been widely applied in engineering is the spectral representation method. The concept of spectral representation of Gaussian random processes was introduced in 1944. Its use, however, in generating simulations of random processes was only proposed in 1972. This method deals with the summation of a large number of weighted trigonometric functions, which is computationally very inefficient. Although fast Fourier transforms algorithms can dramatically reduce the required computational effort, it is not suitable for communication signals, since there are restrictions in defining the range of the variable time. This work assesses the generation of turbulence-corrupted signals using the above mentioned method and its application in simulating data transmission over the atmospheric channel.

8732-5, Session 2

Strehl ratio simulation results under strong turbulence conditions for actively compensated free-space optical communication systems

Juan C. Juarez, David M. Brown, David W. Young, Johns Hopkins Univ. Applied Physics Lab. (United States)

No Abstract Available.

8732-11, Session 3

Buffer requirements of an optical communication system in atmospheric turbulence

Troy T. Leclerc, Florida Space Institute (United States); Ronald L. Phillips, Larry C. Andrews, Robert F. Crabbs, Univ. of Central Florida (United States)

Free-space optical communications are predominantly hindered by optical turbulence induced signal fades, an effect caused by temperature and pressure variations within the atmosphere. The result is an optical wave interfering with itself due to multipath propagation via tiny refractive-index fluctuations across the wave-front. Data collected during past free-space optical experiments in the atmosphere support the gamma-gamma distribution as a practical model for received irradiance fluctuations, although the irradiance fluctuations do occasionally tend towards a lognormal distribution.

Utilization of the gamma-gamma irradiance model allows for calculation of statistical moments of the irradiance threshold level-crossing distribution. Expressions for the mean and variance of signal fade time of a gamma-gamma distributed irradiance are derived and presented. Outcomes of the derived expressions are presented in relation to free-space optical communication system performance.

Comparisons are made between the theoretical analysis and experimental data taken at the Innovative Science and Technology Facility (ISTEF) located at the Kennedy Space Center in Cape Canaveral, Florida. The strength of the atmospheric turbulence is often characterized by three measurable parameters: the refractive index structure constant Cn2, the inner scale l0, and the outer scale L0. The 1km optical path was instrumented with commercial scintillometers. Variance of fade time data were found to agree well for smaller apertures where effects of aperture averaging are not present and in cases where scintillation is weak to moderate. It is suggested that a more appropriate PDF, with a heavier

focus on aperture averaging, may be applied in future studies of these fade statistics.

8732-12, Session 3

Propagation statistical analysis for SMF-coupled free-space optical signal under weak to medium atmospheric turbulences

Yoshinori Arimoto, National Institute of Information and Communications Technology (Japan)

The SMF-coupled free-space optical (FSO) communication terminals, through which a diffraction limited laser beams at 1550-nm wavelength band are transmitted and received, have been developed at NICT to realize multi-Gbps to Tbps class point-to-point wireless optical links. This paper reports a follow-on study on the propagation statistical analysis of direct SMF-coupled optical signal as well as the received beacon signal using area photo-detector using recent outdoor experimental data over 100-500 m horizontal link under medium to weak atmospheric turbulence conditions.

The analysis has been performed based on the continuous one-second statistical data at 1-kHz and 100-Hz sampling which include angle of arrival of beacon laser beam at 980 nm wavelength and received intensity for both the beacon beam and the signal beam coupled to a single mode fiber at 1550 nm wavelength. Fade depth, as a minimum intensity for each one second, and surge height as a maximum in the same period are compared with the theoretical calculation of the tail cumulative distribution based on log-normal assumption and measured scintillation index. The author found good agreement for surge heights for both beacon and signal beam, but, the fade depth of the signal intensities was 2-3 times larger than the log-normal prediction. The angle of arrival measurement result show limited correlation with the scintillation index and the frequency spectrum analysis shows the finite outer scale characteristics due to terrestrial horizontal link configuration. These analysis results provide a method to compare atmospheric turbulence model such as lognormal or gamma-gamma distribution with real experimental data and predict the SMF-coupled signal intensity based on the scintillation index determined by Cn2 profiles.

8732-14, Session 3

Wavelength diversity assessment of fiber bundle receiver under misalignment and turbulence

Peter G. LoPresti, Wei Yi, Eric Rohlman, The Univ. of Tulsa (United States); Hazem Refai, The Univ. of Oklahoma - Tulsa (United States)

Recently, a novel receiver design with an array of small lenses coupling to a fiber bundle made up of large-core fibers was investigated to improve the issue of transmission misalignment, including the angular misalignment and translational misalignment, between the transmitter and receiver in a free-space optical link, and to analyze the effects of turbulence and weather. As the result of previous research, the implementation of wavelength diversity, which consists of multiple wavelengths operating the transmission, is investigate to reduce the impact of turbulence. We present an experimental evaluation of the feasibility of using three diverse wavelengths, 850nm, 1310nm, and 1550nm, for maintaining an FSO link as the link experiences misalignment and turbulence. The first experiments were performed in the laboratory with the receiver on a mobile platform, three different transmitter wavelengths, and a turbulence generator placed between them. The receiver retained the link for a reduced range of misalignment at all wavelengths without adjustment. For outdoor experiments, the 1550nm wavelength is chosen due to power availability, and the experiment investigated how the turbulences or weather, such as the sun, the wind and the temperature, have an impact on the quality of signal collected in the receiver and the misalignment tolerance of receiver in reality.

8732-15, Session 4

World-wide analysis of combined thermal blooming and turbulence effects applying convolved, high energy laser

scaling law models

Kevin J. Keefer, Noah R. Van Zandt, Steven T. Fiorino, Air Force Institute of Technology (United States); Justin T Engel, AFIT / CDE (United States)

Recognizing Defense as well as other Federal Agencies' rapidly evolving desire to further the fielding and/or understand the implications of directed energy systems, this study quantifies the combined effect of thermal blooming and turbulence interactions on system performance for tactical scenarios at representative world-wide locations with propagation occurring through or wholly within the atmospheric boundary layer. The analysis benefits from applying recent, more rigorous theoretical treatment of thermal blooming and turbulence and their interaction, as well as a completely new take on the distortion number expression more sensitive to atmospheric variations. The resulting changes to our fast-running end-to-end high energy laser propagation model are applied to show the anticipated effect of combined thermal blooming and turbulence on world-wide HEL propagation scenarios assessed at multiple wavelengths, including here-to-for non-anchored wavelengths such as 1.07 µm. Atmospheric conditions are defined for all scenarios based on world-wide, probabilistic climatology or gridded numerical forecasts, the latter enabling first-ever 4D calculations of anticipated effects. The engagement scenarios are defined for various platform and target altitudes, speeds, headings, and slant ranges focusing on the effects of representative turbulence and elevated aerosol profiles. Results indicate that most world-wide locations and their associated atmospheric boundary layer conditions can greatly change the combined thermal blooming and turbulence effect as compared to that suggested by applying standard atmospheres, which have significant implications for system development and application. Further, we show the utility of worldwide variability analyses for long-term system development and wargaming, as well as the benefit of applying numerical forecast predictions for shorter term operational mission planning, whether traditional force-on-force or emerging scenarios such as predictive avoidance.

8732-16, Session 4

Scattering from a rough impedance surface in presence of atmospheric turbulence

Santasri Basu, Milo W. Hyde IV, Jack E. McCrae Jr., Steven T. Fiorino, Air Force Institute of Technology (United States)

In directed energy applications that use Adaptive optics (AO), a beacon is usually created at the target to measure and to correct for atmospheric aberrations. A Gaussian Schell Model (GSM) might be a convenient way to model these beacons, which have a finite spatial extent and exhibit varying degrees of spatial coherence. In our earlier work, a full wave computational technique, known as the Method of Moments (MoM) was used to evaluate the scattered field from a rough impedance surface in vacuum. The full wave method captures all aspects of laser-target interaction such as masking, shadowing, multiple reflections etc. and hence improves the fidelity of the analysis. The full wave beacon model showed deviations from GSM, including exhibiting non-stationary behavior. The present work extends this analysis to include atmospheric turbulence. A fully coherent beam is propagated through turbulence and is incident on the rough surface. The light scattered from the rough surface is again propagated through turbulence and the properties of the scattered radiation (irradiance profile, coherence function etc.) in

the far field are studied through numerical simulations. A statistically homogenous and isotropic turbulence is assumed in the analysis. The full wave model results are compared with a GSM. This analysis will aid in understanding the key parameters of extended beacons and how they can impact the overall performance of an AO system.

8732-17, Session 4

Laser beam control with nonlinear phase conjugation

Vladimir B. Markov, Anatoliy Khizhnyak, Advanced Systems & Technologies, Inc. (United States); Phillip Sprangle, Joseph Penano, Antonio Ting, U.S. Naval Research Lab. (United States); Lewis Desandre, Office of Naval Research Global (United States); Chris Davis, Univ. of Maryland, College Park (United States)

Beam control technique is critical for effective laser beam propagation in turbulent atmosphere. Performance most of the current approaches require information on the impact of perturbations on the propagating wavefront. Such information can be acquired by measuring the characteristics of the target-scattered light that comes from a small, preferably diffraction-limited size, beacon. This presentation discusses an innovative beam control approach that can support formation of a tight laser beacon in deep turbulence conditions. The technique employs a Brillouin enhanced four-wave mixing (BEFWM) technique for generating a localized beacon spot on a remote image-resolved target. This technique enables formation of the tight beacon without using any wavefront sensors, AO system or predictive feedback algorithms. Total (amplitude and phase) conjugation is critical for beam control in presence of strong turbulence, whereas conventional adaptive optics (AO) methods do not have such capabilities. The phase information retrieved from the beacon beam can be used then in conjunction with an AO system to effectively propagate the laser beam in deep turbulence.

8732-18, Session 4

PITBUL: a physics-based modeling package for imaging and tracking of airborne targets for HEL applications including active illumination

Noah R. Van Zandt, Jack E McCrae, Steven T. Fiorino, Air Force Institute of Technology (United States)

Aimpoint acquisition and maintenance is critical to High Energy Laser (HEL) system performance. This study demonstrates the development by the AFIT/CDE of a physics-based modeling package, PITBUL, for tracking airborne targets for HEL applications, including atmospheric and thermal effects, active illumination, and sensor effects. High-resolution simulated imagery of the 3D airborne target in-flight as seen from the laser position is generated using the HELSEEM model, and includes solar illumination, laser illumination, and thermal emission. Both CW and pulsed laser illumination are modeled, including the effects of illuminator scintillation, atmospheric backscatter, and speckle. The HEL's heating of the target and atmosphere is modeled. Realistic vertical profiles of molecular and aerosol absorption and scattering, as well as optical turbulence, are generated using AFIT/CDE's Laser Environmental Effects Definition and Reference (LEEDR) model. The spatially and temporally varying effects of turbulence are calculated and applied via a fast-running wave optical method known as light tunneling. Sensor effects, for example blur, sampling, read-out noise, and random photon arrival, are applied to the imagery. Track algorithms, including centroid and Fitts correlation, as a part of a closed loop tracker are applied to the degraded imagery and scored, providing a high fidelity estimate of overall system performance. Tracking results are presented as a function of signal to noise ratio to gauge performance of a laser system against a moving UAV target. Additionally, validation efforts to date involving comparisons between simulated tracking and real tracking of UAVs and other aircraft are presented.

8732-19, Session 4

Adaptive optics with extended target

Anatoliy Khizhnyak, Vladimir B. Markov, Advanced Systems & Technologies, Inc. (United States)

The adaptive optic (AO) method of the correction now is using for improvement image quality in broad area applications: beginning from astronomical, where it was proposed, for imaging through turbulent atmosphere, medical imaging through biological tissue, and other. Now it is very important application concerned with correction the atmospheric propagation of the high power laser beams.

The AO processing is based on using a beacon that is situated on the imaged target or near it on the line of site. The localized character of beacon allows detection the needed wavefront perturbations. Unfortunately in overwhelming numbers of possible applications this scenario can't be used due to lack of beacon.

In case forming beacon by laser illumination the backward scattered waves have essentially difference structure in comparison to the illuminating beam. The reciprocity principle, which is determined AO system processing, doesn't applicable in this scenario. In this presentation we will describe how to use AO in case the fully resolved image target that plays beacon role. In presentation will be shown examples of proposed approaches processing.

8733-1, Session 1

Advances in AlGaInN laser diode technology for defence applications

Stephen P Najda, TopGaN Ltd. (Poland)

The latest developments in AlGaInN laser diode technology are reviewed for defence applications such as underwater telecommunications, sensor systems etc. The AlGaInN material system allows for laser diodes to be fabricated over a very wide range of wavelengths from u.v., i.e, 380nm, to the visible, i.e., 530nm, by tuning the indium content of the laser GaInN quantum well. Advantages of using Plasma assisted MBE (PAMBE) compared to more conventional MOCVD epitaxy to grow AlGaInN laser structures are highlighted. Ridge waveguide laser diode structures are fabricated to achieve single mode operation with optical powers of >100mW in the 400-420nm wavelength range with high reliability. High power operation of AlGaInN laser diodes is also reviewed. We demonstrate the operation of a single chip, high power AlGaInN laser diode 'mini-array' consisting of a 3 stripe common p-contact configuration at powers up to 2.5W cw in the 408-412 nm wavelength range. Low defectivity and highly uniform GaN substrates allow arrays and bars of nitride lasers to be fabricated. Packaging of nitride laser diodes is substantially different compared to GaAs laser technology and new processes & techniques are required to optimize the optical power from a nitride laser bar. Laser bars of up to 5mm with 20 emitters have shown optical powers up to 4W cw at ~410nm with a common contact configuration. An alternative package configuration for AlGaInN laser arrays allows for each individual laser to be individually addressable allowing complex free-space and/or fibre optic system integration within a very small form-factor. TopGaN are developing a new range of high power laser array technology over the u.v.- visible spectrum together with new packaging solutions for optical integration.

8733-2, Session 1

Development of advanced seed laser modules for lidar and spectroscopy applications

Narasimha S. Prasad, NASA Langley Research Ctr. (United States); Alex Rosiewicz, Steve Coleman, EM4, Inc. (United States)

We report on recent progress made in the development of highly compact, single mode, distributed feedback laser (DFB) seed laser modules for lidar and spectroscopy applications from space based platforms. One of the intended application of this technology is in the NASA's Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS) mission. The DFB laser modules operating at 1571 nm and 1262 nm have advanced current and temperature drivers built into them. A combination of temperature and current tuning allows coarse and fine adjustment of the diode wavelengths. The current tuning was demonstrated at a rate of ~0.7 pm/mV over a working range of ~1 V for a total of 0.7 nm. Also, temperature tuning at a rate of ~2 pm/mV over a working range of ~1 V for a total wavelength range of ~2 nm was demonstrated. The current tuning was performed at a rate of up to 200 kHz allowing rapid adjustment and dithering of the laser frequency. Furthermore, the laser linewidth was measured to be at ~100 kHz with frequency stability <10 MHz over 1 hour period. The micro-cooler arrangement embedded inside these modules has provided significant reduction in power consumption. The electronics has been designed, prototyped and tested using space-qualified components within a hermetically sealed package of volume less than 2" x 2" x 0.5". The DFB seed laser technology is suited for NASA's future laser based missions including the ASCENDS mission.

8733-3, Session 1

Recent advances in power scaling of high-power optically-pumped semiconductor lasers for ultrashort pulse generation and continuous wave single frequency operation

Alexandre Laurain, Maik Scheller, Tsuei-Lian Wang, Jorg Hader, Jerome Moloney, College of Optical Sciences, The Univ. of Arizona (United States)

Despite many decades of research and development, high-power tens of Watt to kilowatt class semiconductor lasers manifest themselves as low brightness (incoherent) diode bars emitting highly divergent beams of very poor beam quality. Parallel developments in doped crystal high-power solid state lasers have shown much greater promise in delivering high-brightness beams. The more recent development of OPSLs, semiconductor disk lasers pumped by incoherent diode bars, has led to the promise of developing a whole new generation of high-power, high-brightness all-semiconductor laser sources that have the added advantage of versatility in operating wavelength without constraints on the pump wavelength because of the extremely broad barrier state absorption.

Here we will report on our research in power scaling OPSL around 1µm to exceed 100W per chip by combining a rigorous quantum design of an optimized MQW epitaxial structure, highly accurate and reproducible wafer growth and an efficient thermal management strategy. Recently we have utilized these state-of-the-art optimized OPSL chips to achieve a new record for a mode-locked OPSL with an intra-cavity SESAM. The average output power of the laser in the optimum operation point of mode-locked operation was 3.4W while being pumped with 24W of net pump power. This corresponds to a pulse energy of 7.5nJ and a pulse peak power of 13.3kW. Both are record values for a semiconductor laser operation in the femtosecond regime. These optimized structures have also been used to demonstrate high power operation with a highly coherent TEM00 mode and to demonstrate a record single frequency output power of 13W.

8733-4, Session 1

High-energy laser activities at MBDA Germany

Bernd Mohring, Stephan Dietrich, Leonardo Tassini, Rudolf Protz, Franz Geidek, Jürgen Zoz, MBDA Germany (Germany)

At MBDA Germany a concept for a high-energy laser weapon system is investigated, which is based on existing industrial laser sources. Due to the enormous progress in the field of high-power fiber lasers, commercial industrial fiber lasers are now available delivering a nearly-diffraction limited beam with power levels of up to10 kW. By using a geometric beam coupling scheme, a number of individual high-power fiber laser beams are combined together using one common beam director telescope. A total laser beam power of 100 kW or more can be achieved, which is sufficient for an operational laser weapon system.

The individual beams from the different lasers are steered by servo-loops, using fast tip-tilt mirrors. This principle enables the concentration of the total laser beam power at one common focal point on a distant target, also allowing fine tracking of target movements and first-order compensation of turbulence effects on laser beam propagation. The proposed beam combination concept was demonstrated by using different experimental set-ups. A number of experiments were performed successfully to investigate laser beam target interaction and target fine tracking, also at large distances and at moving targets. Content and results of these investigations are reported, which demonstrate the complete engagement sequence for a C-RAM scenario. This includes the subsequent steps of target acquisition by radar and IR optics, followed by large angle coarse tracking, active fine tracking and destruction of

the target by the laser system. This successful application of geometric beam combining is an important step for the realization of a laser weapon system in the near future.

8733-5, Session 1

Beam-guidance optics for high-power fiber laser systems

Bernd Mohring, Leonardo Tassini, Rudolf Protz, Jürgen Zoz, MBDA Germany (Germany)

The realization of a high-energy laser weapon system by coupling a large number of industrial high-power fiber lasers is investigated. To perform the combination of the individual beams of the different fiber lasers within the optical path of the laser weapon, a special optical set-up is used. To achieve a good overall beam quality, it is important that the mechanical structure of the beam-guidance optics possesses a good mechanical stability and the optical components show low distortions, also when loaded with high laser power.

The components and the optical assemblies of the beam guidance optics have to fulfill different tasks, e.g. the collimation of the individual beams, the combination of several beams or the discrimination of different wavelengths. To perform this, either reflective components like mirrors can be used or refractive optics, like windows and lenses. Both possibilities were investigated by simulations and experiments. The results are compared, regarding various optical components.

From the results, the general aspects for the layout of the beam-guidance optics for a high-power fiber laser system are derived.

8733-8, Session 2

Narrow-line, tunable, high-power diode laser pump for DPAL applications

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We report on a high-power diode laser pump source for diode-pumped alkali lasers (DPAL), specifically rubidium alkali vapor lasers at 780nm. This pump is based on a microchannel water-cooled stack with collimation in both-axes. Wavelength-locking of the output spectrum allows absorption in one of the very narrow resonance lines of the atomic rubidium alkali vapor. To achieve these results, research was conducted to deliver the highest performance on all key components of the product from the diode laser bar which produces the optical power at 780nm to the external Bragg gratings which narrow the spectrum line width. We highlight the advancements in the epitaxy, device design, beam collimation, grating selection, alignment, tunability and thermal control that enable realization of this novel pump-source for DPALs. Design trade-offs will be presented.

8733-9, Session 2

High-efficiency narrow linewidth diode laser pump source for Rb vapor alkali laser systems

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High-power, narrow-linewidth and wavelength-stabilized diode laser pump sources operating in the 78x-nm to 85x-nm band are expected to enable high-energy CW laser systems based on low pressure alkali vapors (such as Rb or Cs). Here we present development of a high-brightness, high-efficiency, narrow-linewidth, and wavelength-tunable 780-nm fiber-coupled diode laser for use in diode-pumped Rb vapor alkali laser experiments. The diode laser module consists of multiple single-emitter diode lasers that are free space coupled into the fiber, and is wavelength locked through wavelength-selective feedback provided by means of a external volume Bragg grating (VBG). The module delivers a maximum power of over 120 W and >50% conversion efficiency as measured from the output of a 200 um, 0.22 NA fiber. To the best of our knowledge, this is the highest conversion efficiency reported for a fiber-coupled 100-W linewidth narrowed diode laser at 780 nm. The module is wavelength locked to <0.05 nm FWHM up to 60 W output power and <0.1 nm up to 100 W output power, and integrated wavelength tunability is included to provide center wavelength adjustment of >0.6 nm, covering Rb absorption at 780.0 nm and providing compatibility for closed-loop control of the wavelength. An excellent 98% power percentage in the narrowband is measured for the spectrum, with broadband emission suppressed by more than 22 dB. Broadening of the emission bandwidth at >60 W of power is constrained by self-heating of the VBG due to optical absorption in the VBG glass.

8733-42, Session 2

Military applications of the laser weapons in the future battlefield

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Contemporary operating environment requires a wide range of tools to respond to a myriad of regular and irregular threats. Accordingly, conventional weapons do not suffice in some cases. As technology improves exponentially, the dominance of conventional weapons is slowly fading away by the advances in laser technology. This study first outlines the characteristics of laser weapons and then provides the military applications of them in land, maritime, air and space domains. This study concludes that any country that is seeking primacy in military terms must allocate extra time and resources to obtain this emerging technology. Since it seems that there are not adequate studies about the military applications and operational concepts of the laser weapons, this study tries to increase awareness about their potential advantages.

8733-10, Session 3

Compact and efficient nanosecond pulsed tuneable OPO in the mid-IR spectral range

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A compact, robust and efficient nanosecond pulsed optical parametric oscillator (OPO) generating radiation in the mid-IR spectral range is reported. The OPO is based on periodically poled material for the efficient non-linear processes of up-converting 1064 nm radiation to 1570 and 3300 nm respectively. Pulsed emission exceeding 90 mW average power at the idler (3300 nm) with a total conversion efficiency of 18%, including both signal and idler, has been reached. The maximum pulse energy of the idler is 15 µJ, pulse duration around 4 ns and peak power up to 4 kW. The results are achieved for an optical pump power of 1.2 W at the entrance of the OPO and an electrical pump power of 14 W. The total size of the OPO device is only 125x70x45 mm3 (LxWxH) including the pump laser at 1064 nm. The output radiation is narrowed by spectral filtering to < 2 nm at the idler and smoothly temperature tuneable over 14 nm. The OPO has a robust design and withstands shocks in operation up to 60g at 8 ms. Storage temperature is -20 to + 60 degree C.

The compact size and low power consumption make this OPO device suitable for many kinds of spectroscopy applications in the areas of environmental monitoring and pollution control as well as in combustion physics and process control.

8733-11, Session 3

Interband cascade lasers with high continuous-wave output powers at room temperature

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The performance of mid-IR interband cascade lasers (ICLs) was improved recently by rebalancing the electron and hole densities in the active wells, which has led to a more efficient utilization of the injected current. As a result, the threshold current density at room temperature has decreased to ≈130 A/cm^2 for lasers with 5 stages emitting at 3.7 um. Maximum cw output powers >290 mW into a nearly diffraction-limited (M^2 ~ 2.2) output beam are realized at room temperature by adding corrugations to the sidewalls of a 25-um-wide ICL epitaxial-side-down mounted ridge, with the purpose of suppressing higher-order lateral modes. Comparing devices with corrugated and straight sidewalls, it is shown that the corrugations result in a 20% improvement in the maximum brightness. A 0.5-mm-long ridge with an HR-coated back facet and an uncoated front facet exhibited a maximum cw wall-plug efficiency of nearly 15% at room temperature. The ICL ridges with corrugated sidewalls are compared to lasers with tapered ridge widths that also raise the loss of higher-order lateral modes. The tapered laser emits >190 mW of cw power into a nearly diffraction-limited beam (M^2 ~ 1.5). The effect of taper angle and the dimensions of the tapered section are studied in detail. We also discuss distributed-feedback ICLs capable of emitting up to 27 mW of cw output power into a single lasing mode at 40 deg. C. Another device lased in a single spectral mode with <100 mW of drive power.

8733-12, Session 3

Performance and reliability of quantum cascade lasers

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We present the burn-in behavior and power stability of multiple quantum cascade lasers (QCLs) that were measured to investigate their long-term performance. For these experiments, the current to the QCL was cycled every ten minutes, and the output power was monitored over time for durations as long as two months. A small increase in power for a given injection current is observed for almost all of the QCLs tested during the burn-in period. Although the amount and duration of the burn-in varied among the devices tested, we observed that QCLs that operated with a lower threshold current exhibited a smaller burn-in change from initial conditions for the first ten hours of operation.

The effect of packaging the QCLs is also investigated to determine its impact on performance and reliability. The power stability is measured for the packaged QCLs along with the effect of changes in the operational conditions. Although the set point temperature of the QCL is kept constant, the case temperature is varied to monitor its correlation with any changes in power or frequency. Power changes and small frequency shifts are observed under these conditions. One possible explanation for these changes is the influence of optical feedback from the AR-coated window in the package due to the window's change in optical and mechanical properties arising from temperature fluctuations. The data from all of these experiments will be presented along with its impact on QCL performance and reliability.

8733-13, Session 3

Wide-band coherent supercontinuum generation

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We have studied broadband mid-IR supercontinuum generation (SCG) in a lead-silicate microstructured fiber (the glass for simulation is SF57). The total dispersion of the fiber can be tailored by changing the core diameter of the fiber so that dispersion profiles with two zero dispersion wavelengths (ZDWs) can be obtained. Numerical simulations of the SCG process in a 4 cm long SF57 fiber/fiber taper seeded by femto-second pulses at telecommunications wavelength of 1550 nm are presented. The results show that a fiber taper features a continuous shift of the longer zero dispersion wavelength. This extends the generated continuum to longer wavelength region compared to fibers with fixed ZDWs. The phase-matching condition (PMC) is continuously modified in the fiber taper and the supercontinuum generated extends from ~1000 to ~ 5000 nm. We have also studied the coherence properties of the generated supercontinuum. Simulations are conducted by adding quantum noise into the input pulse at 1550 nm, and the complex degree of first-order coherence function and the overall spectral degree of coherence are both calculated. Although the spectral broadening is comparable, the degree of coherence is shown to vary with different pumping conditions. It decreases with higher peak power and longer duration due to the significant competition between the soliton-fission process and the noise-seeded modulation instability. By a suitable choice of the input pulse parameters, it is possible to generate perfectly coherent supercontinuum with a flat broadened spectrum extending to ~5000 nm in this fiber taper.

8733-14, Session 3

Tunable mid-infrared generation using a synchronized programmable fiber laser: extending to the 2nd atmospheric window

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Over the last years, the interest level has grown significantly towards the development of Mid-Infrared (Mid-IR) laser sources for applications in remote sensing, laser-based countermeasures, pollutant monitoring, and narcotic/explosive detection. However, the number of commercially available lasers on the market is still limited and the tunability of those sources is restrained.

We present here our latest development results in Mid-IR laser based difference-frequency generation (DFG) in a nonlinear crystal pumped by synchronized and tunable picosecond near-infrared fiber lasers. The system is based upon a programmable laser where the emitted wavelength can be varied continuously and rapidly (up to 80,000 different wavelengths per second) and a tunable Master Oscillator Power Amplifier (MOPA) synchronized to the programmable laser. The synchronized laser does not have any moving parts and both the wavelength tuning and the synchronization are performed electronically. Furthermore, a long (several 10s of meters) of standard optical silica fiber (not IR fiber) can be used to deliver the light to the DFG crystal, allowing for many versatile configurations not possible with current technologies.

The programmable laser was tuned from 1910nm up to 1980nm and was mixed with 1530nm, 1575nm and 1585nm MOPA wavelengths in AgGaSe2, AgGaS2 and Orientation-Patterned GaAs (OP-GaAs) crystals. Wavelengths from 6.7μm and up to 9.3μm were generated continuously with up to the a few mW power level. We expect to increase this tuning range by increasing the tunability of the PL and the MOPA to longer wavelengths to allow us to cover the 6-12 um range.

8733-17, Session 4

Spectroscopic analysis of efficient laser material Ho3+:YVO4

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The spectroscopic properties of Ho3+-doped YVO4 were studied at cryogenic temperatures in the 2 µm spectral region to clarify our recent observation of efficient dual-wavelength laser operation in this material. Polarized absorption cross sections were measured, and stimulated emission cross sections were determined using the reciprocity method coupled with Füchtbauer-Ladenburg calculations. The observed laser emission wavelengths were at 2053 nm and 2068 nm; the former corresponding to a pi transition with peak cross section 1.7x10-19 cm2 and the latter to a sigma transition with a peak cross section of 2.0x10-20 cm2. Radiative lifetimes for the 5I7 manifold were calculated to be 3.3 ms, and fluorescence lifetimes were measured to be 2.9 ms, indicating a quantum efficiency of ~90% for transitions to the ground state. The relevance of these results to the dual wavelength laser operation will be discussed.

8733-18, Session 4

Rare-earth ions doped PTR glass DBR laser

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The need of compact, narrow line laser sources stimulated the development of hybrid devices such as distributed feedback (DFB) lasers and distributed Bragg reflector (DBR) laser.

Recent development in recording of volume holographic elements in PTR glass has led to the production of high efficiency volume Bragg gratings(VBGs), which allow narrowband filters in both spectral and angular spaces.On the other hand, co-doping of PTR glass with luminescent ions and recording VBGs inside the glass paves a way for creation of compact monolithic DFB and DBR volume solid state lasers.

We report on the first Distributed Bragg Reflector solid state laser recorded in Nd-doped PTR glass.An emitting at 808-nm laser diode with maximum power of 40 W was used as a pump source. In order to prevent heating, the pumping was in pulsed regime with pulse duration of 1 ms and repetition rate of 50 Hz. The DBR element (2% Nd-doped PTR glass) with an aperture of 2?6 mm2 and thickness of 11 mm was kept in a copper housing mounted on the TEC for temperature control.

The telescope type laser cavity was formed by a broadband mirror,focusing lens and DBR element which was acting as an active element (Nd-doped PTR glass) and output coupler (VBG with diffraction efficiency ~99%). The DBR laser produced 3W narrow line (~30 pm) radiation around 1060 nm. The laser was operating in a single transverse mode and no signature of saturation caused by a thermal lens effect was observed.

8733-19, Session 4

Er-doped sesquioxides for 1.5-micron lasers: spectroscopic comparisons

Larry D. Merkle, Nikolay Ter-Gabrielyan, U.S. Army Research Lab. (United States)

Sesquioxides are good hosts for rare earth laser ions, as they have better thermal properties than the more commonly-used YAG. We recently studied the spectroscopy of Er:Lu2O3 in the 1400 1700 nm wavelength range, and here report its comparison with our earlier results on Er:Y2O3 and Er:Sc2O3, in which we have observed efficient laser operation at cryogenic temperatures. These studies include absorption and fluorescence spectra, fluorescence lifetimes, and inference of absorption and stimulated emission cross sections, all as a function of temperature.

At room temperature, optical absorption limits practical laser operation to wavelengths longer than about 1600 nm. In that spectral range, the strongest stimulated emission peak is that at 1665 nm in Er:Sc2O3, with an effective cross section considerably larger than those of Er:Y2O3 and Er:Lu2O3.

At 77K, the absorption is weak enough for efficient laser operation at considerably shorter wavelengths, where there are peaks with much larger stimulated emission cross sections. The three hosts all have peaks near 1575-1580 nm with comparably strong cross sections. As we have reported earlier, it is possible to lase even shorter wavelengths efficiently at this temperature, in particular the line at 1558 nm in Er:Sc2O3. Our new spectroscopic studies of Er:Lu2O3 indicate that its corresponding peak, like that of Er:Y2O3, is somewhat weaker and thus less favorable. Reasons for the differences will be discussed.

We conclude that for most operating scenarios, Er:Sc2O3 is the most promising of the Er-doped sesquioxides studied for laser operation around 1.5-1.6 microns.

8733-35, Session PTues

Compact passively mode-locked fiber laser near 1.55 um with low timing jitter of 8 fs

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We report a compact all fiber passively mode-locked laser with a repetition rate of 250 MHz, a center wavelength at 1563 nm and a 3-dB bandwidth of 11 nm. The laser has a timing jitter of ~8 fs (100 Hz - 1 MHz) measured at third harmonic of 750 MHz.

8733-38, Session PTues

Ray matrix approach for the analysis of optical-axis perturbation in nonplanar ring resonators based on appropriate coordinate system

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Non-planar ring resonators are widely used for high precision ring laser gyroscopes including Zero-Lock Laser Gyroscopes. The analysis of optical-axis perturbation in nonplanar ring resonators is important for resonator design. Ray matrix approach based on appropriate coordinate systems has been employed to analyze the optical-axis perturbation in nonplanar ring resonators. The sensitivities of optical-axis decentration (SD) and optical-axis tilt (ST) in nonplanar resonators with 90° and 270° image rotation are discussed in detail in the region of 0< K <8, where K is the ratio of the total cavity length to the radius of the curvature mirrors. There are both four singular points in the whole region of 0< K<8. On the left of the first singularity, it is found that the longer the mirror radius, the less the optical-axis decentration sensitivity. This is opposite the behavior of planar ring resonators, but the behaviors of optical-axis tilt sensitivity in planar and nonplanar ring resonators are similar. In planar resonators, it also demonstrates that in the region of 0< K<2, larger the mirror radius is, higher sensitivity of optical-axis decentration will be, but lower sensitivity of optical-axis tilt will be. These results are confirmed by related experiments. It is worth to note that SD and ST in the nonplanar

resonator with certain parameters have the similar singularities. The analysis in this paper is important for the resonator design, improvement and beam position control nonplanar ring resonators.

8733-39, Session PTues

Simulation of atmospheric turbulence compensation through piston-only phase control of a laser phased array

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Beam propagation from a laser phased array system through the turbulent atmosphere is simulated and the ability of such a system to compensate for the atmosphere via piston-only phase control of the sub-apertures is evaluated. Directed energy (DE) applications demand more power than most lasers can produce, consequently many schemes for high power involve combining the beams from many smaller lasers into one. When many smaller lasers are combined into a phased array, phase control of the individual sub-apertures will be necessary to create a high-quality beam. Phase control of these sub-apertures could then be used to do more, such as focus, steer, and compensate for atmospheric turbulence. Atmospheric turbulence is well known to degrade the performance of both imaging systems and laser systems. Adaptive optics can be used to mitigate this degradation. Adaptive optics ordinarily involves a deformable mirror, but with phase control on each sub-aperture the need for a deformable mirror is eliminated. The simulation conducted here evaluates performance gain for a 127 element phased array in a hexagonal pattern with piston-only phase control on each element over an uncompensated array for varying levels of atmospheric turbulence. While most simulations were carried out against a 10 km tactical scenario, the turbulence profile was adjusted so performance could be evaluated as a function of the Fried Parameter (r0) and the log-amplitude variance somewhat independently. This approach is demonstrated to be effective as long as r0 is larger than the sub-aperture diameter, degrading smoothly as this constraint is exceeded.

8733-40, Session PTues

Experimental evaluation and performance optimization of a flash lamp pumped er: glass laser system over temperature extremes

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In this study, behavior of flash lamp pumped, opto-mechanically Q-switched Er: glass laser system has been experimentally investigated over temperature extremes (-30 deg C to +65 deg C). In one set of experiments, dependence of performance of high speed motor as part of opto-mechanical Q-switch at different temperatures is examined. It is found that motor speed varies with temperature and this will result into change in laser performance, as the synchronization between flash lamp current pulse and rotating Q-switch changes with motor speed. In another set of experiments, dependence of laser threshold on temperature extremes is investigated experimentally in two phases. First, laser thresholds for laser transmitter (laser optical head) alone is measured and later on laser thresholds of entire laser system (i.e. laser transmitter including flash lamp pulse forming network) is evaluated at various temperatures. It is observed that laser threshold of laser optical head alone and same for complete laser system, varies differently especially at (-) negative temperatures. In order to understand this difference, electrolytic capacitors of flash lamp pulse forming network were subjected to temperature test and observations were recorded. It is observed that equivalent series resistance (ESR) of electrolytic capacitors significantly changes with temperature, especially below zero degrees Celsius. Next, all observations of experiments were analyzed and system parameters were optimized such that fairly constant laser output (+/- 10%) is maintained over temperature extremes. This work also enables the development of a compact and high peak power eye safe laser system for defense applications.

8733-41, Session PTues

Methods of optimizing APD optical receiver performance characteristics for low SWaP laser rangefinders

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The performance of gain controlled, high performance APD's operated in linear mode can be optimized in real time over a 125°C operational temperature range resulting in an order of magnitude decrease in NEP at comparable SWaP to current state of the art PIN devices. We have demonstrated this device using a linear mode, low excess noise avalanche photo-diode (APD) flip-chip die bonded to a custom low noise ASIC.

The ASIC functions include a wide dynamic range amplifier, threshold comparator, temperature sensor and optimization algorithms. Various use case scenarios are optimized for sensitivity, range walk and damage threshold utilizing an on-board microprocessor. In this paper we discuss test results of the device, provide comparison with current state of the art PIN and APD solutions and discuss the advantages of this approach to higher performance, lower cost laser rangefinders.

8733-20, Session 5

Highly efficient resonantly pumped Er:YAG large area channel waveguide laser with diffraction limited output

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We demonstrated nearly quantum defect limited, quasi-CW operation of a resonantly pumped Er:YAG crystalline channel waveguide laser with diffraction limited output. The 41 mm long waveguide consisted of a 61.2 um x 61.6 um Er(0.25%):YAG core embedded into a 3 x 5 mm undoped YAG cladding. A QCW output power of 9.1 W with slope efficiency of 92.8% with respect to absorbed pump has been achieved with 1532-nm resonant pumping by a narrow-bandwidth Er-fiber laser. A measured divergence of the output laser beam was ~ 28 mrad, which was in an agreement with the expected low value of the numerical aperture (NA ~ 0.02) of the waveguide. A spectrum of the waveguide laser consisted of two wavelengths centered at 1617 nm and 1645 nm, when laser cavity outcoupling loss was relatively small (less than 20-25%). The output exhibited only one wavelength, 1617 nm, for higher outcoupling loss.

8733-21, Session 5

Stimulated Brillouin scattering in optical fibers excited by broad-band pump waves in the presence of feedback

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Stimulated Brillouin scattering (SBS) is the main limitation on achieving high-power, narrowband laser light from fiber laser systems. Various techniques have been used to increase the SBS threshold in fiber laser designs. One widely used technique for SBS suppression is modulating the pump wave to broaden its linewidth to a value larger than the Brillouin linewidth, resulting in an increase in the SBS threshold. In this

paper, we extend the transient theory of SBS in passive optical fibers, excited by a broad-band pump wave, by including the effects of pump feedback. We find, when the pump linewidth approaches the Brillouin frequency shift, a weak reflection of the pump can effectively seed the Stokes wave resulting in a decrease in SBS threshold. In one example, a 0.01% reflection of a pump wave with a linewidth equal to the Brillouin frequency shift is predicted to reduce the SBS threshold by as much as a factor of 1.5. Furthermore, fluctuations of the Stokes wave near threshold are greatly reduced in the presence of feedback. The implications of these results on the design of high-power fiber laser systems that utilize spectral broadening to suppress SBS are presented.

8733-22, Session 5

High power modal instability measurements of very large mode area (VLMA) step index fibers

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High average power lasers with diffraction limited outputs are key subsystems of Directed-Energy Weapons (DEW). The most promising approach for generating such high brightness laser beam is coherent combining of multiple beams from Yb-doped fiber amplifiers. Stimulated Brillion Scattering (SBS) and thermal-modal instability are the two main physical phenomena that limit fiber amplifier output powers. SBS is a well understood fiber non-linearity and can be effectively suppressed by increasing laser line-width. Coherent combining requires line-width less than 10GHz, corresponding to sub-millimeters path matching distances. Modal instability is a much less well understood mechanism that results in excitation of higher order modes above a threshold power level. Currently modal instability limits power levels to ~1.6kW (with ~10GHz line-width) for 25um core sized step index fiber. Available theories for modal instability do not predict power threshold accurately and experimental results are very important in base-lining empirical models. Here a comprehensive set of high power (~1kW) experiments using VLMA step index and gain tailored fibers are presented. Characterized step index and gain tailored fibers are: (core/clad size) 35/500um, 45/375um, 60/500um; (doped-core/undoped-core/clad size) 40/60/400, 50/80/530um with core NA-0.08. Experimental results include: mode quality degradation, intensity noise broadening and line-width variation with output power. Except for 35um fiber, all the fibers exhibit modal instability thresholds below 1kW. In controlled experiments bend radius and seeding content dependence of power threshold are sought. Current model that treat power exchange between LP01 and LP11 modes is extended to multiple modes and is base-lined using experimental results.

8733-23, Session 5

Analytical and numerical studies of modal instabilities in high-power fiber amplifiers

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There have been recently several reports that large mode area (LMA) high-power fiber amplifiers are susceptible to the onset of modal instabilities. These instabilities are characterized by sudden and dramatic increase in the modal content of higher-order modes as well as rapid temporal oscillations. We present a detailed theoretical and numerical investigation of modal instabilities in high-power Yb-doped fiber amplifiers using a time-dependent temperature solver coupled into the optical fields. An alternating direction implicit (ADI) method is implemented in polar coordinates to solve for the thermal effects as this coordinate system is well-suited to describe the fiber geometry and boundary conditions. The convergence and accuracy of the numerical simulations are validated through a series of comparisons to analytical solutions as well as other numerical techniques. The need to capture the temporal evolution in order to accurately predict the threshold of the instabilities is analytically verified. Using this model, the dependence of threshold on seed power, gain-tailoring, and core size is investigated and compared to experiments. Furthermore, the thresholds of the modal instabilities for different pumping configurations, such as co-pumping and counter-pumping, are computed and compared. The effect of laser linewidth on the instabilities by solving an expanded system of coupled nonlinear equations is examined and presented along with the experimental findings. Finally, we suggest several techniques to mitigate the instabilities.

8733-25, Session 6

Melt growth and equilibria of cesium germanium chloride

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The cesium germanium halides, $CsGeCl_3$ and $CsGeBr_3$, are a highly promising class of nonlinear optical frequency conversion materials. We have successfully grown single crystals of $CsGeCl_3$ from the melt and devised a method for the direct synthesis of $CsGeCl_3$ from ultra-high purity starting materials. We have also studied the composition of the gases that evolve from a CGC melt in order to understand the relevant equilibria and apply that knowledge to improving the growth conditions.

8733-26, Session 6

Optimizing laser performance in Er and Yb codoped phosphate glasses

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Erbium doped bulk glasses are of high interest to many applications in the defense and medical fields. Current active use of these materials are in amplifiers for optical fiber communications, fiber lasers, LIDAR, q-switched, microchip lasers for laser range finding and in bulk solid state lasers. The dominant laser transition for the Er^{3+} ion is of a three level nature, from the 4I13/2 metastable manifold to the ground-state manifold, 4I15/2. The transition between these two manifolds is strongly influenced by the local fields generated in the host materials leading to emission wavelengths that may peak somewhere in the 1.53?m – 1.6?m region. Moreover, the three level nature of the transition necessitates high population densities resulting in high pump thresholds and low efficiencies.

The Er^{3+} laser performance in materials, especially in glass, can be enhanced by codoping with large amounts of Yb^{3+}. This enables laser diode pumping near 980 nm. Here, absorption by the Yb 2F5/2 state transfers energy to the 4I11/2 state of Er^{3+}, giving rise to sensitized emission with significant reduction in the absorption length of the gain medium. Aside from Yb, Cr and Ce doping is also used in glasses in order to enhance laser performance.

For the development of future eye-safe laser products, the study reported here focused on examining the complex interactions between Cr, Ce, Yb and Er. The effect of these dopants on the thermal, physical, optical, and laser properties of a single host glass composition is evaluated in detail. Our goal is to understand how the dopant concentrations may be optimized for various laser cavity configurations in order to increase the overall output efficiency in phosphate glasses. The main variables that are related in this study are the absorption and emission cross sections at key wavelengths, emission bandwidth and thereby gain coefficient, radiative and excited state lifetimes of the various dopants, and the thermo-mechanical performance of the glass in relation to thermal lensing effects. We show that significant improvement in laser performance can be achieved by utilizing the findings outlined.

8733-27, Session 6

Intrinsically-low Brillouin gain optical fibers

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Numerous methods to increase the stimulated Brillouin scattering (SBS) threshold have been previously implemented. Some are passive, based on acousto-optic fiber designs that incorporate longitudinally- or radially-tailored optical and/or acoustic index profiles, leading to broadened Brillouin gain spectra (BGS) with reduced peak gain. Some are active, relying on an applied temperature or strain distribution, also resulting in broadened BGS. Broadening the laser spectrum still represents the most effective method to-date to obtain large-scale (> 20 dB) decreases in the gain, but the suitability of this method depends largely on the application and system requirements on the laser spectrum. Despite these technologies, some introduced only in the last decade, the vast majority of high-energy, narrow-linewidth fiber laser systems are still limited by SBS rather than the availability of pump power. We present an alternative approach; rather than focusing on 'suppressing' SBS in waveguide or other designs, we propose implementing materials with intrinsically low Brillouin gain. We focus on high-density, high-sound-velocity, large acoustic-damping-coefficient, and low-photoelastic-constant materials wherein the correct balancing of physical characteristics gives rise to extremely low Brillouin gain. In general, the approach requires the use of compositions that would be considered to be highly unconventional and unachievable utilizing standard fiber fabrication methods. For example, we describe recent results on sapphire-derived fibers (among other compositions) wherein a Brillouin gain nearly 20 dB lower than those of more conventional fibers has been realized. Other compositions will also be presented, including those predicted to have zero-valued photoelastic constants, and therefore zero Brillouin gain.

8733-28, Session 6

Recent progress in ceramic YAG cladding technology for fiber laser applications

HeeDong Lee, Brian Sirn, Ii-Seok Park, UES, Inc. (United States)

In order to realize high energy and high power fiber laser systems based on the single or polycrystalline doped YAG fibers, high quality YAG cladding layer with tens of microns in thickness needs to be coated around the fiber cores. However, suitable cladding technology has not been identified yet. UES has been developing the advanced fiber cladding technologies via EB-PVD process. The preliminary results showed that it was highly feasible to produce optically transparent YAG cladding with 20 ~ 30 microns in thickness by a modified co-deposition process The properties of YAG cladding including thermal conductivity, CTE, and refractive index appear to be strongly dependent on crystallinity and off-stoichiometry, and that needs to be further tuned and characterized in the near future.

8733-29, Session 6

Synthesis and spectroscopic properties of Nd3+ and Er3+:MgO ceramics

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MgO is an attractive material with thermal properties very favorable for high energy laser applications. Unfortunately, doping single crystals of this material with laser-active rare earth (RE3+) ions has always been a challenge due to significant ionic radius differences between the Mg3+ site and RE3+ dopant. This work reports significant advances toward developing RE3+ doped MgO ceramic laser material based on our effort in material synthesis, combined with spectroscopic investigation of Er- and Nd-doped MgO, powder and ceramic. Nd3+ or Er3+:MgO powder was synthesized by either blending of rare earth precursor with commercial MgO high purity powder or by a co-precipitation synthesis of high surface area powder. Subsequently, Nd3+ or Er3+:MgO ceramic samples were produced via pressureless sintering of synthesized powder at 1350-1550°C. The results of spectroscopic investigations for a number of states of Nd3+ and Er3+ ion doped MgO ceramic are presented. The fluorescence lifetime for Nd3+ 4F3/2 and Er3+ 4I13/2 levels was measured in a temperature range of 10 - 300K. The stimulated emission cross-section for Nd3+ 4F3/2 4I11/2 and Er3+ 4I13/2 4I15/2 transitions was inferred from fluorescence and excitation spectra using Fuchtbauer-Ladenburg relationship. The potential for laser action at room and cryogenic temperatures is analyzed and presented.

8733-30, Session 7

Recent advancements in transparent ceramics and crystal fibers for high power lasers

Woohong R. Kim, U.S. Naval Research Lab. (United States); Catalin Florea, Sotera Defense Solutions, Inc. (United States); Colin Baker, Guillermo Villalobos, Daniel Gibson, Brandon Shaw, Steven R. Bowman, Shawn O'Connor, Shyam S. Bayya, U.S. Naval Research Lab. (United States); Bryan Sadowski, Sotera Defense Solutions, Inc. (United States); Michael Hunt, Univ. Research Foundation (United States); Ish D. Aggarwal, Sotera Defense Solutions, Inc. (United States); Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

In this paper, we present our recent results in the development of rare-earth (Yb3+ or Ho3+) doped sesquioxides such as Lu2O3 or Y2O3 for high power solid state lasers. We have fabricated various high quality transparent ceramics using nano-powders synthesized by a co-precipitation method. This was accomplished by developments in high purity powder synthesis and low temperature scalable sintering technology developed at NRL. The optical, spectral and morphological properties as well as the lasing performance from highly transparent ceramics are presented. In the second part of the paper, we also discuss our research effort in developing cladded-single crystal fibers for high power single frequency fiber lasers potentially significantly exceeding the capabilities of existing silica fiber based lasers. Single crystal fiber cores with diameters as small as 35µm have been drawn using high purity rare earth doped ceramic or single crystal feed rods by Laser Heated Pedestal Growth (LHPG) process. The mechanical, optical and morphological properties of these fibers have been characterized. The fibers are very flexible and show good overall uniformity. We also measured the optical loss as well as the non-radiative loss of the doped crystal fibers and the results show that the fibers have excellent optical quality. The gain coefficient of the crystal fiber matches the low quantum defect laser model and it is a good indication of the high quality of the fibers. Our recent results on the development of suitable claddings on the crystal fiber core are also discussed.

8733-31, Session 7

M2 and power in the bucket measurements of the beams diffracted by volume Bragg gratings

Christopher Lantigua, Julien Lumeau, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Vadim Smirnov, OptiGrate Corp. (United States); Leonid Glebov, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Volume Bragg gratings (VBG) provide a very efficient way to control the

spectral and angular properties of high power lasers. The fabrication of VBGs with high quality of diffracted beams requires perfect control of the glass homogeneity and the holographic recording process. In this paper, the methods and challenges associated with measuring the quality of the beams diffracted by such VBGs are presented. First a thorough study of the measurement of the M2-value of the beams diffracted by VBGs is performed. The presence of wings in the beam profile is shown to be one common source of deterioration in the beam quality; such a measurement of the M2-value after diffraction on a VBG is a challenging process and cannot be easily achieved using commercial systems and conventional software. In addition, while these wings can represent only a tiny fraction of the total power, they can result in a dramatically increased M2-value of the diffracted beam. However, their exact role in deteriorating the overall beam quality is not obvious. To overcome this difficulty, power in the bucket measurements are introduced and compared with M2 measurements for the same beams. Correlation and differences between these two methods are discussed.

8733-32, Session 7

Coilable single crystal fibers of doped YAG for high power laser applications

Gisele Maxwell, Nazila Soleimani, Bennett Ponting, Eminet Gebremichael Gebremichael, Shasta Crystals (United States)

Single crystal fibers are an intermediate between laser crystals and doped glass fibers. They can combine the advantages of both by guiding laser light and matching the efficiencies found in bulk crystals, making them ideal candidates for high-power laser and fiber laser applications. In particular, a very interesting feature of single crystal fiber is that they can generate high power in the eye-safe range (Er:YAG) with a high efficiency, opening new possibilities for portable directed energy weapons. This work focuses on the growth of a flexible fiber with a core of dopant (Er, Nd, Yb, etc…) that will exhibit good waveguiding properties. Direct growth or a combination of growth and cladding experiments are described. We have, to date, demonstrated the growth of a flexible foot long 45 microns doped YAG fiber. Scattering loss measurements at visible wavelengths along with dopant profile characterization are also presented. Laser characterization for these fibers are in progress.

8733-34, Session 7

New nonlinear optical crystals for power-scalable mid-IR lasers *(Invited Paper)*

Peter G. Schunemann, BAE Systems (United States)

Great advances in mid-infrared nonlinear optical (NLO) crystals have been achieved in the last five years, and these are having – and will continue to have - a significant impact on current and emerging military laser applications requiring high energy or high average power output in the 2 to 12 µm spectral range. ZnGeP2 (ZGP) in particular has emerged as the NLO material of choice for 2-to-8 m operation, and has grown in importance with the advent of high power thulium fiber lasers. Larger ZGP aperture sizes, lower losses, and higher laser damage thresholds have enabled mid-IR OPOs to operate at higher energies and output powers. ZGP still has two main limitations, however: 1) its transparency and phase-matching range make it incompatible with 1- and 1.5-micron laser pumping; and 2) its usefulness for generating output in the 8-12µm atmospheric window is limited by severe multi-phonon absorption. We have developed two new mid-infrared nonlinear crystals which overcome these limitations: cadmium silicon phosphide (CdSiP2, or CSP) and orientation-patterned gallium arsenide (OPGaAs).

CdSiP2 is a large band gap analog of ZnGeP2 (ZGP) with low near-IR losses and a negative birefringence (-0.05) large enough for phase-matched frequency shifting of 1 m, 1.5 m, and 2 m lasers into the mid-infrared. The nonlinear coefficient of CSP - 84.5 pm/V - is even higher than that of ZGP (the highest of any new bulk phase-matchable crystal in the last 40 years), and its 2-µm absorption coefficient is lower by a factor of 10. It offers non-critically phase-matched (NCPM) generation of 4.6 µm output (with simultaneous signal output at 1.6 µm) when pumped at 1.2 µm using a Raman-shifted fiber laser or a high-power optically-pumped semiconductor.

Orientation-patterned gallium arsenide (OPGaAs) is a new quasi-phase-matched (QPM) semiconductor which is comparable in performance to ZGP under 2-m pumping but enables high power output in the 8-12 m window. It is grown using an all-epitaxial processing technique based on the use of polar-on-nonpolar molecular beam epitaxy (MBE) to grow a polar GaAs film on a thin non-polar lattice-matched Ge layer with an orientation that is inverted with respect to the GaAs substrate: the inverted layer is then photo-lithographically patterned with the grating period(s) for the desired wavelength interaction(s) and alternate domains are etched back to the original substrate surface. Both orientations are then re-grown, first by MBE then by hydride vapor phase epitaxy (HVPE) at rates > 150 µm /hr to produce thick QPM layers for in-plane laser pumping. We routinely produce 3-inch OPGaAs wafers with > 1.5-mm-thick QPM layers capable of generating pulsed multi-watt mid-IR OPO output, and recently demonstrated the first continuous wave OPO in this material which produced 5W of average power (3.8- m signal and 4.68-m idler) from a low-loss 40-mm-long OPGaAs crystal. We are currently developing a new QPM semiconductor OPGaP compatible with 1-?m pump laser sources.

8733-50, Session 7

Advances in semiconductor core optical fibers

John Ballato, Advanced Materials Ctr. (United States); Stephanie Morris, Thomas Hawkins, Clemson Univ. Research Foundation (United States)

Glass-clad optical fibers comprising cores of crystalline semiconductor materials have garnered considerable attention in recent years. However, despite much progress, losses remain high. This talk will focus on optimization efforts including annealing, tapering, core geometry control, and reactive chemical processes to reduce losses towards device-practical levels. Selected devices and applications-relevant measurements made to date will also be presented.

8733-33, Session 8

Enhanced power scaling potential for solid state and fiber laser systems incorporating anti-reflection microstructures

Douglas S. Hobbs, Bruce D. MacLeod, Ernest Sabatino III, TelAztec LLC (United States)

Single crystal yttrium aluminum garnet (YAG), widely used as a host material in metal-ion doped solid state lasers, is difficult and expensive to grow in the large sizes needed to power scale by increasing aperture size. Polycrystalline YAG materials are more versatile and can be fabricated at low costs in the larger scales needed for kilowatt class high energy laser (HEL) programs such as the Army's Robust Electric Laser Initiative (RELI) and the Department of Energy's National Ignition Facility (NIF). In these solid state HEL configurations, very high intensity light is propagated through free-space optics or launched from fused silica fiber laser oscillators into YAG slab amplifiers where internal reflections must be eliminated at every interface, often through the deposition of thin-film material anti-reflection (AR) coatings (ARCs). These ARCs however, suffer permanent damage at intensity levels well below the untreated material damage threshold, forcing elaborate work-arounds such as the Brewster angle configuration, fiber end caps, and wavefront distorting angle cuts on fiber facets. In addition, ARCs present problems with uniformity, consistency, adhesion, absorption, thermal lensing, and degradation from water absorption or carbon contamination. Non-scattering AR micro-textures (ARMs) etched into fiber and planar waveguide facets, offer a more reliable single material alternative to ARCs. Prior work has demonstrated pulsed laser damage thresholds for ARMs in fused silica

that are up to 5 times higher than equivalent performance ARCs. In this work, the results of continuous-wave laser damage tests completed with Raytheon and Textron, will be presented for ARMs in fused silica, Yb:YAG, and Nd:YAG relative to untreated and thin-film AR coated substrates.

8733-36, Session 8

Tunable fiber laser with external transverse chirped Bragg grating as an output coupler

Aleksandr Ryasnyanskiy, OptiGrate Corp. (United States); Nikolai Vorobiev, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Vadim Smirnov, Larissa Glebova, Oleksiy Mokhun, Eugeniu Rotari, Alexei Glebov, OptiGrate Corp. (United States); Leonid Glebov, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Cost effective, tunable laser sources at 1 µm are important for nowadays science and technology. A combination of high output power and wall plug efficiency makes double clad Yb-doped fiber laser an attractive solution for many applications, such as spectroscopy,sensing, frequency doubling, etc.

In this paper we report on a simple scheme for realization of compact, narrow line, tunable Yb-fiber laser source with a transverse chirped Bragg grating (TCBG) acting as a narrow band tunable output coupler. A fiber coupled laser diode with a fiber diameter of 105 µm, NA of 0.12, maximum output power - 30 W was used as a pump source. A 120-cm-long Yb-doped double-clad fiber with a core diameter of 10 ?m and cladding diameter of 125 ?m was used as a gain medium. The external cavity was formed by a dichroic mirror with a high transmission for the pump (976 nm) and high reflection for the signal wavelengths (1020-1100 nm) and a TCBG as an output coupler.

The TCBG had a fan-shaped structure with a transversely chirped grating period, providing a variation of the reflected wavelength over the grating's transverse direction. We used the TCBG with a chirp rate of 0.8 nm/mm, spectral bandwidth of 160 pm and diffraction efficiency of 50%. Linear translation of TCBG in transverse direction allowed continuous tuning of an emission line of the Yb-fiber laser operating in a single transverse mode in the wavelength range of 1025-1035 nm with a power up to3 W and linewidth ~50 pm.

8733-37, Session 8

High-efficiency, high-pulse energy fiber laser system

Mark S. Bowers, Jason Henrie, Megan Garske, Dan Templeman, Robert Afzal, Lockheed Martin Aculight (United States)

In this paper, we report a master-oscillator/power-fiber-amplifier (MOFA) laser system flight qualified for high altitude aircrafts. The MOPA system consists of a fiber-coupled single-frequency diode laser (master oscillator), which is directly modulated by an electronically controlled pulsed driving current thus setting the pulse duration and repetition rate. The diode output is pre-amplified using two stages of single-transverse-mode, Yb-doped fiber pumped by single-stripe diode lasers. This is followed by two stages of photonic crystal fiber (PCF) amplifiers, with both stages using a single-polarization, single-mode Yb-doped PCF (40 µm core-diameter, 200 µm cladding diameter). Both PCF are end-pumped in a counter-propagating direction, and beam-expanding endcaps are fabricated on their output end to prevent facet damage. To couple pump light into the PCF and for injecting amplified pulses from one PCF stage to the next, environmentally rugged subassemblies featuring connectorized fibers and fiber collimating ports along with non-adjustable free-space optics were developed. In this configuration, the laser achieves 1.2 mJ in a 3.4 ns pulse width at a repetition rate of 19 kHz with near diffraction limited beam quality (M2 < 1.1) and an electrical to optical efficiency of 20%. Furthermore, the laser was put through extensive environmental testing for flight qualification in high altitude aircrafts. This laser provides unprecedented performance (high brightness and efficiency) from a ruggedized pulsed fiber laser source.

8733-49, Session 8

Recent progress towards efficient and powerful fibre laser emission at 3 µm *(Invited Paper)*

Stuart D. Jackson, Darren D. Hudson, The Univ. of Sydney (Australia)

There is a strong applications requirement for the development of high power and efficient light sources with emission in the 3 µm region of the spectrum. The use of the fibre laser is preferable to solve this problem but there are many outstanding challenges. In this talk we will briefly review our work in the area of fluoride-glass-based fiber lasers with emission at 3 µm.

8734-1, Session 1

Simulation and Signal Processing of Through Wall UWB radar for Human Being's Periodic Motions Detection

Jing Li, Fengshan Liu, Penglong Xu, Delaware State Univ. (United States)

The ultra wideband (UWB) radar has numerous applications in searching and rescuing at disaster relief site. Identifying vital sign and locating the buried survivor are two important research areas. Comparison with moving human, the stationary human's weak vital sign, such as breathing and heartbeat are difficult to be identified due to the environment interference and weak amplitude of itself. In this paper, we build the model which two survivors buried in a collapsed building and apply finite difference time domain (FDTD) method to simulate vital sign response. Advancements in signal processing may improve imaging and analysis signal. Firstly, apply the cross-correlation analysis and Curvelet transform to remove direct wave and decompose the background clutter, then use singular value decomposition (SVD) to reduce the noise in the life signals and present the results base on FFT and ensemble empirical mode decomposition (EEMD) combines with the Hilbert-Huang transform (HHT) to separate and extract vital signs frequencies of breathing and heartbeat and human's micro-Doppler shift characteristic. The laboratory test results also demonstrate that combination of UWB radar and various processing methods has potential for human's vital sign detection and location in complex environment, such as disaster search, rescue operation and so on. Submitted to Special Session on Human Micro-Doppler Radar Signatures.

8734-2, Session 1

Wideband radar micro-doppler applications

David Tahmoush, U.S. Army Research Lab. (United States)

Wideband radar provides a significant improvement over traditional narrowband radars for micro-Doppler analysis because the high bandwidth can be used to separate many of the signals in range, allowing a simpler decomposition of the micro-Doppler signals. Recent work has focused on human micro-Doppler, but there is a point where the narrowband approximation used to analyze the micro-Doppler signals breaks down. The effect is shown to be independent of frequency, but the relative error is shown to be inversely proportional to the frequency. This error can create a smearing effect in the observed Doppler if it is not corrected, leading to more diffuse targets with reduced signal-to-noise. The possible applications of wideband micro-Doppler radar are also shown, including the separation of arm movement from human motion which could enable the classification of armed versus unarmed.

8734-3, Session 2

Micro-doppler radars for human gait analysis using joint range-time-frequency representation

Aly E. Fathy, Yazhou Wang, The Univ. of Tennessee Knoxville (United States)

Human physical activity is a complex motion that is comprised of movements of individual body parts, including head, torso, leg, arm and foot. For example, the people walking activity generates a number of different frequency shifts in the radar returned signal, also called micro-Doppler frequency shifts and could be a distinctive signature of the person. Radar micro-Doppler signatures can be used to detect the presence of human beings and their movement behind walls. The detection of multi-static micro-Doppler can be enhanced by adding spatial diversity to simultaneously track more than one person.

Several radar technologies can be used to detect micro-Doppler signatures of human activity, including CW, FMCW, pulse compression, and pulse radar. CW radar, however, is limited to certain applications which do not require target range information. CW with dual frequency can be used for range detection as well, but subject to multipath. Wideband FMCW and pulse compression radars are quite complicated and expensive to implement. UWB pulse-Doppler radar technology is used because of its relatively low prototyping cost, and capability of providing high resolution range profile using a versatile range-time-frequency.

A UWB pulse-Doppler radar has been developed recently. The developed radar is used for intelligent human gait recognition. Several experiments, including human marching and walking, multiple people walking, have been performed. Promising experimental results have been achieved from joint range-time-frequency representation. The developed radar is also capable of detecting vibrations of respiration and heartbeat for stationary human targets buried in collapse for searching and rescuing operations.

8734-4, Session 2

A measurement approach based on micro-doppler maps for signature and motion analysis

Roberto Ricci, Alessandro Sona, Univ. degli Studi di Padova (Italy)

Over the last few years, the development of modern and powerful technologies in the field of electronic, informatics, sensors and microwave, has significantly increased the effectiveness and potentialities of tools and applications for the detection and tracking of objects, animals and humans. Doppler effect is an interesting phenomenon that can be exploited for motion analysis purposes. It consists in a frequency shift affecting a generic wave when the source, generating the wave, is moving relative to an observer. The Doppler processing outputs are typically in the form of bi-dimensional spectrograms. With respect to the Doppler maps, which account only for gross translation, micro-Doppler ones are more complex. They typically appear as a set mixed trajectories, difficult to analyse and assess separately. In this paper, a novel and comprehensive measurement approach is proposed for the detection and analysis of human motion signature. The approach combines theoretical concepts and tools of micro-Doppler theory, image processing, and human modeling, in a original way. The attention is primarily focused on the description of the most meaningful parameters influencing the accuracy of the obtained signature. The ultimate purpose is to provide a framework through which organizing, comparing, and merging future research activities, ideas and results in the field of human motion signature analysis for security, health and disaster recovery purposes. Some simulation and experimental results underlying the feasibility and effectiveness of the measurement approach are also summarized and analysed.

8734-5, Session 2

An image-based approach for classification of human micro-doppler radar signatures

Fok Hing Chi Tivive, Abdesselam Bouzerdoum, Son Lam Phung, Univ. of Wollongong (Australia)

There has been an increasing interest in new technology for S-band and mm-wave micro-Doppler radars due to its numerous potential civilian and military applications. This type of sensing modality can be deployed in a wide range of weather conditions, during the day or at night. It captures the kinematics properties of a moving target by generating sidebands about the target Doppler frequency, which are referred to as the micro-

Doppler signature or phenomenon in radar. In this paper, we propose an image-based approach to classify different human movements based on their micro-Doppler radar signatures. The proposed image-based classification framework can be briefly described as follows.

Since the radar signals are time-varying, a joint time-frequency analysis is firstly performed to capture the target micro-motions from the radar trace. The time-frequency representation is cast as a two-dimensional image where an image enhancement technique, Naka-Rushton transformation, is used to highlight the weak micro-Doppler frequencies characterizing the feet and arms motions of a walking human. In contrast to existing image-based classification approaches which employ the entire time-frequency representation of the recorded radar signal, we propose a local-based feature extraction method to extract the time-varying frequency features around the human torso frequency. The rationale for this feature extraction scheme is that it is independent of the target speed and it is robust against occlusion as the classification is done on local windows centered on the torso frequency depicted in the time-frequency representation. In other words, overlapping local windows along the torso frequency are extracted from the time-frequency representation, and each local window is transformed into a feature vector by using the proposed image-based feature extraction method. The feature vectors corresponding to the overlapping location windows are then sent to an SVM classifier. To classify the radar trace, the classification scores are aggregated via a majority voting rule.

To evaluate the effectiveness of the proposed approach, we used a frequency-modulated continuous-wave (FMCW) radar system operating at a carrier frequency of 24GHz to interrogate a person walking with different arm motions in outdoor environments. The operation radar range is from 1m to 20m. Each person is required to perform three types of motions: (1) walking normally with both arms swinging, (2) walking while carrying an object in one hand, and (3) walking while holding a heavy object with both hands. These types of motions can be useful for situation awareness or rise assessment. The database consists of 20 subjects where half of them are males and the other half are females, performing motions (1) to (3) for three times. For evaluation, a five-fold cross-validation procedure was employed and several existing micro-Doppler classification methods were tested on the same database. The experimental results showed that the proposed image-based classification approach successfully classifies the human motions and its classification is comparable with those of the existing approaches.

8734-6, Session 2

Radar classification of human motions under various training scenarios

Dustin P. Fairchild, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

The identification and classification of human motions has become a popular area of research due to its broad range of applications. Knowledge of a person’s movements can be a useful tool in surveillance, security, search and rescue operations, and the medical fields. Classification of common stationary human movements has been performed under various scenarios for two different micro-Doppler radar systems: S-band radar and millimeter-wave (mm-wave) radar. Each radar system has been designed for a specific scenario. The S-band radar is designed for through-the-wall situations at close distances, whereas the mm-wave radar is designed for long distance applications and also for through light foliage. Here, the performance of these radars for different training scenarios is investigated. The S-band radar will be analyzed for classification without a wall barrier, through a brick wall, and also through a cinder-block wall. The effect of a wall barrier on micro-Doppler signatures will be briefly discussed. The mm-wave radar will be analyzed for classification at distances of 100 feet, 200 feet, 300 feet, and through light foliage. Because a given classifier may be very sensitive to the training scenario (dependent on the distance to the target, the presence or absence of a barrier, barrier material, etc.), it will be shown that classification under one scenario will not necessarily produce accurate classification results under another scenario.

8734-7, Session 2

Multi-aspect angle classification of human radar signatures

Cesur Karabacak, TOBB Univ. of Economics and Technology (Turkey); Sevgi Z. Gurbuz, TOBB Univ. of Economics and Technology (Turkey) and TÜBITAK UZAY (Turkey); Mehmet B. Guldogan, Turgut Özal Univ. (Turkey); Ali Cafer Gurbuz, TOBB Univ. of Economics and Technology (Turkey)

Micro-motion dynamics, such as the vibration or rotation of any part of a target, generate frequency modulations of the return signal in addition to the Doppler shift caused by translational motion that are known as micro-Doppler. For example, the rotation of the wheels of a vehicle, treads of a tank, and blades of a helicopter all result in radar micro-Doppler. The human micro-Doppler signature - caused by the complex time-varying motion of the human body, arms, legs, hands, and feet – is a unique signature that can be easily visually discriminated from those of any other target type, including animals, and is strongly dependent on the activity being engaged in. Thus, the micro-Doppler signature of a human walking, running, crawling, or jumping all differ, while maintaining some commonalities stemming from physical constraints imposed by the human body. Classification of targets based on micro-Doppler generally involves joint time-frequency analysis of the radar return coupled with the extraction of features that may be used to identify the type or characteristics of a target. Many techniques have been investigated, including artificial neural networks, support vector machines, and wavelets; however, most techniques suffer from a drastic drop in classification performance as the aspect angle of human motion relative to the radar increases.

This paper aims at ameliorating the dependence on target motion by using a radar network to obtain micro-Doppler data at multiple aspect angles. It has been shown in the literature that a target’s multi-static micro-Doppler signature contains unique information in addition to that provided by the mono-static micro-Doppler signature. In this work, knowledge of human walking kinematics is exploited to fuse the multi-aspect data obtained from the radar network in the time-frequency domain. The quality of features extracted from the fused spectrogram is compared to that from features extracted from the spectograms generated from each antenna independently. A multi-aspect classifier is designed based on the features extracted and performance compared to that of mono-static systems.

8734-9, Session 3

A probabilistic model for simulating the effect of airborne dust on ground-based LIDAR

Christopher Goodin, Phillip J. Durst, U.S. Army Engineer Research and Development Ctr. (United States); Zachary Prevost, Univ. of Mississippi (United States); Patrick Compton, U.S. Air Force Academy (United States)

The U.S. Army Engineer Research and Development Center developed a high-fidelity simulation environment, called the Virtual Autonomous Navigation Environment (VANE), which includes physics-based simulations of LIDAR sensors as well as other sensors commonly used in robotics. The LIDAR simulations in the VANE include the target surface properties and laser-beam divergence effects. A set of experiments was recently conducted to develop a model for quantifying the effect of airborne dust on LIDAR sensors for inclusion in the VANE.

Field and laboratory measurements of LIDAR interactions with dust were performed for two types of common ground-based LIDAR sensors. The laboratory experiments revealed a strong linear correlation between the probability for a return from the dust and the optical depth of the dust. Based on the experimental correlation, a probabilistic model for quantifying LIDAR interactions with dust was developed and integrated into the VANE high-fidelity ray-tracing simulation. The probabilistic model was verified in field experiments at three locations with different road

conditions including crushed limestone, clay, and sandy loam soil. In this paper, the experiments will be described, and the resulting model will be presented. The results of integrating the model with the VANE simulation will also be shown.

Permission to publish was granted by Director, Geotechnical and Structures Laboratory

8734-10, Session 3

Image and signal processing algorithm performance in the Cloud

Kelly W. Bennett, U.S. Army Research Lab. (United States); James Robertson, Clearhaven Technologies LLC (United States)

The U.S. Army Research Laboratory (ARL) supports and performs classification, detection, tracking, and localization algorithm development using geophysical (acoustic, seismic, E-field, magnetic field, PIR) and imaging sensors (visual and IR). Development and testing of the algorithms using large data set signatures of various modalities requires high-performance computing resources, which increases and challenges existing infrastructures. Cloud services offering low-cost, pay-as-you-go pricing models, scalability, and elasticity may provide solutions to develop and optimize algorithms without having to procure additional hardware and resources. This paper provides a detailed look at using a commercial cloud service provider, such as Amazon Web Services (AWS), to develop and test simple image and signal processing algorithms in a cloud environment using large data sets. Analytical results will compare the existing ARL infrastructure with a commercial cloud infrastructure. A discussion on security best practices for using the cloud with government data will provide insight into security concerns of using a cloud-computing environment.

8734-11, Session 3

Amplification of radar and lidar signatures using quantum sensors

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

One of the major scientific thrusts from recent years has been to try to harness quantum phenomena to dramatically increase the performance of a wide variety of classical devices. These advances in quantum information science have had a considerable impact on the development of photonic-based quantum sensors. Even though quantum radar and quantum lidar remain theoretical proposals, preliminary results suggest that these sensors have the potential of becoming disruptive technologies able to revolutionize reconnaissance systems. In this paper we will discuss how quantum entanglement can be exploited to increase the radar and lidar signature of a variety of targets. In particular, we will show how the effective visibility of certain targets is increased if observed with an entangled multi-photon quantum interferometer. In addition, we will examine how this effect can be used to beat the Rayleigh diffraction limit that bounds the performance of traditional sensing devices. Finally, we will present a new set of equations that describe how photon redundancy can be used to beat the effects of a noisy environment.

8734-13, Session 3

Applications of composite signatures for natural disasters 2.0

Chadwick Todd Hawley, National Signature Program (United States)

No Abstract Available.

8734-32, Session 3

Challenges in multimodal spectral tracking

Mark A. Sartor, RDIS, LLC (United States)

No Abstract Available.

8734-14, Session 4

Approaches to modeling composite signatures

Beverly Richardson, TASC, Inc. (United States)

Composite Signatures expand the possibilities for remote sensing exploitation by introducing data fusion into the definition of a signature. The Composite Signature expands the notion of a signature to encompass activities and contexts rather than a singular focus on an object being identified. This approach enables remote sensing applications to use lower thresholds, or exploit phenomenology which previously unusable due to excessive false alarms in the environment. This paper explores the benefits and draw-backs of two different composite signature data fusion methodologies. A predictive analytics approach can be employed to define the best algorithms for fusing multiple data sources when a data set of true positives is available for algorithm training. Dempster-Shafer Combination of Evidence can be employed when too few true positive examples are available and additionally has the benefit of being designed to quantify uncertainty.

8734-15, Session 4

Raman albedo and deep-UV resonance Raman signatures of explosives

Balakishore Yellampalle, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

Deep-ultraviolet resonance Raman spectroscopy (DUVRRS) is a promising approach to stand-off detection of explosive traces due to large Raman cross-section and background free signatures. In order to design an effective sensor, one must be able to estimate the signal level of the DUVRRS signature for solid-phase explosive residues. The conventional approach to signal estimation uses scattering cross-sections and molar absorptivity, measured on solutions of explosives dissolved in an optically-transparent solvent. Only recently have researchers started to measure solid-state cross-sections. For most solid-phase explosives and explosive mixtures, neither the DUV Raman scattering cross sections nor the optical absorption coefficient are known, and they are very difficult to separately measure. Therefore, for a typical solid explosive mixture, it is difficult to accurately estimate Raman signal strength using conventional approaches. To address this issue, we have developed a technique to measure the Raman scattering strength of optically-thick (opaque) materials, or "Raman Albedo", defined as the total power of Raman-scattered light per unit frequency per unit solid angle divided by the incident power of the excitation source. We have measured Raman Albedo signatures for a wide range of solid explosives at four-to-six different DUV excitation wavelengths. These results will be presented, and we will describe the use of Raman Albedo measurements in the design and current construction of a novel stand-off explosive sensor, based on dual-excitation-wavelength DUVRRS.

8734-31, Session 4

Infrared enhanced detection for laser imaging and biometrics

Martin U Pralle, SiOnyx, Inc (United States); J Carey, SiOnyx (United States); Homayoon Haddad, SiOnyx, Inc (United States)

SiOnyx has developed infrared enhanced CMOS image sensors leveraging a proprietary ultrafast laser semiconductor process technology. This technology demonstrates 10 fold improvements in infrared sensitivity over incumbent imaging technology while maintaining complete compatibility with standard CMOS image sensor process flows. Furthermore, these sensitivity enhancements are achieved on a focal plane with state of the art noise performance of 2 electrons/pixel. The focal plane is color enabled but high transmission of near infrared light allows for near infrared imaging from 850 to 1200 as well. The quantum efficiency enhancements have significant performance benefits in imaging 1064nm laser light as well as 850nm imaging of iris signatures for improved biometric identification.

8734-35, Session 4

Multimodal contributions for volumetric object and scene recovery *(Invited Paper)*

Charmaine Gilbreath, U.S. Naval Research Lab. (United States); Chadwick Todd Hawley, National Signature Program (United States)

In this paper, we present a description of an experiment to capture data from objects and scenes using VIS, SWIR, MWIR, LWIR, and RF SAR sensors. We describe how the data from this spectrum of signature modalities combine to enable volumetric reconstructions of specific targets and scenes. True volumetric imaging provides significantly improved situational awareness with applications spanning the Defense and Civil sectors.

8734-16, Session 5

Significance test with data dependency in speaker recognition evaluation

Jin Chu Wu, Alvin F. Martin, Craig S. Greenberg, Raghu N. Kacker, Vincent M. Stanford, National Institute of Standards and Technology (United States)

The National Institute of Standards and Technology conducts an ongoing series of Speaker Recognition Evaluations. To evaluate the performance of speaker recognition systems, a detection cost function defined as a weighted sum of the probabilities of type I and type II errors is employed. The sampling variability can result in measurement uncertainties. Hence, the standard errors (SE) of the detection cost functions must be taken into consideration in speaker recognition evaluations. In our previous studies as presented in the last SPIE Conference, the SEs of the detection cost functions were computed using the two-layer nonparametric two-sample bootstrap method by taking account of the data dependency which was caused by multiple uses of the same subjects. In this article, using such SEs, a significance test is performed to determine whether the difference between the measured performance levels of two speaker recognition algorithms is statistically significant. While conducting hypothesis testing for comparing two algorithms' performances, the correlation coefficient between the two systems' cost functions is taken into account. An algorithm for computing SEs of cost functions and a synchronized algorithm for calculating the correlation coefficients are presented. And also examples involving five speaker recognition systems are provided.

8734-17, Session 5

Active-SWIR signatures for long-range night/day human detection and identification

Robert B. Martin, Mikhail Sluch, Kristopher M. Kafka, Robert V. Ice, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

The capability to detect, observe, and positively identify people at a distance is important to numerous security and defense applications. Traditional solutions for human detection and observation include long-range visible imagers for daytime and thermal infrared imagers for night-time use. Positive identification, through computer face recognition, requires facial imagery that can be repeatably matched to a database of visible facial signatures (i.e. mug shots). Night-time identification at large distance is not possible with visible imagers, due to lack of light, or with thermal infrared imagers, due to poor correlation with visible facial imagery. An active-SWIR imaging system was developed that is both eye-safe and invisible, capable of producing close-up facial imagery at distances of several hundred meters, even in total darkness. The SWIR facial signatures correlate well to visible signatures, allowing for biometric face recognition night or day. Night-time face recognition results for several distances will be presented. Human detection and observation results at larger distances will also be presented. Example signatures will be presented and discussed.

8734-18, Session 5

On the use of Hough transform in an ultrasound measurement system for human signature analysis

Roberto Ricci, Alessandro Sona, Univ. degli Studi di Padova (Italy)

Human motion analysis is a task of increasing interest in several modern application fields. It can be carried out in a number of different ways and technologies such as for example: cameras-based systems, inertial mechanisms, and wireless devices, based on optic, sound, ultrasound, or radiofrequency waves. Wireless technologies rely on the fact that a backscattered signal coming from a human target, once illuminated by a suitable direct wave, may contain the signature of the target. Such a signature is often represented by a spectrogram, and it depends on the result of many phenomena and factors, including the Doppler effect, environmental conditions, and target behavior. The measurement and analysis of such information are not easy: it typically implies nontrivial operations in terms of measurement and post-processing operations. In this work, the use of Hough transform is considered and studied in the case of human signature analysis. In particular, the choice of some of its meaningful set-up characteristics is pointed out and some helpful hints are finally provided. The purpose is to deduce helpful information about how to optimally set some Hough transform parameters (specifically, quantization step and range), in order to improve human signature analysis. To this aim, Hough transform has been applied to a set of reference images (spectrograms) achieved by using a measurement system, ultrasound waves and a purposely developed reference target. The obtained results underlines the importance of Hough transform in the human signature analysis as well as the proper set-up of some its set-up parameters.

8734-22, Session 5

An inverse-kinematic appraoch using Groebner basis theory applied to gait cycle analysis

Kimberly Kendricks, Central State Univ. (United States); Anum Barki, Ronald F. Tuttle, David J. Bunker, Christoph C. Borel, Air Force Institute of Technology (United States)

Kinematics of the human body has been researched for a long time for clinical studies, sports and human recognition. Over the years, human recognition has become an important task in applications such as security and surveillance. Studies in the past have shown that gait signatures can be extracted out of video and used to identify individuals. The political issues of today, such as national security, are the main causes that have motivated the team at The Air Force Institute of Technology (AFIT) to research pattern recognition in the human gait cycle to identify individuals carrying a concealed load on his or her body. The goal of INSPIRE (Integration of a Sensor Package for Identifying Radical Extremists) is to identify gait signatures of human subjects and distinguish between subjects carrying a concealed load to subjects without load. This research will focus on studying the human gait cycle as well as methods used in identifying gait signatures. The main focus is concerned with the movement of the lower extremities, in particular, the placement of the foot and how the joint angles are affected with carrying extra load on the body. A method of Inverse Kinematics using Groebner Basis Theory is applied to derive a model of the lower extremities to determine all possible configurations of the joint angles, given a specific position and orientation of the foot, and specifically determine how these joint angles behave at different intervals of the gait cycle when load is applied.

8734-34, Session 5

Preview of the newly acquired NVESD-ARL multimodal face database

Kenneth A. Byrd, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

This paper previews the newly acquired multi-modal database of human facial images collected by the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) and the Army Research Laboratory (ARL). The database is comprised of Visible-Color (VIS-COLOR), Visible-Monochrome (VIS-MONO), Shortwave Infrared (SWIR), Midwave Infrared (MWIR) and Longwave Infrared (LWIR) images acquired from 50 volunteers in our indoor testing facility. Images were acquired for three different scenarios. In scenario 1, a total of 5 volunteers were imaged before and after exercise, in daytime and nighttime conditions. In scenario 2, 25 volunteers were imaged in daytime conditions, without exercise, and in scenario 3, 20 volunteers were imaged during daytime conditions, before and after exercise. Images were collected from each volunteer at three ranges: 1m, 2m, 4m, for a duration of 15 seconds per capture at 30Hz. A digital photometer was also used to record the luminance level off the forehead of each volunteer prior to image capture. For volunteers participating in scenarios requiring exercise, rest time was recorded prior to capture, after exercise. It is our intention that this database be used to benchmark the performance of existing and future facial recognition algorithms, in addition to predicting the probability of facial identification task performance using human perception.

8734-19, Session 6

Unmixing hyperspectral skin data using non-negative matrix factorization

Asif Mehmood, Jeffrey D. Clark, Air Force Institute of Technology (United States)

The ability to accurately detect a target of interest in a scene is largely dependent on the spatial and spectral resolution. While hyperspectral imaging provides high spectral resolution, the spatial resolution is mostly dependent on the optics and distance from the target. Many times the target of interest does not cover a complete pixel and thus is concealed within a pixel, i.e. the target signature is mixed with other constituent material signatures within the field of view of that pixel. Extraction of spectral signatures of constituent materials from a mixed pixel can assist in the detection of the target of interest. Hyperspectral unmixing is a process to identify the constituent materials and estimate the corresponding abundances from the mixture. In this paper, we present a framework based on non-negative matrix factorization (NMF) that is utilized to extract the spectral signature and fractional abundance of human skin in a scene. The NMF technique is employed in a supervised manner such that the spectral basis of each constituent are computed first, and then these basis are applied to the mixed pixel. Experiments using synthetic and real data demonstrate that the proposed algorithm provides an effective supervised technique for hyperspectral unmixing of skin signatures.

8734-20, Session 6

Reflectance measurements of human skin from the ultraviolet to the shortwave infrared (250 nm to 2500 nm)

David W. Allen, Catherine A. Cooksey, National Institute of Standards and Technology (United States)

While published literature of the optical properties of human skin is prevalent for the visible region, data is lacking in the shortwave infrared. This paper details an initial study of the reflectance properties of different skin tones over the spectral range of the ultraviolet to the shortwave infrared. A commercial spectrophotometer was used to collect the directional-hemispherical reflectance of each participant's skin from 250 nm to 2500 nm. The portion of skin under test was located on the participant's forearm and was approximately 2.5 cm in diameter. The results will serve as a point of reference for researchers developing optical measurement methods for applications ranging from security surveillance to medical imaging technologies.

8734-21, Session 6

Multimodal gait signatures and motion studies

Christoph C. Borel, David J. Bunker, Ronald F. Tuttle, Anum Barki, Air Force Institute of Technology (United States); Charmaine Gilbreath, U.S. Naval Research Lab. (United States)

AFIT has analyzed a database of gait videos captured under the INSPIRE (INtegration of a Sensor Package for Identification of Radical Extremists) program. The aim of INSPIRE was to distinguish between normal people and potential terrorists carrying a load on the upper body in the form of a suicide vest. We propose to perform high-precision laboratory measurements to find clearer signatures through test dynamic changes in step sizes, direction and obstacles. We are using multiple sensor modalities (passive optical (visible, near infrared and thermal), active optical (Kinect), acoustic, microwave Doppler and millimeter wave imaging) and extended the signature library from walking and climbing signatures to other high-value motions such as vehicle dismounts and digging.

We describe a multi-modal sensing signature library of natural motions by using a number of the above described sensors for a limited set of subjects with different loads, clothing and typical activities such as walking, climbing/descending stairs, exiting and getting in a car or truck, waiting, sitting down and getting up, digging, chopping, cooking, etc. Capturing such activities by multiple sensor modalities simultaneously might make their identification more robust and reduce the number of false positives. From a research point of view it might be possible to then better understand observables such as measured Doppler spectra of a person digging and develop aspect angle dependent signatures which could be used in imaging Radar and periodic movements of a head in persistent surveillance video data.

8734-23, Session 7

Influence of surface of explosive on its detection and identification using the SDA method for analysis of the reflected THz signal

Vyacheslav A. Trofimov, Svetlana A. Varentsova, Lomonosov Moscow State Univ. (Russian Federation); Mieczyslaw Szustakowski, Norbert Palka, Military Univ. of Technology (Poland)

The SDA (Spectral Dynamics Analysis) method is applied for the

detection and identification of the PWM C4 explosive, having inhomogeneous surface after its surfacing by the sandpaper with grit and without inhomogeneity. The second case corresponds to a disk with various curvature of the surface.These problems are considered with the aim of the possibility for the detection and identification of the material. In this report we illustrate that the problem of explosive detection can be solved using the dynamics of spectral lines of substance response. We show that the SDA-method is good tool for the detection and identification of explosive using THz signal reflected from the sample.

8734-24, Session 7

Active-mode standoff IR sensing of explosives: angular dependence, LOD values, and substrates

Carlos A. Ortega-Zúñiga, Nataly Y. Galán-Freyle, John R. Castro-Suarez, Leonardo C. Pacheco-Londoño, Samuel P. Hernandez-Rivera, Univ. de Puerto Rico Mayagüez (United States)

A standoff calibration for detection of highly energetic materials (HEM) using infrared spectroscopy is presented in this report. The procedure consists in the detection at 1 meter distance and the variation of three parameters of detection. The first parameter considered was the angular dependence: 0 to 70 for source-target with respect to alignment of target-detector. The second parameter was the use of different surfaces in which the material was deposited. The substrates used were smooth aluminum, roughened aluminum and anodized aluminum. The third parameter studied was the dependence on analyte loading: surface concentration: from 10-200 ug/cm2. Calibration curves were based on the use of robust chemometrics routines such as partial least squares (PLS) regression analysis. These algorithms were used to evaluate the impact of the angular dependence, the surface concentration of HEM deposited and the detection limits and statistical significance of analyses performed.

8734-25, Session 7

Passive RF imaging: transparent urban structures

Thomas Carpenter, CACI International Inc. (United States)

Applied Systems Research (ASR) is developing interferometric Passive RF Imaging (PRFI) techniques that enable precision geolocation, identification, and display of low-level RF source locations emanating from within urban structures. PRFI, an adaption of radio astronomy interferometry methods, uses multiple coherent receivers with a sparsely populated antenna array to perform the geolocation. By using multiple observations to remove ambiguities and appropriate comparison of the phases of the common signals at the different antenna locations, the full width of the antenna array can be used to provide fine resolution of the emitter location. The presence of buildings along RF paths will alter the signal phases but it has been found that for many buildings of interest, the distortions in the phase differences are modest and geolocation accuracy is generally good to better than one meter. ASR has performed a number of field tests to demonstrate this technology using existing commercial-off-the-shelf hardware. Recently ASR designed and developed a limited prototype version of PRFI for a mobile platform. The PRFI mobile prototype system calculated the location of the sources with measured accuracies to within 0.5 meters. These tests successfully demonstrated the capability for the precision geolocation of emitters of interest inside a building using a stand-alone moving mobile platform. The imaging and identification results were provided to the operator within a few seconds following the vehicle passing along the building of interest. Test data from the Camp Lejeune demonstration will be presented along with the methodology employed as a pre-prototype mobile system.

8734-33, Session 7

An evaluation of electric field sensors for small-arms bullet detection

Cassandra A. Browning, Stephen J. Vinci, David M. Hull, U.S. Army Research Lab. (United States); Maciej A. Noras, The Univ. of North Carolina at Charlotte (United States)

No Abstract Available.

8734-36, Session 7

Shape recognition using voxel representation of point cloud data collected with motion stereoscopy

David Bonanno, Frank Pipitone, Charmaine Gilbreath, U.S. Naval Research Lab. (United States); Chadwick Todd Hawley, National Signature Program (United States); Brendan Berman, Paul McGee, U.S. Naval Research Lab. (United States)

We address the challenge of creating useful surfaces from noisy point cloud data generated from motion stereoscopic systems. These systems allow for better side registration of objects and can be used to generate very dense point clouds yet tend to have lower accuracy than other 3D sensing systems. As such, we look at the effects of converting these data sets into voxel representations. We explore simple methods of removing poorly registered voxels. In addition we demonstrate how various sensing algorithms can be used to rapidly identify objects based on their geometric profile in a voxel space.

8735-1, Session 1

Scorpion hybrid-optical-based inertial tracker (HObIT)

Robert Atac, Eric Foxlin, Gentex Corp. (United States)

Gentex Corporation has developed a new helmet tracker based on a hybrid inertial optical approach. It uses the inside-out concept and dual InterSense NavChip Inertial Measurement Units (IMUs). A unique feature of the tracker is that there is no aircraft mounted equipment. A few circular bar code like fiducial stickers are placed on the interior surface of the cockpit. The tracker allows operation in both hybrid inertial/optical and inertial alone. This paper describes the tracker, its features and flight performance results.

8735-3, Session 1

De-interlacing: a helmet-mounted display application perspective

Erkan Yavuz, Ismail Ozsarac, ASELSAN Inc. (Turkey)

Helmet mounted displays (HMD) increase the situational awareness and reduce workload of the warfighter by displaying day and night imagery and symbology in front of his eye and head tracking capability to slave the sensor and weapon systems on the platform according to head movements. The usage of HMD is increasing by integrating them into both newly developed and existing platforms. In helmet mounted display systems, the video displayed on miniature display is projected to pilots visor via optical components. While the previous systems include cathode ray tube (CRT) based displays, the recent systems have pixel based ones. Most of the sensor systems installed on the existing platforms still have analog interlaced video outputs. Hence, for the pixel based displays, it is necessary to convert interlaced videos to progressive ones before the other image processing steps. The de-interlacing method is crucial if the symbology of the sensor could not be re-generated and there is a need to de-interlace the symbology overlaid interlaced video. Moreover, as far as total system latency is concerned, this process should be real-time such that it will not cause an annoying delay. In this study, spatial and spatio-temporal methods using a few interlaced lines or frames in the literature are applied on the symbology overlaid infrared videos, implemented on Field Programmable Gate Array (FPGA), real time analysis are made and compared via HMD application perspective.

8735-4, Session 1

Novel method for characterization and compensation for canopy distortion over a large head-box

Robert Atac, Mark Edel, Gentex Corp. (United States)

Gentex Corporation has developed a novel method for characterization of canopy distortion for a large head box. Canopy distortion occurs when the user is looking through any curved transparency. Any helmet mount display system must either add canopy distortion error to its total error budget or compensate for the error. To date, canopies have been characterized for only a few discrete locations in the cockpit. This results in a partial reduction of canopy distortion error as the pilot will rarely sit in one of the few defined locations. The described method allows for canopy distortion characterization and compensation for the entire HMD head-box.

8735-5, Session 1

Active matrix organic light emitting diode (AMOLED)-XL performance and life test results

David A. Fellowes, Michael E Botkin, Russell S Draper, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Jason Coletta, USSOCOM HQ (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 2012 with the US Government, eMagin made additional improvements in OLED life and developed the first SXGA (1280 X 1024 triad pixels) and WUXGA (1920 X 1200) OLED microdisplays. US Army RDECOM CERDEC NVESD conducted life and performance tests on these displays, publishing results at the 2007, 2008, 2009, 2010, 2011, and 2012 SPIE Defense, Security and Sensing Symposia. Life and performance tests have continued through 2012, 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.

8735-6, Session 1

Dynamic sunlight filter (DSF) for HMD: controlling background illumination in a passive way

Ariela Donval, Noam Gross, Eran Partouche, Ido E. Dotan, Ofir Lipman, Moshe Oron, KiloLambda Technologies, Ltd. (Israel)

Some HMDs allow the computer generated image (CGI) to be superimposed on a real-world view. Combining real-world view with CGI can be done by projecting the CGI through a partially reflective mirror and viewing the real world directly. This method is often called Optical See-Through. In see-through HMD the background illumination is a crucial factor influence the ability of viewing the display. When using the HMD at a very bright day, the display image risks vanishing due to the sun illumination. However, at a very cloudy day, one needs all the light to pass through the display to the user eye. The need for a better light control was the trigger for our effort in developing Dynamic Sunlight Filter (DSF), which is a passive solution dedicated to regulate sunlight overpower events.

KiloLambda's Dynamic Sunlight Filter (DSF), is a passive solution dedicated for sunlight controlling and regulating applications, and is based on limiting mechanism. The limiting function implies that 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 direct sun, the DSF transmission decreases, eventually reaching a darkened state. This process is reversible and the filter returns to its transparent state once the intensity of light decreases to its normal level. When placing such a DSF at the outer face of the HMD, it provides the benefit of keeping background illumination at the desired level, regardless of the real weather conditions, such as bright sun or clouds. We present at this talk the DSF functionality and the benefits for the HMD application.

8735-18, Session 1

Sampled MTF of fused fiber optic components and bonded assemblies

Thomas E. Carter, SCHOTT Lighting and Imaging (United States)

Fused fiber optic devices are bundles of glass optical fibers that have been successively drawn and re-bundled to smaller and smaller sizes, effectively creating a zero optical path window. Due to the nature of fiber's clad and core design, pixelization or sampling of the resulting image occurs; this sampling fundamentally degrades the image. Typically, and most conveniently, the degradation of a resulting image caused by an optical system can be quantified by way of its Modulation Transfer Function. However, since fused fiber optic devices first sample then effectively project the original image (object), they do not meet the Fourier Transform's prerequisite conditions of being linear and isoplanatic.

This paper discusses the test methods developed and subsequent measurement of the sampled modulation transfer function for varying designs of fused fiber optic straight through bundles. Additionally, current technologies at Schott Lighting and Imaging have initiated a study to determine methodology for measuring the MTF of bonded assemblies, such as bonded Faceplate-to-OLED and Faceplate-to-sensor assemblies. The use of randomly generated targets imaged through the bonded assemblies proved to be a useful tactic. The results are discussed.

8735-7, Session 2

Insight into vergence/accommodation mismatch *(Invited Paper)*

Martin S. Banks, Univ. of California, Berkeley (United States)

No Abstract Available.

8735-8, Session 2

Investigation of rotary wing pilot cueing and helmet mounted display symbology for increased pilot situational awareness in a degraded visual environment

Bradley M. Davis, U.S. Army Research Lab. (United States); Jared J. Sapp, U.S. Army Research Lab. (United States) and US U.S. Army Armament Research, Development and Engineering Ctr. (United States); Michael S. Jessee, Anthony W. Morris, U.S. Army Research Lab. (United States); James J. Hauser, Mark A. Salverson, Product Manager Air Warrior (United States)

An investigation of rotary wing pilot cueing and helmet mounted display (HMD) symbology was conducted for the US Army's Air Soldier System program. Six US Army Aviators flew a UH-60L flight simulator through realistic mission scenarios, including very challenging takeoff and landing tasks in a brown-out degraded visual environment (DVE). Takeoffs were executed in both DVE and visual conditions. As a part of the Army's crew station working group method, pilots evaluated various cueing technologies including combinations of helmet mounted display symbology, 3-dimensional audio, moving map displays, and tactile feedback. Of these technologies, symbology cues presented in a HMD provided the largest improvement in situational awareness. The focus of this paper is on the HMD symbology, which included two conditions, legacy 2D symbology and the proposed 3D head tracked conformal symbology. The investigation indicated that the 3D symbology significantly improved crew situation awareness, reduced pilot workload, and improved takeoff and landing safety over the legacy 2D symbology. Most critically, the 3D symbology eliminated the 4 crashes out of 54 DVE landings (7.4%) observed in the 2D symbology condition. This result alone represents the prevention of up to 60 fatalities and approximately $80 million in airframe losses. These results have been instrumental to the success of the Air Soldier System program, as well as an exemplar application of human systems integration research early in a program lifecycle. The investigation is being continued by further optimizing the 3D HMD symbology for aircraft operations in DVE.

8735-11, Session 2

Testing and evaluation of a wearable augmented reality system for natural outdoor environments

David C. Roberts, Alberico Menozzi, James Cook, Todd Sherrill, Stephen Snarski, Patrick Russler, Brian Clipp, Robert Karl, Eric Wenger, Matthew Bennett, Jennifer Mauger, William Church, Herman Towles, Stephen MacCabe, Jeffrey Webb, Jasper Lupo, Applied Research Associates, Inc. (United States); Jan-Michael Frahm, The Univ. of North Carolina at Chapel Hill (United States); Enrique Dunn, The Univ. of North Carolina at Chapel Hill (United States); Christopher Leslie, Univ. of North Carolina Chapel-Hill (United States); Greg Welch, Univ. of Central Florida (United States)

This paper describes a low-SWaP soldier-worn augmented reality prototype system that provides intuitive 'heads-up' visualization of tactically-relevant geo-registered icons. The system combines a soldier pose estimation capability with a small wearable computer and helmet mounted see-through display to accurately overlay geo-registered iconography (i.e., navigation waypoints, blue forces, points of interest) on the soldier's view of reality. Applied Research Associates (ARA), in partnership with BAE Systems, Mercury Computer Systems, EVO Design, the University of Central Florida, and the University of North Carolina – Chapel Hill (UNC-CH), has developed this system in Phase 3 of the DARPA ULTRA-Vis (Urban Leader Tactical, Response, Awareness, and Visualization) program.

We achieve accurate and robust pose estimation through fusion of inertial, magnetic, pressure, GPS, and computer vision data acquired from helmet kit sensors. Icons are rendered on a full-color, high-brightness, 40°x30° field of view see-through display. The system incorporates an information management engine to convert CoT (Cursor-on-Target) external data feeds into mil-standard icons for visualization. The user interface provides intuitive information display to support soldier navigation and efficient communication of tactical information to and from external sources.

In this paper, we report on Phase 3 efforts to minimize size, weight, and power of the helmet- and body-worn sensor and computing platform components. We discuss development of a full-color see-through display and enhanced pose estimation algorithms. We evaluate Phase 3 prototype performance for a broad range of outdoor operational conditions, including the presence of magnetic disturbances, highly-dynamic user head motions, and low-light conditions.

8735-12, Session 3

Advancements in HMD technology: the DARPA-sponsored SCENICC program *(Invited Paper)*

Randall Sprague, Arthur Zhang, Scott Cookson, Innovega Inc. (United States); Lee Hendrick, Tyrone O'Brien, Rockwell Collins (United States); Joseph Ford, UCSD (United States); Eric Tremblay, EPFL (Switzerland); Todd Rutherford, Doug Reinert, Greenlight Optics (United States); Adam Johnson, Distant Focus (United States)

No Abstract Available.

8735-13, Session 3

HMD Digital Night vision System for Fixed Wing Fighters

Bobby D. Foote, Rockwell Collins, Inc. (United States)

Digital night sensor technology offers both advantages and disadvantages over standard analog systems. As the digital night sensor technology matures and disadvantages are overcome, the transition away from analog type sensors will increase with new programs. In response to this growing need Rockwell Collins is actively investing in digital night vision systems that will provide the performance needed for the future.

Rockwell Collins continues to invest in digital night technology and has completed laboratory, ground and preliminary flight testing to evaluate the important key factors for night vision. These evaluations have led to a summary of the maturity of the digital night capability and status of the key performance gap between analog and digital systems.

Introduction of Digital Night Vision Systems can be found in the roadmap of future fixed wing and rotorcraft programs beginning in 2015. This will bring a new set of capabilities to the pilot that will enhance his abilities to perform night operations with no loss of performance.

8735-14, Session 3

Advances and trends of head-up displays systems in land vehicles

J. Alejandro Betancur Ramírez, Alejandro Mejía, Felipe Cadavid, Univ. EAFIT (Colombia)

Currently, in the automotive industries the interaction between the driver and augmented reality systems is a subject of research, specially, the identification of advantages and risks that this kind of interaction represents. This paper attempts to put in evidence the potential of the head-up displays applied to automotive vehicles, pretending to show applications and tendencies that at the moment are being studied. In general, the automotive research associated with augmented reality devices, suggests the partial integration of the head-up displays in the automotive vehicles; however, its still a matter of discussion which should be the right way to do it.

8735-15, Session 3

Optical see-through head-mounted display with occlusion capability

Chunyu Gao, Augmented Vision, Inc. (United States); Hong Hua, Yuxiang Lin, College of Optical Sciences, The Univ. of Arizona (United States)

Lack of mutual occlusion capability between computer-rendered and real objects is one of fundamental problems for most existing optical see-through head-mounted displays (OST-HMD). Without the proper occlusion management, the virtual view through an OST-HMD appears “ghost-like”, floating in the real world. To address this challenge, we have developed an innovative optical scheme that uniquely combines the eyepiece and see-through relay optics to achieve an occlusion-capable OST-HMD system with a very compelling form factor and high optical performances. The proposed display system was based on emerging freeform optical design technologies and was designed for highly efficient liquid crystal on silicon (LCoS) type spatial light modulator (SLM) and bright Organic LED (OLED) microdisplay. The proposed display technology was capable of working in both indoor and outdoor environments. Our current design offered a 1280x720 color resolution based on 0.7” microdisplay and SLM. The MTF values for the majority of the fields at the cutoff frequency of 40lps/mm, which is determined by the pixel size of the microdisplay, are better than 15%. The design achieved a diagonal FOV of 40 degrees, 31.7 degrees horizontally and 25.6 degrees vertically, an exit pupil diameter of 8mm (non-vignetted), and an eye clearance of 18mm. The optics weights about 20 grams per eye. Our proposed occlusion capable OST-HMD system can easily find myriads of applications in various military and commercial sectors such as military training, gaming and entertainment.

8736-1, Session 1

A SWIR radiance model for cockpit instrumentation *(Invited Paper)*

John Green, Tim Robinson, Esterline Control Systems (United States)

Night Vision Imaging Systems technology is advancing at a rapid pace. These advances can be broadly divided in two distinct categories; performance and data management. There is an encouraging trend towards higher sensitivity, better resolution, and lower power consuming devices. These improvements, coupled with the shift from analog to digital data output, promise to provide a powerful night vision device. Given a digital system, the data can be managed to enhance the pilot's view (image processing), overlay data from multiple sensors (image fusion), and send data to remote locations for analysis (image sharing).

The US Air Force Research Laboratory (AFRL) has an active program to introduce a helmet mounted digital imaging system that extends the detection range from the near infrared (NIR) band to the short-wave infrared (SWIR) band. Aside from the digital output, part of the motivation to develop a SWIR imaging system includes the desire to exploit the SWIR ambient night glow spectrum, see through some levels of fog and haze, and use a robust sensor technology suitable for 24 hours per day imaging.

Integrating this advanced SWIR imaging system into a cockpit presents some human factor issues. Light emitted from illuminated instruments may hinder the performance of the imaging system, reducing the pilot's ability to detect low-visible objects at night. The transmission of light through cockpit transparencies and through the atmosphere may also impact performance. In this paper we propose a model that establishes cockpit lighting SWIR radiance limits, much like MIL-STD-3009 specifies NVIS radiance limits for NVGs. This model is the culmination of a two year program sponsored by AFRL.

8736-4, Session 1

Task analysis modeling to improve sensor and display system design

Gail M. Nicholson, Tanya Geiersbach, Naval Surface Warfare Ctr. Crane Div. (United States)

Translating requirements for a sensor and display system application can be difficult, leading to increased design costs, rework, and ineffective or even unused systems. A task analysis model was developed to solve this issue that was utilized during sensor and display research on a ring mount gunner situational awareness application. The techniques were validated and successfully applied to additional research areas. This modeling method can also be applied throughout the DoD Acquisition lifecycle. The methodology and examples of successes and impacts will be presented.

8736-5, Session 1

Neuroergonomic methods to identify cockpit display improvements *(Invited Paper)*

Steven D. Harbour, U.S. Air Force (United States); James C. Christensen, Air Force Research Lab. (United States)

This study utilized a workload protocol that employed Electrocardiogram (EKG) data collection for the assessment of pilot workload and situation awareness in-flight during various phases of airborne operation. Contrasts and evaluations were made between the original Head Up Display (HUD) configuration which has not been endorsed as a Primary Flight Display (PFD) and the Head Down Display (HDD) which was previously certified by the FAA as a PFD. Quantitative results were produced to guide the resource decision making regarding cockpit systems for this aircraft. Low and no cost improvements were identified and recommendations were implemented. This work developed a neuroergonomic methodology for display improvements.

8736-19, Session 1

Towards a metric of antialiasing sufficiency for stereoscopic displays

Charles J. Lloyd, Visual Performance, LLC (United States)

This paper describes the development, measurement, computation, and initial testing of a metric of antialiasing sufficiency for stereoscopic display systems. A summary is provided of two previous evaluations that demonstrated stereoscopic disparity thresholds in the range of 3 to 10 arcsec are attainable using electronic displays with a pixel pitch as coarse as 2.5 arcmin, however, only if sufficient antialiasing is performed. Equations are provided that describe the critical level of antialiasing required as a function of pixel pitch. The proposed metric uses a radial test pattern that can be photographed from the user eyepoint using a hand held consumer color camera. Several candidate unitary metrics that quantify the spatial sampling noise in the measured test pattern were tested. The correlation obtained between the best candidate metric and the stereoscopic disparity threshold model from our previous paper was R2 = 0.994. The standard deviation of repeated measurements of the metric was no greater than 0.5% of the range of the metric, indicating the metric is capable of discriminating fine differences in sampling noise. The proposed method is display technology independent and requires no knowledge of the display pixel structure or how the antialiasing is implemented.

8736-6, Session 2

An innovative algorithm for panoramic representation in observation systems *(Invited Paper)*

Cristian Luison, Valeria Aquilanti, Altran Italy S.p.A. (Italy); Aldo Riccobono, Claudio Liberace, SELEX Galileo S.p.A. (Italy)

This paper presents the study and the experimental work carried out in Selex Galileo on an innovative algorithm for panoramic representation in situational awareness system, operating with passive optical sensors (IR and CCD).

The aim of the algorithm is to allow a planar representation of 360° scenario, by using staring sensors and overcoming drawbacks due to moving platform, optical lens distortion and scenario evolution. The stitching algorithm is developed "sensor independent" and completely real time and does not require complex scanning systems. The sensor scans the scene rotating continuously at a constant speed depending on the required scanning rate. The algorithm recovers stabilization errors due to motion platform, making itself suitable for several application (land, naval and airborne).

The algorithm has been implemented and tested on the vision system JANUS NAVAL, property of Selex Galileo. The vision system consists of an IR camera (640 x 512 pixels operating in the MWIR band) and a CCD camera (4 Mega Pixels) located inside an electro-optical head, mounted upon a two-axis-stabilized platform. Both cameras output a PAL standard video signal, whose are digitalized and processed according to the described algorithm. The panoramic representation is showed on a LCD display, dividing the entire 360° scene into four horizontal stripes of 90° each one, with the proper azimuth scale. Furthermore, the algorithm allows to zoom a selectable area into an additional window located below

the four stripes. This final representation has been agreed and validated by the Italian Navy.

8736-7, Session 2

Design of graphics display manager (GDM) software for naval combat management systems (CMS)

Tushar K. Patra, Kranti Lal, Deepika Gupta, Bharat Electronics Ltd. (India)

In modern Command and Control Systems (C4I), Surveillance and Decision Support Systems vast amount of digital data needs to be processed, correlated, stored and displayed in synchronization with the real time change of information in the operational clusters or external world. Display, being the front end of such systems, plays a key role for providing comprehensive tactical pictures to the war fighters with requisite accuracy and timeliness and also for Command and Control and Decision-making. With the ever increasing complexity of graphical user interfaces (GUI) requirements and advanced display concepts and with limitations of graphics hardware subsystems, the Modeling and Design of Tactical Display Software for CMS (C4I) Systems is of particular interest and has become a big challenge over the years.

In this paper we have presented the design model and advanced display concepts we have used for development of tactical display software (we call it Graphics Display Manager, GDM) for CMS Projects for Indian Navy. Also a widely accepted Graphical User Interface, which has been designed and developed with extensive interaction with customers, is presented. Though the GDM currently runs on Dual Multi Function Consoles (DMFC) and Multi Function Horizontal Consoles (MFHC), it has been designed with a view of providing platform independent display solution for the ongoing as well as futuristic defense projects in the country.

The GDM software has been designed as per the Object Oriented Design paradigm and thus has been modeled as collections of cooperating objects, treating individual objects as instances of a class within the hierarchy of GDM Classes. The levels of hierarchy represents the different levels of abstraction, each built upon others and each understandable by itself.

8736-8, Session 2

A low-bandwidth graphical user interface for high-speed triage of potential items of interest in visual imagery

David J. Huber, Deepak Khosla, Kevin Martin, Yang Chen, HRL Labs., LLC (United States)

A great deal of interest has been generated in automated surveillance systems that detect anomalies in real-time visual imagery. These systems employ a fast, high-detection front-end that analyzes a scene and extracts items of interest, which are forwarded to some other system for analysis and/or identification of threats. Many employ a "human-in-the-loop" configuration, where the final decision about whether a particular anomaly is an actual threat falls to a human operator. However, since humans are easily fatigued and cannot process raw data as quickly as a computer, the method by which data is presented to a user is critical.

In this paper, we introduce a user interface called the "Threat Chip Display" (TCD) for rapid human-in-the-loop analysis and detection of "threats" in high-bandwidth visual imagery from a list of "Items of Interest" (IOI), which includes objects, targets and events that the human is interested in detecting and identifying. Typically some front-end algorithm (e.g., computer vision, cognitive algorithm, EEG RSVP based detection, radar detection) has been applied to the video and has identified a list of potential IOI. The TCD facilitates rapid analysis of this list of IOI to detect and confirm actual threats and is designed for ease of use, fast triage of IOI, and a low bandwidth requirement. Additionally, a very low mental demand allows the system to be run for extended periods of time. This work was applied to Phases 2 and 3 of DARPA Cognitive Technology Threat Warning System (CT2WS) program and used during field testing.

8736-9, Session 2

Testing a collision avoidance display with high-precision navigation *(Invited Paper)*

Niklas Peinecke, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Maarten Uijt de Haag, Pengfei Duan, Ohio Univ. (United States); Rene Küppers, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Bram Beernink, Technische Univ. Delft (Netherlands)

Recent years have seen a rise in sophisticated navigational positioning techniques. Starting from classical GPS, differential GPS, ground based augmentation, and raw data submission have opened possibilities for high precision lateral positioning for beyond what was thinkable before. This yields new perspectives for technologies like ACAS/TCAS, by enabling last-minute lateral avoidance as a supplement to the established vertical avoidance maneuvers.

Working together with Ohio University's Avionics Department, DLR has developed and tested a display for situational awareness and lateral last-minute avoidance in a collision situation. The display includes the possibility to foresee the hazard zone of a possible intruder and thus avoid that zone early. The display was integrated into Ohio University's experimental airplane, and a flight experiment was conducted to make a first evaluation of the applicability. The tests were carried out in fall 2012.

We will present the principal architecture of the display and detail the implementation into the flight carrier. Furthermore, we will give first results of the display performance.

8736-10, Session 3

Advances in liquid crystal on silicon (LCOS) spatial light modulator technology *(Invited Paper)*

William P. Bleha Jr., Lijuan A. Lei, HOLOEYE Systems Inc. (United States)

LCOS (Liquid Crystal on Silicon) is a reflective microdisplay technology based on a single crystal silicon backplane which drives a liquid crystal layer. Using standard CMOS processes, microdisplays with extremely small pixels, high fill factor (pixel aperture ratio) and low fabrication costs are created. Recent advances in integrated circuit design and liquid crystal materials have increased the application of LCOS to displays and other optical functions. Pixel pitch below 3 µm, resolution of 8K x 4K, and sequential contrast ratios of 100K:1 have been achieved. These devices can modulate light spatially in amplitude or phase, so they act as an active dynamic optical element. Liquid crystal materials can be chosen to modulate illumination sources from the UV through far IR. The new LCOS designs have reduced power consumption to make portable displays and viewing elements more viable. Also innovative optical system elements including image and illumination waveguides and laser illuminators have been combined into LCOS based display systems for HMD, HUD, projector,and image analysis/surveillance direct view monitor applications. Dynamic displays utilizing the fine pixel pitch and phase mode operation of LCOS are advancing the development of true holographic displays. The paper will review these technology advances of LCOS and the display applications and related system implementation.

8736-11, Session 3

Precision guided firearms: disruptive small arms technology

Bret Boyd, John Lupher, TrackingPoint, Inc. (United States)

Based on fighter jet "lock and launch" technology, Precision Guided Firearms (PGFs) deliver a quantum leap in shooting accuracy by employing target tracking, heads-up displays and advanced fire control technology to amplify shooting precision, particularly at long range. PGFs eliminate many of the most common sources of shooter error including, aiming, trigger jerk and shot setup miscalculation. Regardless of skill level or experience, PGFs can significantly increase First Shot Success Probability (FSSP) up to 5-times compared to traditional technology, even at extreme ranges of 1200 yards or more. More than just a scope, Precision Guided Firearms are fully integrated systems based on standard caliber bolt action or semi-automatic rifles with a networked tracking scope, guided trigger and precision conventional ammunition. Onboard wireless technology allows PGFs to connect with local and wide area networks to deliver voice, video and data to mobile devices and systems. PGF technology is the most revolutionary technological development in long-rage shooting in decades and has both military and commercial applicability.

TrackingPoint is the Austin, Texas-based applied technology company that created the first Precision Guided Firearm (PGF). In this presentation, TrackingPoint developers will outline the electro-optical-mechanical integration effort behind the system, and the advantages PGFs present for defense and security applications.

8736-12, Session 3

High brightness AMLCD overlay displays in man portable applications

Timothy J. Edwards, Timothy Hogan, Kopin Corp. (United States)

Overlay display applications require very high brightness levels to provide images that are viewable when combined on see-through daytime scenery. Most current and historic micro-display applications support low to moderate brightness suitable for non see-through systems. High brightness levels have been demonstrated in existing and legacy daytime HMDs but not at power levels that can be supported in portable battery driven applications.

In this paper we will discuss evolutionary improvements made in the application of Kopin display technology for high brightness daytime overlay applications. To achieve required luminance performance at battery power levels Kopin has implemented higher efficiency backlights, lower power drive electronics and improved display performance. Backlight efficiencies, which dominate total display power in high brightness conditions, have been improved by more than 20x. Graphics generation and bi-level display drive electronics have been implemented with at less than half the power. Results for display configurations including VGA, SVGA, SXGA and 2kx2k will be presented. The ability to combine a high brightness display onto a daytime scene provides dramatic new capabilities for direct view optical sights. This paper will discuss the performance and capability of Kopin displays in both clip-on and integrated configurations

8736-13, Session 3

Development of a spacesuit helmet mounted display testbed system

Daryl J. Schuck, Honeywell International Inc. (United States)

The next generation spacesuit, currently under development by NASA, is anticipated to incorporate Helmet or Head Mounted Display (HMD) technologies in order to make the crew more autonomous through a robust informatics system. In anticipation of this, NASA and Honeywell produced an HMD testbed system that provides the capability to explore display designs and operational concepts in analogous field environments. The system was designed as an extension of an established spacesuit informatics system that included a variety of data including procedures, photo, video, and navigational parameters. Using a Near To Eye optical solution, the device was housed in a military style dust goggle. The system also implemented a spacesuit glove compatible user interface device and intuitive user interface hosted on a fanless, small form factor, low power PC. The purpose of this paper is to provide an overview of the various parts of this system, describe the software architecture, and describe its initial testing that was conducted prior to delivery. The paper will also address field testing that occurred post delivery. Challenges for integrating this technology in a spacesuit platform are also discussed.

8736-14, Session 4

The use of optical waveguides in head up display (HUD) applications

Malcolm G. Homan, BAE Systems (United Kingdom)

This paper addresses the design drivers behind the development of the next generation of Head Up Displays and their compatibility with evolving cockpit architectures and structures. The implementation of large scale optical waveguide combiners capable of matching and exceeding the display performances normally only associated with current digital display sourced HUDs has enabled BAE Systems Electronic Systems to solve the volume and installation challenges of the latest military and civil cockpits with it's LiteHUD technology.

Glareshield mounted waveguide based HUDs are compatible with the trend towards the addition of Large Area Displays (LAD) in place of the traditional multiple Head Down Displays (HDD) within military fast jet cockpits. They use an "indirect view" variant of the display which allows the amalgamation of high resolution digital display devices with the inherently small volume and low mass of the waveguide optics. This is then viewed using the more traditional technology of a conventional HUD combiner. This successful combination of technologies has resulted in the LPHUD product which is specifically designed by BAE Systems Electronic Systems to provide an ultra-low profile HUD which can be installed behind a LAD; still providing the level of performance that is at least equivalent to that of a conventional large volume glareshield mounted HUD.

In many current Business Jet and Air Transport cockpits overhead mounted HUDs employ a conventional optical combiner to relay the display from a separate projector to the pilot's eyes. In BAE Systems' Electronic Systems Q-HUD configuration this combiner is replaced by the waveguide and the bulky, intrusive overhead projector completely eliminated. The result is a significant reduction in equipment volume and mass and a much greater head clearance combined with a substantially larger Head Motion Box. This latter feature is a fundamental outturn of waveguide optical solutions which removes the restrictions on pilot eye positioning associated with current conventional systems.

LiteHUD, developed by BAE Systems Electronic Systems, achieves equivalent optical performance to in-service HUDs for less cost, mass and volume.

8736-15, Session 4

Integration of head-up display systems in automobile industry: a generalized application approach

J. Alejandro Betancur Ramírez, Alejandro Mejía, Univ. EAFIT (Colombia); Gilberto Osorio, Universidad EAFIT (Colombia)

Throughout the development of the automotive industry, driving aid and support has been a subject of research and analysis, always looking for new ways to provide security to the driver and passengers;

in order to contribute to this subject, this paper summarises from past research experiences the use of head-up display systems applied to the automobile industry, covering it from two main points of discussion: the first one, from a technical point of view, in which the main principles of optical design associated with an experimental set up are brought out; and the second one, an operational approach where an applied driving graphical interface is presented. Up to now, the results suggest that the experimental set up here discussed could be adaptable to any automobile vehicle, but it is needed further research and investment.

8736-22, Session 4

Head up and eyes out: advances in head-mounted displays capabilities

Alexander A. Cameron, BAE Systems (United Kingdom)

There are a host of helmet and head mounted displays, flooding the market place with displays which provide what is essentially a mobile computer display. What sets aviators HMDs apart is that they provide the user with accurate conformal information embedded in the pilots real world view (see through display) where the information presented is intuitive and easy to use because it overlays the real world (mix of sensor imagery, symbolic information and synthetic imagery) and enables them to stay head up, eyes out, - improving their effectiveness, reducing workload and improving safety.

Such systems are an enabling technology in the provision of enhanced Situation Awareness (SA) and reducing user workload in high intensity situations. Safety Is Key; so the addition of these HMD functions cannot detract from the aircrew protection functions of conventional aircrew helmets which also include life support and audio communications.

These capabilities are finding much wider application in new types of compact man mounted audio/visual products enabled by the emergence of new families of micro displays, novel optical concepts and ultra-compact low power processing solutions. This papers attempts to capture the key drivers and needs for future head mounted systems for both aviation and non-aviation applications and to set out a vision for future product capabilities, capability gaps and technology drivers.

8736-17, Session 5

Bio-inspired adaptive color arrays

Richard Fu, Eric Forsythe, Steven Blomquist, Eric Wetzel, U.S. Army Research Lab. (United States)

Cephalopods, the class of mollusks that include squid, cuttlefish, and octopus, have unique abilities to mimic the color and texture of their environments through arrays of chromatophores. The chromatophores are pigment sacs beneath the transparent epidermis layer allowing for selective presentation of yellow, red and brown pigments. The research objective is to demonstrate an analog color reflecting device that mimics the nature of the chromatophore which modifies color by expanding and contracting a pigment sac thereby changing the color state from transparent to reflecting in a color spectrum.

Two basic approaches are developed: an electrostatic field actuates a parallel plate and moves the liquid contained between the plates; and a gas pressure applies a force on a liquid and moves the liquid in and out from a transparent window. The electrical signal is utilized to regulate the pressure flow through two related designs, microblower and microvalve. The individual pixel was expanded into an array of pixels. In addition to color changes in the pixels, these device concepts can undergo a structural change similar to the biological chromatophore and unlike traditional display designs.

A microblower is shown with promising results for both generating and controlling air flow applied to the device with lower power consumption, and is able to achieve cephalopod chromatophore-like effects in an efficient manner. A microvalve alone can only be used to regulate a constant pressure source; however, its design and fabrication details can be used as a basis for future work.

Conference 8737: Degraded Visual Environments: Enhanced, Synthetic, and External Vision Solutions 2013

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8737-1, Session 1

Enhancing old helicopters search and rescue capabilities through using synthetic vision system (SVS)

Karim A. Fouad, Egyptian Air Force (Egypt)

In this paper, an implementation of navigation grade AHRS system, VOR and Flux valve, in addition to GPS and multifunction displays to an old helicopter in order to get low-altitude flying risks lower, and increase flight capabilities in bad weather conditions. This is accomplished through adding navigation displays that can display basic flight data , terrain and real time altitude for the helicopter with respect to surrounding terrains. Accomplishing this project involved many activities which are mainly the design and implementation of real time system for integration of added navigational systems, building terrain database with different resolution, design and implementation of basic flight display embedded with terrain digital map. Finally integrating different system components and running final flight tests. The tests showed great improvements in ordinary flights and especially rescue ones, where reaching to destination was faster, more accurate location identification in addition to an important psychological fact which is the added confidence to flight and rescue crew to fulfill the required missions.

8737-3, Session 1

Operational requirements for helicopter operations low level in degraded visual environment

Thorsten W. Eger, German School of Army Aviation (Germany)

In order to assist the pilot to safely operate helicopters in degraded visual environment (DVE), an integrated system of various technologies that will provide improved situation awareness (SA) with minimal interpretation whilst controlling the aircraft is essential.

DVE is defined as reduced visibility of potentially varying degree, wherein situational awareness (SA) and aircraft control cannot be maintained as comprehensively as they are in good visual meteorological conditions (VMC) and may be lost. DVE can be caused by dust or sand (brownout), snow (whiteout), rain, fog, smoke, salt spray or any element that degrades the use of visual cues. DVE can be experienced in all modes of flight, day and night.

To determine the most effective and affordable solution set to enhance helicopter operations in degraded visual environments at low altitudes and to help scope the potential range of solutions, the critical tasks of helicopters are to be defined. Crew workload must be managed at an acceptable level in all scenarios.

Solutions should be considered for existing as well as future aircraft and for legacy, non-digital aircraft as well as modernized aircraft with digital cockpits. It is envisioned that a combination of handling qualities, human factors design, active or passive sensors, and annunciations will produce effective solutions and that any one of these things alone will not adequately address the problem.

This presentation will provide an overview on the operational environment and the resulting requirements for operating helicopters low level in degraded visual environment.

8737-4, Session 1

Sensor supported pilot assistance for H/C flight in DVE

Tim Waanders, Eurocopter Deutschland GmbH (Germany); Thomas R. Muensterer, Martin J. Kress, Cassidian (Germany)

Helicopter operations at low altitude are to this day only performed under VFR conditions in which safe piloting of the aircraft relies on pilot's visual perception of the outside environment. However, there are situations in which a deterioration of visibility conditions may cause the pilot to lose important visual cues thereby increasing workload and compromising flight safety and mission effectiveness.

This paper reports on a pilot assistance system for all phases of flight which is intended to:

- Provide navigational support and mission management
- Support landings/take-offs in unknown environment and in DVE
- Enhance situational awareness in DVE
- Provide obstacle and terrain surface detection and warning
- Provide upload, sensor based update and download of database information for debriefing and later missions.

The system comprises a digital terrain and obstacle database, tactical information, flight plan management combined with an active 3D sensor enabling the above mentioned functionalities. To support pilots during operations in DVE, an intuitive 3D/2D cueing through both head-up and head-down means is proposed to retain situational awareness.

This paper further describes the system concept and will elaborate on results of simulator trials in which the functionality was evaluated by operational pilots in realistic and demanding scenarios such as a SAR mission to be performed in mountainous area with different visual conditions. The objective of the simulator trials was to evaluate the functional performance and HMI aspects.

8737-5, Session 1

Vision assisted aircraft lateral navigation

Mohamed Ibrahim Mohideen, Honeywell Technology Solutions Lab (India); Peter Seiler, Univ. of Minnesota (United States); Dinesh Ramegowda, HCL Technologies Ltd (India)

Surface operation is currently one of the least technologically equipped phases of aircraft operation. The increased air traffic congestion necessitates more aircraft operations in degraded weather and at night. The traditional surface procedures worked well in most cases as airport surfaces have not been congested and airport layouts were less complex. Despite the best efforts of FAA and other safety agencies, runway incursions continue to occur frequently due to incorrect surface operation. Several studies conducted by FAA suggest that pilot induced error contributes significantly to runway incursions. Further, the report attributes pilot's lack of situational awareness - local (e.g., minimizing lateral deviation), global (e.g., traffic in the vicinity) and route (e.g., distance to next turn) - to the problem. An Enhanced Vision System (EVS) is one concept that is being considered to resolve these issues. These systems use on-board sensors to provide situational awareness under poor visibility conditions. In this paper, we propose the use of an IR camera to estimate the aircraft position and orientation relative to taxiway markings to use as lateral guidance aid. We estimate aircraft yaw angle and lateral offset from slope of the taxiway centerline and horizontal position of vanishing line. Unlike automotive applications, several cues such as aircraft maneuvers along assigned route with minimal deviations, clear ground markings, even taxiway surface, limited aircraft speed are available and enable us to implement significant algorithm optimizations.

We present experimental results to show high precision navigation accuracy with sensitivity analysis with respect to camera mount, optics, and image processing error.

8737-6, Session 1

Helicopter synthetic-vision-based DVE processing for all phases of flight

Patrick L. OBrien, David Baughman, Honeywell, Inc. (United States); Bruce Wallace, Defense Advanced Research Projects Agency (United States)

Helicopters experience nearly ten times the accident rate of fixed wing platforms, due in large part to the nature of their mission, requiring frequent operations in close proximity to terrain and obstacles. Degraded visual environments (DVE) including brownout or whiteout conditions generated by rotor downwash results in loss of situational awareness during the most critical phase of flight, and are a significant contributor to this accident rate. Considerable research into sensor and system solutions to address DVE has been conducted in recent years; however, the promise of a synthetic vision avionics backbone (SVAB) extends far beyond this single issue and enables improved situational awareness and mission effectiveness during all phases of flight and in all visibility conditions.

Advantages of a “sensor agnostic” SVAB allow platform and mission diversity with an efficient upgrade path, even while research continues into new and improved sensors for use in DVE conditions. Through the careful integration of multiple sources of information: sensors, terrain and obstacle databases, mission planning information and aircraft state information; enhancements to operations in all conditions and all phases of flight will be discussed.

8737-7, Session 2

Enhanced vision presentation in a commercial cockpit for low-visibility surface operations

Jarvis J. Arthur III, NASA Langley Research Ctr. (United States); Robert M. Norman, The Boeing Co. (United States); Lynda J. Kramer, Lawerence J. Prinzel III, Kyle K. Ellis, NASA Langley Research Ctr. (United States); Stephanie Harrison, Virginia Polytechnic Institute and State Univ. (United States); James R. Comstock, NASA Langley Research Ctr. (United States)

NASA Langley Research Center and the FAA collaborated in an effort to evaluate the effect of displaying enhanced vision system information in a commercial flight deck during low visibility surface operations. As interest grows in using Enhanced Flight Vision Systems (EFVS) and Enhanced Vision Systems (EVS) such as Forward Looking Infrared (FLIR) in commercial flight decks, the FAA and NASA wanted to collect data on the influence and efficacy of EFVS and EVS for low visibility surface operations. Surface operations were simulated at the Memphis, TN (FAA identifier: MEM) airfield during nighttime with 500 Runway Visual Range (RVR) in a high fidelity, motion simulator. Twelve commercial airline crews participated in the research that included manipulation of the location of an EVS/EFVS display designed to test location effects in addition to issues of parallax and minification of the EVS image. The research paper shall discuss qualitative and quantitative results of the simulation experiment, including the effect of EVS display placement on eye gaze (attention) as measured by the use of non-obtrusive oculometry and pilot workload.

8737-8, Session 2

Degraded environment enhanced pilotage

Trevor L. Bushell, Raytheon Network Centric Systems (United States)

Following the Advanced Dristributed Aperture System program, and new advance Mil Spec Multiimage processor was funded to enable testing of the ADAS Distributed Aperture system, that gives full spheriacl coverage of the aircraft, with two independant Helmet Mouted Displays. enabling an evaluation of the system in Degraded Enviroments like Brownout

8737-9, Session 2

Fused sensor image display for degraded visual environment

Carlo L. Tiana, Rockwell Collins, Inc. (United States); Keith W. Alter, xVS, LLC (United States); Chris Holser, Aireyes, Inc. (United States); Joy Matsumoto, Monterey Technologies, Inc. (United States)

We describe a Fused Sensor Image Display System (FSIDS) designed to guide the landing of helicopters during brownout conditions. FSIDS employs multiple sensors concurrently to create a high resolution synthetic scene of the landing area and potential obstacles. We developed methods for overcoming degraded visual environments for helicopter pilots attempting to land in brownout or other compromised visibility conditions. The system utilizes multi-sensor image fusion integrated with a Synthetic Vision System. In a novel aspect of this system, sensor inputs are evaluated in real time to determine the point at which each sensor’s contribution to the assessment of the landing area is no longer of value, and to remove that sensor’s input from the information presented to the pilot. Each sensor has its own unique rejection point, determined through sophisticated processing and algorithms. The research demonstrated the feasibility and robustness of algorithms and systems that might be used to detect brownout in an imaging sensor (or other sensors, e.g., 3D radar, lidar). The Synthetic Visual System provided a realistic representation of the landing area using detailed data from the best sensor output and adding detection and visual representation of obstacles in and around the landing area. To support the identification and representation of obstacles, an ontological system provided detailed classification and definition of obstacles and terrain types and their contribution to determining appropriately safe landing zones of potential obstacles. FSIDS has direct application to improving the safety of helicopters operating in degraded visual environments including civilian helicopters.

8737-10, Session 2

Sensor-based 3D conformal cueing for safe and reliable HC operation specifically for landing in DVE

Thomas R. Muensterer, Martin J. Kress, Stephanus Klasen, Cassidian (Germany)

The paper describes the approach of a sensor based landing aid for helicopters in degraded visual conditions. The system concept presented employs a long range high resolution ladar sensor allowing for identifying obstacles in the flight and in the approach path as well as measuring landing site conditions like slope, roughness and precise position relative to the helicopter during long final approach. All these measurements are visualized to the pilot. Cueing is done by 3D conformal symbology displayed in a head tracked HMD enhanced by 2D symbols for data which is perceived easier by 2D symbols than by 3D cueing. All 3D conformal symbology is placed on the measured landing site surface which is further visualized by a grid structure for displaying landing site slope, roughness and small obstacles. Due to the limited resolution of the employed HMD a specific scheme of blending in the information during the approach is employed. The interplay between in flight and in approach obstacle warning and CFIT warning symbology with this landing aid symbology is also investigated and exemplarily evaluated for the NH90 helicopter which has already today implemented a long range high resolution ladar sensor based obstacle warning and CFIT symbology. The paper further describes the results of simulator and flight tests performed with this system employing a ladar sensor and a head tracked head mounted display system. In the simulator trials a full model of the ladar sensor producing 3D measurement points was used working with the same algorithms used in flight tests.

8737-11, Session 2

Contribution of TopOwl Head Mounted Display System in Degraded Visual Environments

Olivier Lemoine, Jean-Michel François, Thales Avionics S.A. (France); Pascal Point, Thales Avionics (France)

Piloting an Helicopter in a Degraded Visual Environment (DVE) is a very complex task, and the evolution of the H/C missions tend to augment the probability of such degraded flight conditions (increase of night flights, all-weather flights, with brownout or whiteout phenomena…). When the direct view of the external situation is degraded, the avionic system can be of great help to the crew to recover the lost visual references. TopOwl Head Mounted Display (HMD) is particularily adapted to such situations, allowing the pilot to remain “eyes-out” while visualizing the on-board DVE-penetrating imaging sensor (EVS), the flight symbology, the terrain elevation data (SVS), and/or the night vision images coming from the integrated Image Intensifier Tubes. To achieve this, TopOwl is composed of a see-through display with a large binocular field of view, a robust head tracking system to allow (the) display of conformal data (symbology and image), an integrated binocular night vision system, an enhanced human machine interface, and an integrated SVS processing with stereoscopic display for “true 3D” SVS. The benefits of such an HMD in the full scale experiment are described in this article.

8737-12, Session 3

Increasing situational awareness in DVE with advanced synthetic vision

Tobias Schafhitzel, Michael Hoyer, EADS Deutschland GmbH (Germany); Philipp Völschow, Cassidian (Germany)

One of the major causes for hazardous situations in aviation is the lack of a pilot’s situational awareness. Common causes for degraded situational awareness are Brownout and Whiteout situations, low level flights, and flights in DVE.

In this paper, we propose advanced synthetic vision (ASV), a modern situational awareness solution. ASV combines both synthetic vision (SVS) and enhanced vision in order to provide the pilot most timeliness information without being restricted in the areal coverage of the synthetic representation. The advantages to a common Enhanced Synthetic Vision System are the following: (1) ASV uses 3D ladar data instead of a 2D sensor. The 3D point cloud is classified in real-time to distinguish between ground, wires, poles and buildings; (2) the classified sensor data is merged with onboard data base contents like elevation or obstacles. The entire data fusion is performed in 3D, i.e. output is a merged 3D scenario instead of a blended 2D image. Once the sensor stopped recording due to occlusion, ASV switches to pure data base mode; (3) the merged data is passed to a 3D visualization module, which is fully configurable in order to support synthetic views on head down displays as well as more abstract augmented representations on helmet mounted displays; (4) the extendable design of ASV supports the graphical linking of functions like 3D landing aid, TAWS, or navigation aids.

This paper discusses the technology ASV, its intended operational application, and gives some insight to the latest results of our HMI workshops.

8737-13, Session 3

Investigations on intense solar exposure and recovery of long-wave infrared sensors

Carlo L. Tiana, Gary B. Kingsley, Daniel J. Henry, Gladys Yanez, Rockwell Collins, Inc. (United States)

Sensitive infrared cameras are often deployed in airborne, maritime and ground systems where exposure to solar radiation cannot be avoided. We investigated the impact of and recovery from such exposure in natural settings as well as the laboratory, and report on both the impact and relevant mitigation techniques.

8737-14, Session 3

Characterization of the OPAL obscurant penetrating LiDAR in various degraded visual environments

Evan Trickey, Philip M. Church, Xiaoying Cao, Neptec Design Group Ltd. (Canada)

The OPAL obscurant penetrating LiDAR was developed by Neptec and characterized in various degraded visual environments (DVE) over the past five years. Quantitative evaluations of obscurant penetration were performed using the Defence Research and Development Canada instrumented obscurant chamber for obscurants such as dust and fog. Experiments were done with the sensor both at a standoff distance and totally engulfed in the obscurants. Field trials were also done to characterize the sensor in snow conditions and in smoke. Finally, the OPAL was also mounted on a Bell 412 helicopter to characterize its dust penetration capabilities, in environment such as Yuma Proving Ground. The paper provides a summary of the results of all of the OPAL evaluations demonstrating it to be a true “see through” obscurant penetrating LiDAR and explores commercial applications of the technology

8737-15, Session 3

Real-time passive millimeter-wave imaging for brownout mitigation

Christopher A. Schuetz, Richard D. Martin, Thomas E. Dillon, Daniel Mackrides, John P. Wilson, Phase Sensitive Innovations, Inc. (United States); James Bonnett, Petersen F. Curt, EM Photonics, Inc. (United States); Charles Harrity, Alicia Zablocki, Phase Sensitive Innovations, Inc. (United States); Dennis W. Prather, Univ. of Delaware (United States)

Passive millimeter-wave imaging presents an attractive sensor modality for DVE mitigation due to its unique capability to both penetrate obscurants and FLIR-like imagery to pilots. To date, however, such imagers have been technologically limited to size, weight, and power consumptions that are too high for most military platforms. Herein, we present video-rate passive millimeter-wave imager based on optical upconversion. This imaging modality offers a distributed aperture with low size and weight that is amenable to many platforms. Such an sensor has been realized and field tested and results from these field tests will be presented. Real time imagery has been demonstrated through extremely dense dust clouds generated by rotorcraft downwash with little to no degradation in image quality.

8737-16, Session 3

MMW radar enhanced vision systems: the helicopter autonomous landing system (HALS) and radar-enhanced vision system (REVS) are rotary and fixed wing enhanced flight vision systems that enable safe flight operations in degraded visual environment.

Jack Cross, John Schneider, Pete Cariani, Sierra Nevada Corp. (United States)

Sierra Nevada Corporation is developing rotary and fixed wing millimeter wave radar enhanced vision systems. The Helicopter Autonomous Landing System (HALS) is a rotary-wing enhanced vision system that enables multi-ship landing, takeoff, and enroute flight in Degraded Visual Environments (DVE). 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. HALS recently completed a 5th round of US Army flight tests while a hardened version of the system is being produced for field user evaluation by the US Army. The Radar Enhanced Vision Systems (REVS) is a fixed-wing Enhanced Flight Vision System (EFVS) undergoing prototype development testing. Both systems are based on a fast scanning 3-dimensional 94 GHz radar that produces 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, for HALS, approach and landing command guidance cuing. The combination of see-through imagery and symbology provide the key information a pilot needs to perform safe flight operations in DVE conditions. This paper discusses the HALS and REVS systems and technology, presents imagery, and summarizes the recent flight test results.

8737-17, Session 4

Real-time imaging DUSPEN lidar for helicopter situational awareness in DVE

James T. Murray, Jason Seely, Jeffrey J. Plath, Gregory J. Fetzer, William L. Ryder, Neil R. Van Lieu, Ronald W. Goodwin, Eric Gotfreson, Tyler J. Wagner, Nick Kridler, Chris Melancon, John R. Engel, Ken Panici, Arete Associates (United States)

One of the major technical challenges of military rotary wing aviation is the ability to effectively and safely operate in brownout, whiteout, sea-spray, fog, and rainy conditions. Landing or maneuvering in a Degraded Vision Environments (DVE) is a common problem for pilots. Blinding plumes of dust, snow, sea-spray, fog, and rain can envelop helicopters as they land or take-off, increasing the likelihood that pilots will lose their bearings and drift into unseen obstacles, including other rotary wing aircraft in multi-ship operations. These conditions can escalate into crashing descents, lateral drift rollovers, and collisions with ground features or obstacles.

Imaging laser radar (ladar or lidar) is a particularly promising DVE sensor technology because it can provide wide field-or-regard, high-resolution, 3-dimensional real-time imagery of the region surrounding a helicopter in severe DVE conditions. Areté Associates has developed and flight tested next-generation real-time dust-penetrating (DUSPEN) lidar system under Office of Naval Research, Future Naval Capability program Helicopter Low-Level Operations (HELO) Product 2.

Areté's DUSPEN system captures full lidar waveforms and uses sophisticated real-time detection and filtering algorithms to discriminate hard target returns from dust and other obscurants. Down-stream 3D image processing methods are used to enhance visualization of threat objects (e.g. wires, cables, poles, posts, foliage, obstacles, etc.) and ground features (e.g. ditches, berms, rocks, boulders, sloping terrain, etc.). Areté is maturing the DUSPEN packaging under separate DoD funding for integration into an existing FLIR turret.

This paper will show results from recent flight tests at Yuma Proving Grounds from a CH-53 platform.

8737-18, Session 4

Diffusion and normalized cross correlation combined image registration

Bing Li, Lockheed Martin Systems Integration-Owego (United States)

Image registration is a process of transforming a data set from one coordinate system into another. There are two typical approaches for image registration: Intensity-based and feature-based. The feature-based approach is relatively fast, using points to establish the correspondence between two images, but it involves feature extractions and parameter selection to create feature points. Feature extractions are usually ill-posed problems that often involve derivatives and may lead to robustness issues. The intensity-based approach compares intensity patterns using a correlation metric such as normalized cross correlation (NCC). Since it does not require feature extraction, it is simple and not sensitive to noise,however its computational cost is high. Even when some fast techniques like FFT are used to reduce the computational cost, the implementation is still time consuming. In this paper, we propose a combined diffusion equation and normalized cross correlation (NCC) method to perform robust image registration with low computational cost.

We first apply the diffusion equation to two images received from two sensors (or the same sensor) and allow these two images to evolve by this diffusion equation. Based on the characteristics of evolutions, we select a very small percentage of stable points in the first image and perform the normalized cross correlation to the second image at each transformation point. The highest NCC point provides the transformation parameters for registering these two images. The new method is resistant to noise since the evolution of the diffusion equation reduces noise and it chooses only stable points for the NCC computation. Furthermore, the new method is computationally efficient since just a small percentage of pixels is involved in the transformation estimation. Finally, the experiments for video motion estimation and image registration will be presented to demonstrate that the new method is able to estimate the registration transformation reliably in real time.

8737-19, Session 4

Improvement algorithm for the unfocused image captured by CMOS camera module

Woonchul Ham, Chonbuk National Univ. (Korea, Republic of)

In this paper, we present an algorithm for obtaining original image which becomes blurred because of size of aperture of CMOS camera module in capturing object near to camera. We introduce the mathematical property of circulant matrix which can used for describing the PSF and propose a new algorithm based on this matrix. We suggest new algorithms for both one dimensional signal processing case and two dimensional processing case. The validness of proposed algorithm is checked by computer simulation results for two dimensional image sythesized by using CMOS camera model based on pinhole camera model proposed by our research team previously. We also comments on the fact that the implemetation of restoring procedure is more easy and efficient when the weighted averaging mask of blurr is rectagular. But the difficulty to implement the restoring algorithm comes from the fact that the inverse filtering transfer function is marginally stable. The algorithm to enhancement the margin of stability should be researched for improving the sensitivity problem of restoring algorithm.

8737-20, Session 4

An adaptive approach for visibility enhancement in aerial imagery

Numan Unaldi, Suleyman Demirci, Turkish Air Force Academy (Turkey)

Due to limited dynamic range of currently available imaging and display devices, images captured in high dynamic ranges scenes commonly suffer from poor visibility due to either overexposure causing saturation or underexposure resulting in low contrast dark images in which some important features are lost or become hard to detect by human eyes.

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 10^8:1 absolute range from fully adapted dark vision to fully adapted lighting conditions at noon on the equator. They can see about 3*10^4:1 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.

Although real world scenes generally have high dynamic ranges, there are some exceptions such as turbid (e.g. fog, heavy rain or snow) imaging conditions under which acquired images and the direct observation resembles each other. The extreme narrow dynamic range of such scenes leads to extreme low contrast in the acquired images. Aerial images captured from aircrafts, spacecraft, or satellites usually suffer from lack of clarity, since the atmosphere enclosing the Earth has effects upon the images such as turbidity caused by haze, fog, clouds or heavy rain. The visibility of such aerial images may decrease drastically and sometimes the conditions at which the images are taken may only lead to near zero visibility even for the human eyes. Even though human observers may not see much than smoke, there may exist useful information in those images taken under such poor conditions.

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 degraded visual conditions. The enhancement algorithm employs an adaptive approach in which local image statics, namely the local standard deviation and the local mean in the image are enhanced simultaneously using an intensity transform via an “S” shape curve whose curvature parameter is determined adaptively followed by a local contrast clipping/stretching process.

The image in hand is first converted into an intensity image which is then split 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. Four-time calculated pixel values in the overlapped regions are weighted averaged, that 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.

8737-21, Session 4

ALLFlight: detection of moving objects in IR and ladar images

Hans-Ullrich Doehler, Sven Schmerwitz, Niklas Peinecke, Thomas Lueken, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Supporting a helicopter pilot during landings and takeoffs in a degraded visual environment (DVE) is one of the challenges within DLR’s project ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites). Different types of sensors (TV, Infrared, mmW radar and Ladar) are mounted onto DLR’s research helicopter FHS (flying helicopter simulator) for gathering different sensor data of the surrounding world. A high performance computer cluster architecture acquires and fuses all the information to get one single comprehensive description of the outside situation.

While both TV and IR cameras deliver images with frame rates of 25 Hz or 30 Hz, Ladar and mmW radar provide georeferenced sensor data with only 2 Hz or even less. Therefore, it takes several seconds to detect or even track potential moving obstacle candidates in mmW or Ladar sequences. Especially if the helicopter is flying with higher speed, it is very important to minimize the detection time of obstacles in order to initiate a replanning of the helicopter’s mission timely. Applying feature extraction algorithms on IR images in combination with data fusion algorithms of extracted features and Ladar data can decrease the detection time appreciably. Based on real data from flight tests, the paper describes applied feature extraction methods for moving object detection, as well as data fusion techniques for combining features from TV/IR and Ladar data.

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8738-1, Session 1

Is augmented reality glass a reality? *(Invited Paper)*

Hong Hua, College of Optical Sciences, The Univ. of Arizona (United States)

Abstract (Keynote address): An augmented reality (AR) display, which enables the ability to overlay computer-generated imagery on a person's real-world view, has long been portrayed as a transformative technology to redefine the way we perceive and interact with digital information. With the rapidly increased bandwidth of wireless networks and the miniaturization of electronics, a significant research and market drive is to realize an eyeglass-style, unobtrusive AR display that integrates the functions of a wearable display, mobile devices and miniature GPS technologies within the volume of a pair of eyeglasses. Such an AR display will make access to wireless networks, video display, 3D contents, and location-specific information easier than ever, and has the potential to revolutionize many fields of practices and penetrate through the fabrics of life. In this keynote address, I will provide an overview on the various optical technologies that have been explored for the development of lightweight AR glasses, review recent technological advancements, demonstrate applications of AR glasses in 3D visualization, and discuss potential impacts of such technologies.

8738-2, Session 1

Flickerless 3D shutter glasses for full-resolution stereoscopic display *(Invited Paper)*

Dae-Sik Kim, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); Ho-Sup Lee, Sergey Chestak, Samsung Digital City (Korea, Republic of)

We propose the new structure of shutter glasses to develop flickerless shutter glasses by ambient light as well as crosstalk caused by viewer's head tilt,. In structure of the shutter glasses, front polarizer is replaced with 4/? retardance film, not just omitted. And, instead of single TN cell, we use the combination of two cells which rubbing directions are same, but twist directions are different each other (front cell is clockwise, and rear cell is counter-clockwise). This is for shutter glasses to have retardance range from -λ/2 to λ/2. Replacing front polarizer to retardance film is for ambient light passing through shutter glasses not to have certain directionality. It makes ambient light flicker doesn't occur. Besides, function of retardance film is to adjust polarized light from the screen to the retardance of LC cell according to tilt angle. Tilt sensor attached to the shutter glasses is sensing the tilt angle, and we have each LC cell operate with different voltages corresponding to measured tilt angle. In this shutter glasses, when tilt direction is right, front cell has the incident light transform from circular-polarized light to linear-polarized one. And, rear cell has the incident light bypass without any function. On the contrary to right direction, for left directional tilt, light just bypasses the front cell, and then is transformed from circular-polarized light to linear-polarized light by passing through rear cell. Lastly, we can see that light cannot pass through rear polarizer in any directional tilt with off state shutter glass. That means crosstalk does not happen with any directional tilt.

8738-3, Session 1

Liquid crystal lens for axially distributed three-dimensional sensing *(Invited Paper)*

Yi-Pai Huang, Chih-Wei Chen, National Chiao Tung Univ. (Taiwan); Myungjin Cho, Hankyong National Univ. (Korea, Republic of); Bahram Javidi, Univ. of Connecticut (United States)

Three-dimensional integral imaging (II) has been used for 3D sensing and visualization. In an integral imaging system, a lens or camera array (laterally distributed) is used to capture 3D information from the scene constructed by multiple 2D images with different perspectives. Another approach, axially distributed sensing (ADS), has also been proposed to record 3D data from the scene by moving a single image sensor along its optical axis. However, the mechanical movement of the image sensor in ADS may be impractical for a compact 3D image sensing system.

In this paper, we propose a 3D sensing system that combines the axially distributed sensing technique with a liquid crystal lens whose focal length can be electronically tuned. Varying the focal length electronically, multiple 2D images with slightly different perspectives can be obtained. Therefore, the axially distributed images can be obtained without moving a sensor. Finally, experimental results of computational 3D reconstruction show that our proposed method is suitable to be implemented for a 3D sensing system.

8738-4, Session 2

Global view and depth (GVD) format for FTV/3DTV *(Invited Paper)*

Masayuki Tanimoto, Kazuyoshi Suzuki, Nagoya Industrial Science Research Institute (Japan)

FTV (Free-viewpoint Television) is 3DTV with infinite number of views and ranked as the top of visual media. It enables to view a 3D world by freely changing the viewpoint. MPEG has been promoting the international standardization of FTV since 2001. The first phase of FTV is MVC (Multi-view Video Coding) and the second phase of FTV is 3DV (3D Video). MVC completed in 2009 encodes multiple camera views efficiently and has been adopted by Blu-ray 3D. 3DV is a standard that targets serving a variety of 3D displays and is currently in progress. 3DV employs MVD (Multi-View and Depth) for data format. MVD is a set of views and depths at various viewpoints. 3DV sends MVD data at a few viewpoints and synthesizes many views at other viewpoints to be displayed on various types of multi-view displays at the receiver side. We propose GVD (Global View and Depth) as an alternative data format. GVD consists of base view, base depth, residual views and residual depths. GVD is a compact 3D expression compared to MVD since redundancy of MVD is removed in GVD.

8738-5, Session 2

Elemental images for integral-imaging display *(Invited Paper)*

Manuel Martinez-Corral, Adrian Dorado, Anabel Llavador, Genaro Saavedra, Hector Navarro, Univ. de València (Spain); Bahram Javidi, Univ. of Connecticut (United States)

One of the differences between the near-field integral imaging (NInI) and the far-field integral imaging (FInI), is the ratio between number of elemental images and number of pixels per elemental image. While in NInI the 3D information is codified in a small number of elemental images (with many pixels each), in FInI the information is codified in many elemental images (with only a few pixels each). The later codification is similar that the one needed for projecting the InI field onto a pixelated display when aimed to build an InI monitor. For this reason, the FInI cameras are specially adapted for captur-ing the InI field with display purposes. In this contribution we search for the optimum capture device, and develop the algorithm that allows adapting the captured field to the specific characteristics of the pixelated display device.

8738-14, Session 2

Projection-type 3D display system considering cross-talk between viewing zone

Hyoung Lee, Yonsei Univ. (Korea, Republic of) and Korea Institute of Science and Technology (Korea, Republic of); Young-Sub Son, Yonsei Univ. (Korea, Republic of); Sung-Kyu Kim, Korea Institute of Science and Technology (Korea, Republic of); Kwang-Hoon Sohn, Yonsei Univ. (Korea, Republic of)

In Auto-stereoscopic multi-view 3 dimensional system, crosstalk(ratio of being overlapped) and low resolution have been a interrupt-driven that disturb observer to perceive the clear depth perception of images. To solve this problem, it is possible to control the crosstalk of adjoining viewing zone at the observation area, with adjusting interval between each projector lens, in projection-type Auto-stereoscopic multi-view 3 dimensional system. Also, making the ray of light pass through a point located in the front of the image position, the amount of crosstalk can be minimized and the ratio of the amount of overlap along the distance are maintained. At last, by merging adjoining viewing zone. the crosstalk can be improved and the luminance of image can be increased.

8738-8, Session 3

Usage of moving nanoparticles for improved holographic recording *(Invited Paper)*

Zeev Zalevsky, Amihai Meiri, Bar-Ilan Univ. (Israel); Eran Gur, Jerusalem College of Engineering (Israel); Javier Garcia, Vicente Micó, Univ. de València (Spain); Bahram Javidi, Univ. of Connecticut (United States)

In this paper we present a technique that uses the random movement of nanoparticles for improving the holographic recording performance. In the first part of our paper we show how the movement of the particles can eliminate the unwanted terms in a Gabor hologram. In the second part we show how their movement can improve resolution and increase the field of view of the reconstruction.

In both cases the free randomly distributed nanoparticles are in proximity to the object and their Brownian motion encodes the spatial features of the object in the recorded hologram. The nanoparticles are localized and a decoding pattern is calculated for each frame. This decoding pattern is then used either to remove the reference beam and the conjugate beam in the reconstruction of the Gabor hologram or to improve resolution or to extend the obtainable field of view in the reconstruction process.

8738-9, Session 3

Identification of malaria-infected RBC with digital holographic microscopy *(Invited Paper)*

Arun Anand, Vani Chhaniwal, The Maharaja Sayajirao Univ. of Baroda (India); Bahram Javidi, Univ. of Connecticut (United States)

Malaria is regarded as one of the most widespread and potentially fatal diseases especially in Africa and Asia. Correct diagnostics of malaria is essential for proper medication and cure. Main clinical diagnostics of malaria is based on microscopic inspection of blood smears, treated with reagents, which stains the malarial parasites. A technician visually inspects these smears to identify malaria infected red blood cells (RBC). In developing countries, visual identification of malarial RBCs may become unreliable due to lack of sufficiently trained technicians, poor quality microscopes and reagents. Also in remote areas, malaria diagnostics could benefit from the use of portable and easy to use instruments to automatically discriminate between malarial and healthy RBCs. So an automatic compact diagnostics tool will be advantageous especially for health care personal working in developing countries, which lack trained professionals and high quality equipments. Digital holographic microscopy is one of the advanced techniques for quantitative evaluation of cells, providing cell thickness information directly. This information obtained by interferometric comparison can be used to identify as well as to compare cells. Here, we describe the use of digital holographic interferometric microscopy (DHIM) with numerical focusing for automatic identification of malaria infected red blood cells (RBC). Identification is done by comparing its shape profile with that of a healthy RBC. A correlation function was used to separate healthy and malaria infected RBCs.

8738-10, Session 3

An alternative approach to develop digital hologram interaction system using bounding volumes for identifying object collision

Sungjin Cho, Korea Photonics Technology Institute (Korea, Republic of) and Korea Institute of Science and Technology (Korea, Republic of); Dong-Su Lee, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Byeong-Kwon Ju, Korea Univ. (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

Many studies on holographic displays have been conducted. However, studies on interaction methods for holographic displays are still in an early stage. Digital holography technology is not yet fully developed to make holograms capable of naturally responding to human behaviors and providing a wide viewing angle to humans. Thus, this study proposes an alternative approach for making it possible to naturally interact with digital holograms by utilizing bounding volume methods, which have been employed in virtual space. In order to propose an intuitive interaction method, we utilize a Kinect. In doing so, humans and environment surrounding them are captured by the depth camera. The captured depth images are simulated on a virtual space, then computer graphic objects are generated on the same virtual space. Detailed location information of humans is continuously extracted to provide a natural interaction with the generated objects. In order to easily identify whether two objects are overlapped or not, bounding volumes are generated around both humans and objects, respectively. The local information of the bounding volumes is correlated with one another, which makes it possible for humans to control the computer-generated objects. The proposed system also tracks the virtual objects' movements and records them as CGH (Computer-Generated Hologram). The recorded fringe patterns generated by CGH can be reconstructed in digital holographic displays, which will help lead to an interactive holograms. The proposed method is expected to be a starting point for establishing an optimized interaction method for digital holograms.

8738-11, Session 4

Generation of flat viewing zone in DFVZ autostereoscopic multiview 3D display by weighting factor *(Invited Paper)*

Sung-Kyu Kim, Seon Kyu Yoon, Ki Hyuk Yoon, Korea Institute of Science and Technology (Korea, Republic of)

A new method is introduced to reduce the three crosstalk problems and the bright change in 3D image by means of the dynamic fusion of viewing zones (DFVZ) using weighting factor. The new method effectively generates the flat viewing zone at the center area of viewing zone. Therefore the new type autostereoscopic 3D display can give less bright tolerance of 3D image when observer moves.

8738-12, Session 4

Effect of Viewing Distance on 3D Fatigue Caused by Viewing Mobile 3D Content

(Invited Paper)

Sungchul Mun, Dong-Su Lee, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Sumio Yano, Shimane Univ. (Japan)

With an advent of autostereoscopic display technique and increased needs for smart phones, there has been a significant growth in mobile TV markets. The rapid growth in technical, economical, and social aspects has encouraged 3D TV manufacturers to apply 3D rendering technology to mobile devices so that people have more opportunities to come into contact with lots of 3D content anytime and anywhere. Even if the mobile 3D technology leads to the current market growth, there is an important thing to consider for consistent development and growth in the display market. To put it briefly, human factors linked to mobile 3D viewing should be taken into consideration before developing mobile 3D technology. Many studies have investigated whether mobile 3D viewing causes undesirable biomedical effects such as motion sickness and visual fatigue, but few have examined main factors adversely affecting human health. Viewing distance is considered one of the main factors to establish optimized viewing environments from a viewer's point of view. Thus, in an effort to determine human-friendly viewing environments, this study aims to investigate the effect of viewing distance on human visual system when exposing to mobile 3D environments. Recording and analyzing brainwaves before and after watching mobile 3D content, we explore how positively and negatively viewing distance influences viewing experience from physiological and psychological perspectives. Results obtained in this study are expected to provide viewing guidelines for viewers, help ensure viewers against undesirable 3D effects, and lead to make gradual progress towards a human-friendly mobile 3D viewing.

8738-13, Session 4

Expanding the degree of freedom of observation on depth-direction by the triple-separated slanted parallax barrier in autostereoscopic 3D display

Kwang-Hoon Lee, Korea Photonics Technology Institute (Korea, Republic of); Yeong-Seon Choe, Korea Institute of Science and Technology (Korea, Republic of); Dong-Kil Lee, Yang-Gyu Kim, Youngsik Park, Korea Photonics Technology Institute (Korea, Republic of); Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of)

In the proposal the triple segmented-slanted parallax barrier (TS-SPB) is designed to form the triple viewing zones with that their centers stand in line on depth direction having an inter distance to enough them be merged to one viewing zone. Therefore the superposed viewing zone makes an expanded viewing area on depth direction. So we can obtain the increased degree of freedom on depth direction by using TS-SPB. In TS-SPB, three segmented barrier rows are consisted and the group of them is periodic arranged on the vertical direction covered to the display. The position of the center of each barrier row is corresponded to the center of sub-pixel in the same row. And the vertical length of the segmented barrier is equal to the sub-pixel height. The unit pixel will be constructed as a slanted shape and consisted tree types of RGB alignments. The center of sub-pixels are separated on the vertical direction having a inter distance as the height of sub-pixel and horizontal direction having the width of sub-pixel in the slanted unit pixel. Core technologies in our work are as follow that first, let the outgoing rays from each R,G,B sub-pixel having a phase difference in the slanted unit pixel of the view image are passed through the aperture of the segmented barrier in the same row, and they make the triple viewing zones in ordered on the depth direction, and three viewing zones are to be an expanded one viewing zone having a high brightness uniformity by superposition process. Second, let define the useable number of view and address image mapping to prevent color dispersion in the expanded viewing zone. The logical validity of our proposal is verified by optical simulation of an actual case.

8738-15, Session 4

Light-intensity simulation in real space by viewing locations for autostereoscopic display design

Jung Guen Jo, Korea Institute of Science and Technology (Korea, Republic of); Kwang-Hoon Lee, Korea Photonics Technology Institute (Korea, Republic of); Dong-Su Lee, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

Autostereoscopic technique is a common method for providing 3D perception to viewers without glasses. Although autostereoscopic displays produce 3D images with a wide perspective, crosstalk is still an obstacle to solve. It is generally accepted that the crosstalk causes distortion of perceived images, and degradation of image quality, which can induce eye fatigue. Many studies have proposed crosstalk simulation systems in autostereoscopic displays to address the problems and offer comfortable 3D views to humans. However, most have focused heavily on calculation of crosstalk regardless of viewers' positions. Thus, the purpose of this study was to propose a light intensity simulator that can calculate crosstalk according to variable viewing positions by automatically tracking heads of viewers. This study is novel in the following aspects. In contrast to previous methods to estimate crosstalk and viewing zones, the proposed system presents a simulation system to automatically provide optimized viewing zones to viewers by estimating crosstalk as a function of viewers' positions. In doing so, we utilize head tracking technique based on infrared laser sensors to detect the observers' viewing positions. In our preliminary experiment, geometrical parameters, such as aperture, barrier, and display size, related to autostereoscopic displays were used to calculate the light intensity distributions and suggest the optimized viewing zones to viewers. The experimental results showed that the proposed system was appropriate to be operated in real space. The proposed method would help to design autostereoscopic display panels in that simulated virtual results projected into the real space ensuring human safety. It is also expected to shorten the term of product development.

8738-16, Session 5

Study on basic problems in real-time 3D holographic display *(Invited Paper)*

Yongtian Wang, Jia Jia, Juan Liu, Yijie Pan, Xin Li, Beijing Institute of Technology (China)

In recent years, real-time three-dimensional (3D) holographic display has attracted more and more attentions. Since a holographic display can entirely reconstruct the wavefront of an actual 3D scene, it can provide all the depth cues for human eye's observation and perception, and it is believed to be the most promising technology for future 3D display. However, there are several unsolved basic problems for realizing large-size real-time 3D holographic display with a wide field of view. For examples, commercial pixelated spatial light modulators (SLM) always lead to zero-order intensity distortion; 3D holographic display needs a huge number of sampling points for the actual objects or scenes, resulting in enormous computational time; The size and the viewing zone of the reconstructed 3D optical image are limited by the space bandwidth product of the SLM; Noise from the coherent light source as well as from the system severely degrades the quality of the 3D image; and so on. Our work is focused on these basic problems, and some initial results are presented, including a technique derived theoretically and verified experimentally to eliminate the zero-order beam caused by

a pixelated phase-only SLM; a method to enlarge the reconstructed 3D image and shorten the reconstruction distance using a concave reflecting mirror; and several algorithms to speed up the calculation of computer generated holograms (CGH) for the display.

8738-17, Session 5

A holographic display based on spatial multiplexing

Jung-Young Son, Oleksii Chernyshov, Konyang Univ. (Korea, Republic of); Min-chul Park, Korea Institute of Science and Technology (Korea, Republic of); Wookho Son, Beom-Ryeol Lee, Electronics and Telecommunications Research Institute (Korea, Republic of); Jinwoong Kim, Electronics and Telecommunication Research Institute (Korea, Republic of)

10 DMD chips of 1280X800 resolution for each chip are combined spatially to construct a large size holographic image. The chips are aligned 5X2 to get the reconstructed images of 15cm X 3cm. The chips produced clear and continuous images of the size.

8738-18, Session 5

Computer-generated hologram for 3D scene from multiview images

Eun-Young Chang, Electronics and Telecommunications Research Institute (Korea, Republic of); Yun-Suk Kang, Gwangju Institute of Science and Technology (Korea, Republic of); KyungAe Moon, Electronics and Telecommunications Research Institute (Korea, Republic of); Yo-Sung Ho, Gwangju Institute of Science and Technology (Korea, Republic of); Jinwoong Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

We propose a new method of generating holograms from multi-view images. For capturing multi-view images, the multi-view camera system composed of five color cameras and one depth camera is implemented. For color camera setup, convergent arrangement is used. The depth camera is positioned appropriately to encompass the field-of-view covered by five color cameras. Five depth maps are calculated by depth calculation process from captured multi-view images. Our depth calculation process is composed of camera calibration, pre-processing for color correction, lens un-distortion, and distortion correction, and stereo matching. Due to the convergent camera setup, we leave image rectification out during the depth calculation process. If we would like to apply image rectification for easy computation, a considerable extent of image regions will be disappeared. Each depth map is converted into 3-D point clouds using intrinsic/extrinsic camera parameters from the camera calibration. 3-D point clouds for each viewpoint are unified into a 3-D point cloud set by erasing duplicated 3-D point clouds severally presented on multi-view images and merging remaining unique 3-D point clouds. A hologram supporting motion-parallax is generated from the unified 3-D point cloud by examining which 3-D point clouds are contributed to each pixel of it.

In order to evaluate the performance of proposed methods numerical and optical reconstructions are used. For numerical reconstruction, several reconstruction images are calculated according to different distances by the HoloVision application in order to verify correct depth effect. Besides the numerical reconstruction, optical reconstructions are also accomplished by our own optical setup. We confirmed that 3-D scenes are correctly reconstructed by the both evaluations.

8738-19, Session 5

Spherically-arranged piecewise planar hologram for capturing a diffracted-object wavefield in 360 degree

Seungtaik Oh, Electronics and Telecommunications Research Institute (Korea, Republic of); Hoyong Seo, Electronics and Telecommunication Research Institute (Korea, Republic of); Chi-Young Hwang, Beom-Ryeol Lee, Wookho Son, Electronics and Telecommunications Research Institute (Korea, Republic of)

Spherical hologram is most ideal since it can record the object wave propagating in all directions. However, computing a diffracted light field on a curved surface is not an easy task and, in general, one cannot use the efficient discrete Fourier transform for curved cases.

In this paper, we propose a practical method to record an object wave propagating in 360 degree. Our idea is to use spherically-arranged elementary planar holograms with the same physical size and number of pixels instead of a single spherical hologram. Every elementary hologram meets a given sphere tangentially at its center and so the total spatial frequency vectors determined by elementary holograms cover the entire directions with almost uniform angular spacing. The range of spatial frequency vectors for a single elementary hologram is determined by the diffraction angle supported by the elementary hologram.

With this arrangement of elementary planar holograms, we can sample plane wave components of an object wave for all directions in a rate, the inverse of the physical hologram size and therefore we can synthesize a new planar hologram tangent to sphere for an arbitrary viewpoint by efficient computation of DFT and angular spectrum transform such as propagation and rotation. This synthesis process can be also used for numerical reconstruction at an arbitrary viewpoint for the given elementary holograms. Numerical results are presented to show the effectiveness of our method as well.

8738-20, Session 5

Holographic 3D display with 1D spatial light modulator with a large pixel number

Osamu Matoba, Ayaka Ueno, Kouichi Nitta, Kobe Univ. (Japan)

Holographic 3D display with 1D spatial light modulator (SLM) can reduce the calculation cost to prepare numerically hologram data from virtual object. We evaluate the reconstructed image quality of 3D object by changing the pixel number of 1D SLM such as 4096 x 1, 8192 x 1 and more.

We also show the experimental verification of the effect of the pixel number on the reconstruction quality.

8738-21, Session 5

A 3D visual conformity with numerical and optical holographic content reconstruction on the stereoscopic holographic display system

Beom-Ryeol Lee, Chi-Young Hwang, Wookho Son, Electronics and Telecommunications Research Institute (Korea, Republic of); Joonku Hahn, Kyungpook National Univ. (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

Stereoscopic Holographic System consists of hologram reconstruction optics symmetrically for viewer's each eye with RGB colors.

We compare to reconstructed hologram image numerically from CGH with optically reconstructed hologram image on the system.

For visually fitting of numerical and optical reconstructing hologram image, we tried to manipulate and evaluate parameters of numerical

hologram generation to getting enhanced visual similarity of reconstruction hologram and adjust and adapt optical setup applicably to conforming with each hologram image on the system.

8738-22, Session 6

Observation of femtosecond light pulse propagation by using digital light-in-flight recording by holography *(Invited Paper)*

Takashi Kakue, Chiba University (Japan); Peng Xia, Tatsuki Tahara, Yasuhiro Awatsuji, Kenzo Nishio, Shogo Ura, Toshihiro Kubota, Kyoto Institute of Technology (Japan); Osamu Matoba, Kobe Univ. (Japan)

Light pulse propagation is one of the ultrafast phenomena, and it is useful to record and observe the propagation for clarifying optimal conditions of light pulse irradiation in nano surgery and characterizing optical and photonic devices. Although there are several techniques for visualizing ultrashort light pulses, visualization of femtosecond light pulse propagation by using a single pulse is impossible for them in principle because they require repetitive light pulses or sequential recording of images. Then, we adopt light-in-flight recording by holography as a technique for recording and observation of femtosecond light pulse propagation because it is possible to observe light pulse propagation as a motion picture which is temporally and spatially continuous and frameless at a desired speed with a single-shot exposure by using the technique. In particular, digital LIF holography, which combines digital holography wth LIF holography, has some features such as development process free, quantitative analysis and evaluation, and low wavelength dependence. In this paper, we introduce a motion picture of femtosecond light pulse propagation obtained by digital LIF holography.

8738-23, Session 6

Evaluation of reconstructed quality in incoherent digital holography *(Invited Paper)*

Osamu Matoba, Yoshiki Tone, Kouichi Nitta, Kobe Univ. (Japan); Yasuhiro Awatsuji, Kyoto Institute of Technology (Japan)

Incoherent diigtal holography is expected to open new applications of digital holography for fluorescence 3D imaging or LED illumination to 3D object. In this presentation, we evaluate the reconstructed image quality in incoherent digital holography by changing the coherence degree of light source.

8738-24, Session 6

Synthesis and 3D display of multiwavelength digital holograms through adaptive transformation *(Invited Paper)*

Pasquale Memmolo, Melania Paturzo, Andrea Finizio, Pietro Ferraro, Istituto Nazionale di Ottica (Italy); Bahram Javidi, Univ. of Connecticut (United States)

Digital color holography was established by Yamaguchi et al, who used a phase shifting method for the recording at different wavelengths. The reconstruction of digital color holograms can be performed using the discrete Fresnel transform or the convolution method with a zero-padding. Other different numerical methods are based on the control of the size of digital holograms, the pixel resolution, the image scaling. In this paper we propose a new reconstructing algorithm of multi-wavelengths digital holograms based on the stretching transformation. This method was proposed in the 2010 by Paturzo et al. and the numerical manipulation of the holograms allows the adaptive compensation for different color holograms, which are subsequently superimposed using a correlation-matching procedure. We test our procedure in different experimental case considering digital color holograms recorded in both microscope configuration and lensless configuration. A synthetic hologram, containing the information of different color recorded holograms of the same object, is designed using the national television systems committee coefficients and the optical reconstruction by a spatial light modulator at one wavelength allows us to display all color features. Finally, using again the stretching technique, a 3D scene of multiple optically recorded digital color holograms of different objects is synthesized and displayed by the spatial light modulator.

8738-25, Session 7

3D integral imaging using compressive sensing: an overview *(Invited Paper)*

Abhijit Mahalanobis, Lockheed Martin Missiles and Fire Control (United States); Bahram Javidi, Univ. of Connecticut (United States)

Compressive Sensing (CS) provides a way to dramatically reduce the amount of data that needs to be collected to form images, which in turn can reduce the storage and bandwidth requirements. In this paper, we explore the effects of CS in acquisition of the elemental images, and ultimately on passive 3D scene reconstruction and object recognition. Our experiments show that the performance of passive 3D sensing systems remains robust even when elemental images are recovered from very few compressive measurements.

8738-27, Session 7

Compressive sensing for improved depth discrimination in 3D holographic reconstruction *(Invited Paper)*

Yair Rivenson, Adrian Stern, Ben-Gurion Univ. of the Negev (Israel); Bahram Javidi, Univ. of Connecticut (United States)

In a recent work we have investigated the reconstruction of a three dimensional object acquired using the single exposure on-line (SEOL) holographic setup. The object's reconstruction was formulated as a compressive sensing problem. Compressive sensing is a joint signal acquisition-reconstruction paradigm, which has gained much attention recently since it provides a framework for the reconstruction highly subsampled signals. Digital holography was demonstrated to be a highly efficient object sensing scheme. This combination has already created many new holographic applications, since its introduction in 2009. In this work we concentrate on the ability to reconstruct a 3D volume from its 2D recorded hologram. Using the single-exposure on-line (SEOL) setup, we show how CS applied to this naturally underdetermined problem enables the improved sectioning (or depth discrimination) of the reconstructed volume when compared to standard in-line holography. This is due to the fact that using the two arms configuration of the SEOL, can be used to produce higher SNR holograms when compared to standard in-line holography.

We also discuss mathematical guarantees for the reconstruction of the 3D volume features from its single 2D hologram and their physical implications for sectioning of 3D objects.

8738-28, Session 7

Advantage of diverging radial type for mobile stereo camera *(Invited Paper)*

Lee Dong-Su, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Jung-Young Son, Konyang Univ.

(Korea, Republic of)

Distortions in the perceived image characteristics for three different camera arrangements of parallel, conversing, and diverging are different according to each focal length, focus distance, field of view angle, color, magnification, and camera aligning direction. The distortions in perceived image for the parallel and converging arrangements have been researched commercially available stereoscopic TV based on high speed LCD and shutter glasses, and mobile devices. However, the distortion in the perceived image for diverging arrangement is not well known. This paper discusses the distortion in perceived image characteristics of diverging type stereo camera and they are compared with those of other camera arrangements such as parallel and converging types. Also, the distortion induces the image closer to the viewers for the diverging type while away for the converging. The inducement is more prominent as the camera distance between two component cameras of the stereo camera for the diverging type. Furthermore, the effect of diverging angle on disparity will be considered that the inter-camera distance can be made as small as possible.

8738-29, Session 7

Information-theoretic metrics for 3D photon-counting integral imaging *(Invited Paper)*

Majeed Hayat, Srikanth R. Narravula, Matthew P. Pepin, The Univ. of New Mexico (United States); Bahram Javidi, Univ. of Connecticut (United States)

Photon-counting integral imaging has been introduced recently and its applications in 3D object sensing, visualization, recognition and classification under photon-starved conditions have been demonstrated. This paper reviews recent developments of the underlying information-theoretic foundation behind the observation that such complex tasks can be performed by means of imaging with far fewer photons than conventional imaging systems. To this end, recently developed information-theoretic metrics for 3D image fidelity, measured by the entropy-normalized mutual information associated with a given imaging system, as well as the photon-information-content metric, represented by the mutual information per photon, are reviewed and discussed in the context of 3D photon-counting imaging. The trade-off between image fidelity and photon-information-content metrics are discussed by examples from 3D integral imaging.

8738-30, Session 8

Concealed object segmentation and three-dimensional localization with passive millimeter-wave imaging *(Invited Paper)*

Seokwon Yeom, Daegu Univ. (Korea, Republic of)

Millimeter waves imaging draws increasing attention in security applications for the detection of objects under clothing. In this paper, concealed object segmentation and three-dimensional localization schemes are reviewed. The segmentation has two stages: global and local segmentation stages. Each of them comprises k-means and expectation maximization algorithms. A segmentation-based stereo-matching method estimates the longitudinal distance from a concealed object. The distance from a concealed object is estimated on the basis of discrepancy between corresponding centers of the segmented objects in the stereo pair. Experimental results are provided with millimeter wave images indoors and outdoors.

8738-31, Session 8

Three-dimensional polarimetric imaging based on integral-imaging techniques

Xiao Xiao, Bahram Javidi, Univ. of Connecticut (United States)

In this paper, we overview a 3D polarimetric computational integral imaging system by using polarization diversity of objects under natural illumination conditions. In the system, we first measure Stokes polarization parameters and generate degree of polarization images of a 3D scene. Then we utilize a modified computational reconstruction method to perform 3D polarimetric image reconstruction by using the calculated degree of polarization for all the elemental images. Experimental results are also given to verify the feasibility of the 3D polarimetric integral imaging. The system may be used to detect or classify objects with distinct polarization signatures in 3D space.

8738-32, Session 8

Real-time motion artifacts compensation of ToF sensors data on GPU

Damien Lefloch, Thomas Hoegg, Andreas Kolb, Univ. Siegen (Germany)

Over the last decade, Time-of-Flight (ToF) sensors brought increasing interest for researchers in computer vision and graphics field. And are nowadays widely used in many applications. Nevertheless, due to their acquisition principle which roughly consists of a temporal phase-shift signal sampling, ToF devices are subjects to strong motion artifacts in the case of dynamic scene. Mainly present on depth and intensity edges, motion leads to incorrect range measurement. Furthermore, ToF cameras solely provide low-resolution depth data which strongly justifies the importance of a robust motion artifacts detection and a valid correction procedure.

To counter this effect, a pre-processing approach is introduced to greatly improve range image data on dynamic scene. Our method is using optical flow algorithm on raw phase data, sampled during the acquisition process and can operate with both, lateral and axial motion. Since raw data is not accessible from all ToF cameras on the market, a discussion is also provided concerning other methods dealing with motion compensation.

We first demonstrate the correctness and robustness of our approach using both “realistic” simulated and real range sensor data. As well as an evaluation of motion compensated depth image based on groundtruth data generates from our ToF simulator. Secondly, our method is validated using live range data from the acquisition of simple groundtruth objects with known dimension, distance and motion. And finally, our GPU based processing pipeline enhances range data reliability in real-time, with no frame rate loss.

8738-6, Session PTues

Analysis of three-dimensional image, using Tutte polynomial for polyhedral graphs

Alejandro Gómez Montoya, Univ. EAFIT (Colombia)

All three-dimensional image, could be represented with a polyhedral graphs, where the number of edges and vertices is proportional to the quality of the image, and this image could be stored in an algebraic expression like a Tutte polynomial, allowing the reconstruction of any three-dimensional image. The Tutte polynomial is calculated using the package Graph Theory of Maple 16, which has been optimized for polyhedral graphs with a lot of edges and vertices, so this could be very useful with three-dimensional complex images or three-dimensional HD image. In this paper, I will present some examples of the useful Tutte polynomial, and for future work, I will investigate the use of Bollobás-Riordan polynomial.

8738-33, Session PTues

A new system parameters analysis method to improve image quality in digital microscopic hologram reconstruction

Jiansu Li, Zhao Wang, Jianmin Gao, Kun Chen, Xi'an Jiaotong Univ. (China); Yun Liu, Xi'an Jiaotong Univ. (China) and Xi'an Univ. of Technology (China)

Digital holographic microscopy can accurately analyze the three-dimensional surface shape structure of the object and the phase information of phase objects. It is divided into the hologram recording and digital reconstruction. The qualified hologram is the foundation of obtaining non-overlapping and high-quality reconstructed image. Therefore, it is vital to analyze the system parameters in digital holographic microscopy. This paper focuses on the system parameters analysis of the pre-magnification digital holographic recording system, which is the most widely used in digital holographic microscopy recording system.

In order to obtain the non-overlapping and high-quality reconstructed image, this paper proposes a new analysis method to determine system parameters in digital holographic microscopy. Nowadays a few scholars have analyzed the system parameters, but they mainly analyze them from the hologram, which need to satisfy the sampling theorem and separate spectrum conditions. So there are three aspects being studied, which are the sampling theorem, spectrum separation conditions and the relationships between the CCD size and reconstructed image. Then the system parameters relationships are proposed, which contribute to acquire the reconstructed image with high quality. The max object size is directly proportional to the wavelength and microscope objective focal length, and it is inversely proportional to the sampling interval. And the min magnification and recoding distance range have been described accurately after analyzing these three aspects. Comparing with the system parameters relationships described by previous papers, these relationships are more accurate and comprehensive. Experiment further demonstrates the proposed analysis method's validity.

8738-34, Session PTues

Recognition of facial expression from variable quality 3D pose data

Manar D. Samad, Khan M. Iftekharuddin, Old Dominion Univ. (United States)

Although recognition of facial expression from 3D models has been advanced for over a decade, it still suffers challenges due to head pose in spontaneous human-computer interaction. Moreover, the reconstructed 3D face models may be incomplete, redundant or inconsistent in terms of discriminative data content for facial expression recognition. Therefore the quality of the reconstructed 3D models becomes an issue in such recognition purpose. We propose a method that computes normal vectors and their angles from 3D models with vertex and face information to represent each expression. A projection of normal vectors on tangent plane would provide distinctive pattern for facial expression. Furthermore, a histogram representation of this projected normal vectors and corresponding angles will show the principal direction of an expression class. These will help us obtain pose and expression related features which will in turn facilitate classification for recognition. We will test and compare the performance of our algorithm over a set of poorly versus neatly reconstructed 3D facial expression data. Similarly, we will study the recognition of facial expression from 3D data subjected to pose. Our method will not require any assignment of landmark, rather it will map all nonuniform datasets into a uniform grid to compute and compare the distribution of projected normal vectors and their angles of orientation. We will evaluate the performance after 10-fold cross validation and the confusion matrix will show the accuracy for different expression.

8738-36, Session PTues

Automated analysis of 3D morphology of human red blood cells via off-axis digital holographic microscopy

Inkyu Moon, Chosun Univ. (Korea, Republic of)

In this paper we overview an automated methods to analyze three-dimensional (3D) morphology of human red blood cells (RBCs) for the purpose of the various types of RBCs identification. Off-axis optical interferometry setup captures the digital holograms of multiple RBCs by CCD camera. The phase images of the RBCs are retrieved from the recorded hologram. The image segmentation algorithm based on marker-controlled watershed is applied to the reconstructed phase image with multiple red blood cells. All of the single RBCs are extracted by using the segmentation method. Finally, the 3D morphology information of RBC such as surface area, mean phase value, dry-mass and density are automatically obtained using digital image processing techniques. Experimental results demonstrate the presented methods can automatically and quantitatively analyze the 3D morphology of RBCs.

8738-37, Session PTues

Coherent scattering stereoscopic microscopy for mask inspection of extreme ultraviolet lithography

Ki Hyuk Kim, Korea Institute of Science and Technology (Korea, Republic of); Jung Guen Jo, Korea Institute of Science and Technology (Korea, Republic of) and Korea Univ. (Korea, Republic of); Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Byeong-Kwon Ju, Korea Univ. (Korea, Republic of); Sungjin Cho, Korea Institute of Science and Technology (Korea, Republic of) and Korea Univ. (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

Mask inspection is essential for the success of any pattern-transfer lithography technology, and extreme ultra-violet(EUV) Lithography in particular faces unique challenges. The phase of structures and defects on EUV masks were quantitatively reconstructed based on aerial image measurements, using a pair of stereoscopic images reconstructed by hybrid input-output algorithm. The reconstructed images interpolate pixel of each other as complementary then they provide detector with the stereoscopic 3D Displays. The stereoscopic microscope elevates the accuracy of mask inspection. In this paper, we proposed a simulated solution of stereoscopic coherent scattering microscopy for mask inspection used extreme ultra-violet lithography.

8738-38, Session PTues

3D profile reconstruction and analysis of liquid crystal lens using fluorescence confocal polarizing microscopy

Yi-Pai Huang, Po-Yuan Hsieh, Lin-Yao Liao, Han-Ping D. Shieh, National Chiao Tung Univ. (Taiwan)

Liquid Crystal (LC) Lens owns a very unique property that focal length is electrically tunable without any mechanical moving and shape changing. The lens effect of LC lenses is achieved by electrically controlling the tilt angle of LC molecules. Therefore, the phase retardations of the light after passing through the LC lens and polarizer will be induced. By plotting the cutting profile of the fringe pattern, the optical path length (OPL) is calculated to estimate the optical properties. However, the fringing pattern is an integral result which is difficult to observe the significant behavior of light inside the LC cells. In this paper, we proposed that using the Fluorescence Confocal Polarizing Microscopy (FCPM) method for analyzing LC lens. The FCPM is a 3D confocal microscopy system recorded the fluorescent light intensity distribution in the cell layer by layer. After that, by calculating the recorded results, the spatial refractive index of the LC lens is obtained. Furthermore, the lens 3D profile could be reconstructed by stacked these layers. Finally, a real experiment is also demonstrated to verify our approach. For advanced design, FCPM method is necessary for the analysis of LC lens.

8738-39, Session PTues

CSpace® scalable, high-resolution 3D display

Mark Willner, 3DIcon Corp. (United States)

Three-dimensional display technologies are under investigation for a wide range of potential applications in the commercial, defense, and security market spaces. Key performance criteria include: ease of viewing, high-resolution, high-fidelity, full-color, scalability of the image size, and reliability. This paper describes 3DIcon research and development efforts that have demonstrated a promising three-dimensional volumetric display, called CSpace® display, with the capability of satisfying the aforementioned performance criteria. CSpace® display utilizes commercial off-the-shelf micro-electro-mechanical systems (MEMS) based mirror arrays and special line generation system to direct infrared light beams into an image space. The image space is occupied by a photonic material suitable to convert the incident infrared light to visible images. To date, monochromatic images have been demonstrated in an image space material that exhibits two-photon upconversion. However, the display system optics are designed to allow the production of full-color images and, to that end, materials research is underway to enable the demonstration of polychromatic images. CSpace® display prototype requires no special viewing aids and produces a volumetric image that is viewable from 360 degrees. The display as presently designed is capable of producing 800 million voxels, or volumetric pixels, of image content. The display design facilitates the scalability of the image space. The use of MEMS based mirror arrays and 3DIcon's line generation system promise improved reliability by avoiding large moving parts. This paper describes the progress of the research to date and critically examines the prospects for future development.

8739-1, Session 1

SUCHI: The Space Ultra-Compact Hyperspectral Imager for small satellites

Sarah T. Crites, Paul G. Lucey, Robert Wright, Univ. of Hawai'i (United States); Jeremy Chan, Hawaii Space Flight Laboratory (United States); Harold Garbeil, Keith A. Horton, Univ. of Hawai'i (United States); Amber Imai, Hawaii Space Flight Laboratory (United States); Mark Wood, Univ. of Hawai'i at Manoa (United States); Lance Yoneshige, Hawaii Space Flight Laboratory (United States)

The Space Ultra Compact Hyperspectral Imager is a long wave infrared hyperspectral imager being built at the University of Hawaii. The sensor will be the primary payload on the HiakaSat small satellite scheduled for launch on the Office of Responsive Space mission ORS 4 and planned for 6 month primary mission extendable to two years operation on orbit. SUCHI is based on a variable-gap Fabry-Perot interferometer employed as a Fourier transform spectrometer and uses an uncooled 320x256 microbolometer array to collect the images. The sensor is low volume (10x10x36 cm3) and low mass (<9kg), to conform to the volume, mass, and power requirements of the small satellite. The commercial microbolometer camera and vacuum-sensitive electronics are contained within a sealed vessel pressurized to 1 atm. The sensor will collect spectral radiance data in the long wave infrared region (8—14 microns) and demonstrate the potential of this instrument for advancing the geological sciences (e.g. mapping of major rock-forming minerals) as well as for volcanic hazard assessment (mapping volcanic ash, quantification of volcanic sulfur dioxide pollution and lava flow cooling rates). The sensor is scheduled for delivery to the satellite in Spring 2013 with launch scheduled for September 2013.

8739-2, Session 1

Lunar magnetic field measurements with a cubesat

Ian Garrick-Bethell, Univ. of California, Santa Cruz (United States) and Kyung Hee Univ. (Korea, Republic of); Robert Lin, Univ. of California, Berkeley (United States); Hugo Sanchez, Belgacem S. Jaroux, NASA Ames Research Ctr. (United States); Manfred Bester, Univ. of California, Berkeley (United States); Patrick Brown, Imperial College London (United Kingdom); Daniel Cosgrove, Univ. of California, Berkeley (United States); Michele K. Dougherty, Imperial College London (United Kingdom); Jasper S. Halekas, Univ. of California, Berkeley (United States); Doug Hemingway, Univ. of California, Santa Cruz (United States); Paulo C. Lozano, Massachusetts Institute of Technology (United States); Francois Martel, Espace Inc. (United States); Caleb W. Whitlock, Massachusetts Institute of Technology (United States)

The scientific targets of the mission are strongly magnetic regions of the lunar crust that have been studied since the Apollo era. The magnetic regions are associated with anomalous surface color markings known as "swirls." The origins of the crustal magnetism and color markings are unknown. Measurements in these regions have been performed by orbiting spacecraft at altitudes >15 km, but near-surface data are required to understand these features.

In addition to magnetic field measurements, we would like to measure the near-surface solar wind flux, which is likely involved in forming the surface markings. The CINEMA 3-unit cubesat built by UC Berkeley Space Sciences Laboratory and Kyung Hee University is well suited for these purposes. CINEMA carries a 1 m boom-based magnetometer that can perform measurements at sufficiently high frequency to capture the last ten milliseconds of data before impact. UC Berkeley has also designed a miniature solar wind flux detector for the lunar mission.

The mother ship that releases the cubesats on impact trajectories has been designed by NASA Ames Research Center and is known as Planetary Hitch Hiker (PHH). PHH is low mass (<150 kg), and is capable of carrying two 3-unit cubesats to the Moon, after achieving geostationary transfer orbit as a secondary payload. PHH enters a highly elliptical orbit around the Moon before releasing the cubesats, and then relays their data to the Earth after they impact. We are also designing a 3-unit cubesat that may be capable of reaching the Moon without a mother ship.

8739-3, Session 1

Large diffractive/refractive apertures for space and airborne telescopes

Howard A. MacEwen, Reviresco LLC (United States); James B. Breckinridge, Breckinridge Associates, LLC (United States); Richard L. Baron, EFOS Corp. (United States)

Over the past decade, a number of projects have addressed the possibility of replacing the main aperture in large space telescopes with a much lighter, more easily packaged and deployed, diffractive/refractive membrane transmissive optical element. In particular, these projects have included the Lawrence Livermore (LLNL) Eyeglass and the DARPA MOIRE program. A new innovative approach to the theory of the diffractive and refractive effects and the fabrication of large membrane optics will be given and analyses presented to show how a broadband and high transmission diffractive/refractive membrane would be developed. Potential applications will be drawn from both the defense and astronomical communities:

- Geosynchronous surveillance satellites
- Space situational awareness and debris detection
- Active surveillance systems (i.e., lidar) for defense and planetary observation
- Unmanned aerial surveillance, both recoverable and expendable
- Balloon-borne astronomical observations
- Very large space astrophysical observatories for the UV through NIR spectra

8739-4, Session 1

An onboard computing system design for a remote sensing cubesat

Jeremy Straub, The Univ. of North Dakota (United States)

This paper focuses on the onboard computing subsystem for a 1U CubeSat, comprised of standard subsystems (excluding propulsion) and a payload consisting of a visible light camera, a limited radio science package and a GPS receiver. The craft also features extensive onboard computing capabilities for performing mosaicking, super-resolution and rudimentary image feature identification and analysis. The onboard computing subsystem consists of a flight computer based on the ATMEL AT91SAM9G20 chipset and a supplemental processing unit based on GumStix computer-on-module (COM) units.

The key design requirement, having an always-on primary processing unit and supplemental capabilities (including a digital signal processor) that can be powered up on an as-needed basis, is discussed and requirement-satisfaction is evaluated. The performance of the supplemental processing unit (in both single and double COM modes) for model-based transmission reduction (MBTR) and mosaicking is characterized, based on an analysis and comparison to the performance of these technologies running on conventional computer hardware. Based on this, a characterization of the prospective mission-utility (the amount of effective knowledge that can be collected, processed and

conveyed to Earth) is presented comparative to a traditional mission approach.

An overview of the spacecraft's design and mission operations plan is presented. The numerous trades required to allow the requisite payload and onboard processing hardware to fit within the size and weight limitations posed by the 1U CubeSat form factor are discussed. Finally, the paper concludes with a review of the functionality provided by the spacecraft and the future capabilities that this functionality will facilitate.

8739-5, Session 1

Mission design and operations of a constellation of small satellites for remote sensing

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The Hawaii Space Flight Laboratory (HSFL) at the University of Hawaii at Manoa is developing the capabilities to design, build, and operate constellations of small satellites than can be tailored to efficiently execute a variety of remote sensing missions. With the Operationally Responsive Space (ORS) Office, HSFL is developing the Super Strypi launch vehicle that on its initial mission in 2013 will launch the HSFL 55-kg HawaiiSat-1 into a near polar orbit, providing the first deployment of these technologies. This satellite will be carrying a miniature hyperspectral thermal imager developed by the Hawaii Institute of Geophysics and Planetology (HIGP). HSFL has also developed a method to efficiently deploy a constellation of small satellites using a minimal number of launch vehicles.

Under a three-year NASA grant, HSFL is developing a Comprehensive Open-architecture Space Mission Operations System (COSMOS) to support these types of missions. COSMOS is being designed as a System of Systems (SoS) software integrator, tying together existing elements from different technological domains. This system should be easily adaptable to new architectures and easily scalable. It will be provided as Open Source to qualified users, so will be adoptable by even universities with very restricted budgets. In this paper we present the use of COSMOS as a System of Systems integrator for satellite constellations of up to 100 satellites and numerous ground stations and/or contact nodes, including a fully automated "lights out" satellite contact capability.

8739-6, Session 2

Design of ground motion compensation servo system

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There is relative motion between staring imager loaded in low orbit satellite and detected aim during exposure time, so the target image recorded in detectors is moved and blur. Thus it is necessary to compensate image shift especially in high resolution aerospace imaging due to the limitation of MTF (Modulation Transform Function). There are several methods for image compensation, for swing mirror compensation, if the swing pointing mirror is installed in the part of object, the whole system's scan range could be large and observe low speed dynamic aims. To eliminate the image shift, the swing pointing mirror has to swing at certain speed during satellite's forward flight, so how to design the servo system of swing compensation mirror is a key to achieve image compensation. This paper designs and simulates an image compensation control system base on swing pointing mirror compensation. The principle of pointing mirror compensation is presented and the mathematical model of pointing mirror's driving motor is established. Based on this model, a high accuracy controller which consists of current loop and velocity loop is designed and simulated. Considering that there is disadvantage of traditional speed PID controller in dynamic performance, which is speed overshoot, the speed loop adopts pseudo derivative feed-forward (PDFF) controller. Theoretical analysis and simulation results show that the designed image compensation control system has good characteristic in following performance, dynamic response and noise resistance.

8739-7, Session 2

Rapid orbital characterization of local area space objects utilizing image-differencing techniques

Paul McCall, Florida International Univ. (United States); Madeleine Naudeau, Air Force Research Lab. (United States); Marlon Sorge, The Aerospace Corp. (United States); Thomas Farrell, Schafer Corp. (United States); Malek Adjouadi, Florida International Univ. (United States)

Satellites in geostationary orbit have limited awareness of nearby objects that might pose a collision hazard. Small, relatively inexpensive on-board optical local area sensors often have limited performance. Proposed are methods to increase the Local Area Awareness provided by such sensors by means of classical and novel image processing techniques. This analysis utilizes image differencing-based techniques, in the development of a detection algorithm and for a novel object-velocity classifier, providing a means of rapidly distinguishing local area objects that pose a possible collision or interference hazard. The latter part of the aforementioned analysis may provide an accelerated means of determining if there is cause for concern of local area objects when an orbital two-line element set is not available. The research presented in this paper focuses on a viable alternative to signal-to-noise ratio intensity-based detection method by proposing a variance-based technique utilizing the stellar background as a reference. The observed object is simulated having multiple orbits, which consists of nearby circular orbits or possible debris orbits, which bring the object within the local area of the observing satellite. This alternative detection method is of significance as it may allow for detection of objects within the local area of the observing geostationary satellite in conditions or environments when the signal-to-noise ratio of the object is sufficiently low. Results presented in this paper further demonstrate the ability of the proposed classifier to provide a means of rapidly distinguishing objects that pose a possible collision or interference hazard within the local area of the sensor platform or observing satellite.

8739-8, Session 2

A close proximity assessment and communications relay satellite for corrective measure determination

Atif Mohammad, Jeremy Straub, The Univ. of North Dakota (United States)

The assessment of physical and other problems with a deployed satellite is a significant challenge, due to the lack of a direct mechanism for ascertaining information about its state. Physical defects or attitude may render the spacecraft incapable of communication with the Earth's surface; logical failures may result in unintended responses to issued commands. Numerous examples of satellites that have experienced loss-of-control problems exist; one such example is the University of Michigan's M-Cubed spacecraft which was believed to be coupled with the E1-P spacecraft (potentially due to insufficient P-POD launch separation).

The Open Space Box (OSB) framework is designed to support recovery in a post-catastrophe situation. This is accomplished via a low-level interrogation-response mechanism that allows state data and stored data products to be accessed, with proper authentication. This paper details a prospective assessment and recovery mission that could be conducted, using a 6-U CubeSat to attempt to restore service and recover data from

a failed high-value spacecraft. The OSB protocol used for this service recovery is detailed. Mission plans for an OSB versus non-OSB recovery and data retrieval (R&DR) missions are presented and compared. Based on this, the value of the OSB framework, for facilitating (comparatively) low-cost R&DR from a high-value spacecraft using a low-cost, small spacecraft is ascertained. The potential for utilizing this technology on planetary science and other more distant missions is also assessed. The changes that would be required are identified and presented.

8739-9, Session 2

Above the cloud computing: creating an orbital service model using cloud computing techniques

Jeremy Straub, Atif Mohammad, The Univ. of North Dakota (United States); Josh Berk, Anders K Nervold, University of North Dakota (United States)

Traditionally, large satellites and interplanetary spacecraft have been self-contained. Each craft includes the capabilities required for mission completion. As a result, the spacecraft carries hardware that is only occasionally utilized, despite incurring its full development and launch costs. Smaller spacecraft cannot use this approach. Due to mass and volume constraints, they cannot carry numerous pieces of scarcely utilized equipment. This paper proposes a cloud computing / service-oriented architecture model for exposing satellite services in an orbital environment. Under this approach, each satellite with available capabilities broadcasts a service description for each service that it can provide (e.g., general computing capacity, DSP capabilities, specialized sensing capabilities, transmission capabilities, etc.) and its orbital elements. Consumer spacecraft retain a cache of service providers and select one utilizing decision making heuristics (e.g., suitability of performance, opportunity to transmit instructions and receive results – based on the orbits of the two craft). The two craft negotiate service provisioning (e.g., when the service can be available and for how long) based on the operating rules prioritizing use of (and allowing access to) the service on the service provider craft and the credentials of the consumer. Service description, negotiation and performance protocols are presented. The required components (e.g., autonomous control and a lightweight orbit determination routine) of participating (consumer or provider) spacecraft are reviewed. The system's performance is compared to traditional approaches, in terms of task performance (e.g., quality and time) and task performance as a function of cost. It is also compared to other spacecraft control architectures.

8739-11, Session 4

PICARD payload thermal control system and general impact of the space environment on astronomical observations

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PICARD is a spacecraft dedicated to the simultaneous measurement of the absolute total and spectral solar irradiance, the diameter, the solar shape, and to the Sun's interior probing by the helioseismology method. The mission has two scientific objectives, which are the study of the origin of the solar variability, and the study of the relations between the Sun and the Earth's climate. The spacecraft was successfully launched, on June 15, 2010 on a DNEPR-1 launcher.

PICARD spacecraft uses the MYRIADE family platform, developed by CNES to use as much as possible common equipment units. This platform was designed for a total mass of about 130 kg at launch. This paper focuses on the TCS (Thermal Control System) design, testing, and first in-orbit performances of the payload, which mainly consists in two absolute radiometers measuring the total solar irradiance, a photometer measuring the spectral solar irradiance, a bolometer, and an imaging telescope to determine the solar diameter and asphericity. Thermal control of the payload is fundamental. The telescope of the PICARD mission is the most critical instrument.

To provide a stable measurement of the solar diameter to few milliarcseconds over three years duration of mission, telescope mechanical stability has to be excellent intrinsically, and thermally controlled. Current and future space telescope missions require ever-higher dimensionally stable structures. Main difficulty was with respect to scientific performances to ensure the thermal stability of the instruments. Space is a harsh environment for optics with many physical interactions leading to potentially severe degradation of optical performance. Thermal control surfaces, and optics of the payload are exposed to space environmental effects including contamination, atomic oxygen, ultraviolet radiation, and vacuum temperature cycling. Environmental effects on the performance of the payload will be discussed.

Telescopes are placed on spacecraft's to avoid the effects of the Earth atmosphere on astronomical observations (turbulence, extinction, ...). Atmospheric effects however may subsist when satellites are launched in low orbits, typically mean altitudes of the order of 700 km.

8739-12, Session 4

Optical analysis of a membrane photon sieve space telescope

Olha Asmolova, Air Force Academy (United States); Geoff P. Andersen, HUA, Inc. (United States); Michael E. Dearborn, U.S. Air Force Academy (United States)

We present FalconSat-7, a CubeSat satellite being constructed at the US Air Force Academy. In a world's first we plan to image the Sun using a deployable membrane primary. In this case the optic is a photon sieve - a diffractive optic consisting of billions of tiny circular pads on a transparent polymer substrate. The 20cm telescope is optimized for H-alpha imaging (656nm) and deployed from a satellite with a total volume of just 3U (30cmx10cmx10cm).

Diffractive optics are a promising technology for creating ultra-large space telescope primaries deployed from compact packages. Aside from being lightweight and compactable, the use of flat optics greatly reduces engineering constraints over conventional reflective elements. At the US Air Force Academy, cadets and faculty are constructing FalconSat-7: a membrane solar telescope deployed from a 3U CubeSat. In a world's first we plan to demonstrate the deployment of a membrane primary to image the Sun at H-alpha (656nm) wavelengths. The primary in question is a photon sieve – a diffractive optic consisting of billions of tiny pads on a flat transparent polymer sheet.

Our 20cm-diameter, F/2 primary uses a 25 micron thick zero-CTE polyimide having a mass less than 10 grams. The membrane is pulled taut by a triangular pantograph support structure. The membrane, support structure, secondary optics, camera and associated control electronics are all packaged within just half the overall satellite volume. When deployed in a low Earth orbit the deployed telescope will collect images of the Sun for transmission to a ground station at the Academy. Cadets are involved in every aspect of the project from program management to component design and testing. In this talk we will present results of initial experiments and provide details of zero-G testing and 2014 launch.

8739-13, Session 4

Monitoring and predicting rate of VIIRS sensitivity degradation from telescope contamination by tungsten oxide

Slawomir Blonski, Univ. of Maryland, College Park (United States); Changyong Cao, NOAA/NESDIS/STAR (United States)

VIIRS (Visible-Infrared Imaging Radiometer Suite) instrument was launched onboard the Suomi NPP (National Polar-orbiting Partnership) spacecraft on October 28, 2011. Shortly after the Earth observations with VIIRS began, it was observed that sensitivity of the sensor's several spectral bands decreases with time much faster than expected. The NIR (near infrared) bands have been the most affected by the degradation, but radiometric response of the neighboring visible and SWIR (short-wave infrared) bands has degraded as well. After an investigation, the anomaly resolution team determined that the VIIRS telescope mirror contamination with tungsten oxide is the root cause of the degradation and that the degradation is controlled by exposure of the mirror surfaces to the UV (ultraviolet) illumination, which cannot be reduced on orbit. We have monitored progress of the degradation using both Earth view measurements from the pseudo-invariant Antarctic Dome C site and onboard calibrator measurements of light reflected from the solar diffuser when it is illuminated by the Sun. After the first year of the VIIRS operations on orbit, kinetics of the degradation is best modeled with a three-exponential function, and an additional exponential term does not improve the fit of the model to the solar diffuser measurements. With the largest time constant of 139 days, the model predicts that the degradation will effectively level off during the second year on orbit. By then, radiometric response of the VIIRS bands most affected by the degradation will be reduced by 33%. Despite this loss, VIIRS radiometric sensitivity will remain within the specified requirements.

8739-14, Session 4

Thermoelectric radiation sensors for the space mission BepiColombo to mercury

Frank Hänschke, Ernst Kessler, Ulrich Dillner, Uwe Schinkel, Andreas Ihring, Hans-Georg Meyer, Institut für Photonische Technologien e.V. (Germany); Jörg Knollenberg, Ingo Walter, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

We present a newly designed thermoelectric detector chip of high detectivity for the space mission BepiColombo to Mercury. The sensor is part of the MERTIS radiometer, which enables radiometric measurements in the spectral range from 7-40 micron to study the thermo-physical properties of the planet's surface material.

In collaboration with the DLR Institute of Planetary Research, the Institute of Photonic Technology has developed a sensor array with a specific detectivity D* of 1.1x 10^9 Jones in vacuum environment and 2 x 15 individual readable channels. In addition, it has an optical slit in the middle, which serves as the entrance slit of a spectrometer downstream. The sensor area is coated with an absorbing layer, in this case silver black having an absorption coefficient of nearly 100 percent in a wavelength range from 0.4 up to 20 micron. To minimize the thermal cross talk between the individual pixels, each pixel is separated by a 50 micron slit in the self-supporting silicon nitride membrane. For good mechanical stability of the pixels, the pixel membrane is tensioned by 10 micron bridges like braces. The sensor is electrically contacted with a starr-flex PCB by direct wire bonding and both are mounted on a milled aluminum housing.

At the Institute of Photonic Technology (IPHT), high detectivity radiation sensors are developed and based on the thermoelectric principle. The thermoelectric materials used are the highly effective combination of n-bismuth(87%)-antimony(13%) / p-antimony. The sensors are designed, in the main, as miniaturized multi-junction thermocouples and made by state of the art thin film technologies allowing for achievable and reproducible detectivities D* in the range of 10^8 up to 2x10^9 Jones.

8739-15, Session 4

High-performance, water-absorption free antireflective optical coatings in the short-wave and mid-wave for earth observing optical systems

Adam M. Phenis, Joseph E. Sauvageau, Robert D. Smith II, SAIC (United States); David C. Utley, CEB Metasystems, Inc. (United States)

The performance of space-based earth observing optical systems operating in the short-wave and mid-wave infrared can be severely compromised in throughput due to optical absorption associated with water/hydroxyl groups trapped in various coatings. These systems also require high-performance optical coatings to maximize throughput and reduce stray light. Water (H2O) and hydroxyl groups (-OH) can contaminate an optical coating during the deposition process and via general exposure to water vapor and humid environments throughout assembly, integration and testing prior to deployment. Water incorporated into the film's polycrystalline grain structure, can be trapped in the deposition process and permanently degrade transmission. This presentation will discuss the antireflective optical coating development process including design and specification of the respective coatings, deposition, optical and environmental testing and present a developed and tested coating process with a coating identifier that the general community can use for optical components that serve similar missions.

8739-16, Session 5

Next-generation photonic true time delay devices as enabled by a new electro-optic architecture

Scott R. Davis, Seth T. Johnson, Scott D. Rommel, Neil A. Rebolledo, Michael H. Anderson, Vescent Photonics Inc. (United States)

We present new photonic-true-time-delay (PTTD) devices, which are a key component for phased array antenna (PAA) and phased array radar (PAR) systems. These new devices, which are highly manufacturable, provide a previously unattainable combination of performance characteristics: large time delay tunability and low insertion loss, all in a form factor that enables integration of many channels in a compact package with very modest power consumption. The low size, weight, and power are especially enabling for satellite deployment. These devices are enabled by: i) "Optical Path Reflectors" or OPRs that compresses a >20 foot change in optical path length, i.e., a >20 nsec tuning of delay, into a very compact package (only centimeters), and ii) electro-optic angle actuators that can be used to voltage tune or voltage select the optical time delay. We have designed and built OPRs that demonstrated: large time delay tunability (>30 nsecs), high RF bandwidth (>40 GHz and likely much higher), high resolution (<200 psec), and low and constant insertion loss (< 1 dB and varying by < 0.5 dB). We also completed a full design and manufacturing run of improved EO angle actuators that met the scanner requirements. Finally, a complete optical model of these integrated devices will be presented, specifically; the design for a multi-channel (400 channels) PTTD device will be discussed. The applicability and/or risks for space deployment will be discussed.

8739-17, Session 5

New electro-optic laser scanners for small-sat to ground laser communication links

Scott R. Davis, Scott D. Rommel, Seth T. Johnson, Stephanie M. McMahon, Neil A. Rebolledo, Michael H. Anderson, Vescent Photonics Inc. (United States); Yijiang Chen, Tien-Hsin Chao, Jet Propulsion Lab. (United States)

In this talk we will discuss revolutionary electro-optic beam steering technology and efforts to combine it with optical telecommunication technology, thereby enabling low cost, compact, and rugged free space optical (FSO) communication modules for small-sat applications. Small satellite applications, particularly those characterized as "micro-sats" are often highly constrained by their ability to provide high bandwidth science data to the ground. This will often limit the relevance of even

highly capable payloads due to the lack of data availability. FSO modules with unprecedented cost and size, weight, and power (SWaP) advantages will enable multi-access FSO networks to spread across previously inaccessible platforms. An example system would fit within a few cubic inch volume, require less than 1 watt of power and be able to provide ground station tracking (including orbital motion over wide angles and jitter correction) with a 50 Mbps downlink and no moving parts. This is possible, for the first time, because of emergent and unprecedented electro-optic (EO) laser scanners which will replace expensive, heavy, and power-consuming gimbal mechanisms. In this paper we will describe the design, construction, and performance of these new scanners. Specific examples to be discussed include an all electro-optic beamsteer with a 60 degree by 40 degree field of view. We will also present designs for a cube-sat to ground flight demonstration. This development would provide a significant enhancement in capabilities for future NASA and other Government and industry space projects.

8739-19, Session 5

Demonstration of space optical transmitter development for multiple high-frequency bands

Hung Nguyen, NASA Glenn Research Ctr. (United States)

As the demand for increasingly multiple radio frequency carrier bands continues to grow in space communication system, the design of compact space optical transmitter having the capability of transmitting selective multiple RF bands is of great interest, particularly for NASA Space Communications Network Programs. This paper presents experimental results that demonstrate the feasibility of a concept based on an optical wavelength division multiplexing (WDM) technique that enables multiple microwave bands with different modulation formats and bandwidths to be combined and transmitted all in one unit, resulting in many benefits to space communication systems including reduced size, weight and complexity with corresponding savings in cost. Experimental results will be presented including the individual received RF signal power spectra for the L, C, X, Ku, Ka, and Q frequency bands, and measurements of phase noise associated with each RF frequency. Also to be presented is a swept frequency power spectrum showing simultaneous multiple RF frequency bands transmission. The RF frequency bands in this experiment are among those most commonly used in NASA space environment communications.

8739-20, Session 6

laser ranging with the MéO telescope to improve orbital accuracy of space debris

Laurent Hennegrave, Marine Pyanet, Hervé Haag, EADS Astrium (France); Etienne Samain, Dominique Albanese, Jocelyn Paris, Observatoire de la Côte d'AZUR (France); Guillaume Blanchet, Sophie Vial, Bruno Esmiller, EADS Astrium (France)

Improving orbital accuracy of space debris is one of the major prerequisite to performing reliable collision prediction in low earth orbit. The objective is to avoid false alarms and useless maneuvers for operational satellites. This paper shows how laser ranging on debris can improve the accuracy of orbit determination.

In March 2012 a joint OCA-Astrium team had the first laser echoes from space debris using the MéO (Métrologie Optique) telescope of the Observatoire de la Côte d'Azur (OCA), upgraded with a nanosecond pulsed laser. The experiment was conducted in full compliance with the procedures dictated by the French Civil Aviation Authorities.

To perform laser ranging measurement on space debris, the laser link budget needed to be improved. Related technical developments were supported by implementation of a 2J pulsed laser purchased by ASTRIUM and an adapted photo detection. To achieve acquisition of the target from low accuracy orbital data such as Two Lines Elements, a 2.3-degree field of view telescope was coupled to the original MéO telescope 3-arcmin narrow field of view. The wide field of view telescope aimed at pointing, adjusting and acquiring images of the space debris for astrometry measurement. The achieved set-up allowed performing laser ranging and angular measurements in parallel, on several rocket stages from past launches.

After a brief description of the set-up, development issues and campaigns, the paper discusses added-value of laser ranging measurement when combined to angular measurement for accurate orbit determination. Comparison between different sets of experimental results as well as simulation results is given.

8739-21, Session 6

Large phase angle observations of GEO satellites

Rita L. Cognion, Oceanit Space Surveillance (United States)

Observations of satellites in geosynchronous orbit (GEO) are routinely performed by optical sensors at night when the phase angle—the angle between the satellite's lines of sight to earth and to sun—is less than about 85 degrees. Daytime optical observations of satellites in the GEO belt will be performed at larger phase angles. In afternoon and morning hours, small phase angles are available, but at mid-day the phase angle is constrained to be greater than a minimum value that depends upon the latitude of the sensor and time of year. On Maui at summer solstice, for example, the minimum phase angle is 110 degrees at mid-day for observations of the GEO belt.

In order to predict their visibility during the daytime, observations of GEO satellites were conducted at night with a small-aperture telescope at the large phase angles available soon after dusk and before dawn. Analysis of the satellite images reveals a flattening in the light curve for phase angles greater than 100 degrees, and the data provide an empirical model of the expected satellite signal at all phase angles.

8739-22, Session 6

Conformal prediction for anomaly detection and collision alert in space surveillance

Huimin Chen, Univ. of New Orleans (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh D. Pham, Erik P. Blasch, Air Force Research Lab. (United States)

Anomaly detection has been identified as an important technique for detecting critical events in a wide range of data rich applications where a majority of the data is considered inconsequential, "normal," and/or uninteresting. We consider the detection of anomalous behaviors among space objects using the theory of conformal prediction for distribution-independent on-line learning to provide collision alerts with a desirable confidence level. We exploit the fact that conformal predictors give valid forecasted sets at specified confidence levels under the relatively weak assumption that the (normal) training data, together with (normal) observations to be predicted, have been generated from the same distribution. If the actual observation is not included in the (possibly empty) prediction set, it is classified as anomalous at the corresponding significance level. Interpreting the significance level as an upper bound of the probability that a normal observation is mistakenly classified as anomalous, we can conveniently adjust the sensitivity to anomalies while controlling the rate of false alarms without having to find any application specific thresholds. The proposed conformal prediction method was evaluated for a space surveillance application using recorded data assumed to be normal. The validity of the prediction sets is justified by the empirical error rate which is just below the significance level. In addition, experiments with simulated anomalous data indicate that anomaly detection sensitivity is superior to that of the existing methods in declaring potential collision events.

8739-23, Session 6

Analysis of orbits of hostile satellites

Genshe Chen, Carl Looney, Intelligent Fusion Technology, Inc. (United States); Khanh D. Pham, Erik P. Blasch, Air Force Research Lab. (United States)

The onboard transponders and GPS receivers are not available for tracking hostile satellites, so multiple radars and laser rangers can be used. We transform polar coordinates (r(tn), θ(tn), φ(tn)) at multiple radar sites to Earth Centered Inertial (ECI) coordinates and fuse them by inverse mean-square error weightings. For an ECI state s(tn) = (x(tn), y(tn), z(tn), x´(tn), y´(tn), z´(tn), x˝(tn), y˝(tn), z˝(tn)), we iterate by: 1) reading new values (r(tn+1), θ(tn+1), φ(tn+1)) at tn+1 at each radar, transform to ECI and fuse them to get the new state snew(tn+1); 2) extrapolating the current state s(tn) forward to sex(tn+1); 3) fusing the extrapolated and new states, sex(tn+1) and snew(tn+1), for the updated state s(tn+1) = (x(tn+1), y(tn+1), z(tn+1), x´(tn+1), y´(tn+1), z´(tn+1), x˝(tn+1), y˝(tn+1), z˝(tn+1)). From multiple fused states the perturbed elliptical orbit parameters (eccentricity, semi-major lengths, period) are determined. The ECI position coordinate values over time are analyzed by Fourier components to obtain the major orbit cycle and those due to total perturbation from the Moon, Sun, drag, etc.). The state needs to be re-established every week or so and its changes are a key to determining any threat it poses.

8739-27, Session 7

Blind and beacon-less TDMA scheduling for ad-hoc LEO Satellite communications

Tien M. Nguyen, Raytheon Co. (United States)

Future satellite missions require low SWAP (Size, Weight and Power) RF subsystem architecture that can support UAVs data rates at the order of Gbps for both uplink and downlink. To meet the UAVs communications capacity requirements, the most commonly used multiple access technique employing dual polarization with TDMA will be considered for the CONOPs discussed in this paper with a LEO satellite constellation. Currently, the TDMA technique for LEO requires a beacon (or a pilot tone) to perform TDMA scheduling. Satellite payload requires a beacon system which increases the SWAP requirements. This paper discusses potential approaches using Blind and Beaconless TDMA Scheduling (BBTS) to perform TDMA scheduling including:

- Approach to search for satellite availability
- On-board TDMA scheduling
- Disseminate schedules to UAV platforms

This paper also discusses advantages associated with BBTS including satellite payload SWAP reduction and unknown priori information of the satellite location.

8739-24, Session 8

An efficient QoS-aware routing algorithm for LEO polar constellations

Xin Tian, Intelligent Fusion Technology, Inc. (United States); Khanh D. Pham, Erik P. Blasch, Air Force Research Lab. (United States); Zhi Tian, Michigan Technological Univ. (United States); Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

In this work, a Quality of Service (QoS)-aware routing (QAR) algorithm is developed for low-Earth orbit (LEO) polar constellations. LEO polar orbits are the only type of satellite constellations where inter-plane inter-satellite links (ISLs) are implemented in real world. The QAR algorithm exploits features of the topology of the LEO satellite constellation, which makes it more efficient than general shortest path routing algorithms such as Dijkstra's, extended Bellman-Ford algorithms. Traffic density, priority, and error QoS requirements on communication delays can be easily incorporated into the algorithm through satellite distances. The QAR algorithm also supports efficient load balancing in the satellite network by utilizing the multiple paths from the source satellite to the destination satellite, and effectively lowers the rate of network congestion. The QAR algorithm supports a novel robust routing scheme in LEO polar constellation, which is able to significantly reduce the impact of ISL congestions on QoS in terms of communication delay and jitter. Examples are shown through implementation of a known LEO constellation communicating with a series of dynamic satellites.

8739-25, Session 8

QoS-aware dynamic spectrum access for cognitive radio networks

Xin Tian, Intelligent Fusion Technology, Inc. (United States); Zhi Tian, Michigan Technological Univ. (United States); Khanh D. Pham, Erik P. Blasch, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Ubiquitous wireless networking requires efficient dynamic spectrum access (DSA) among heterogeneous users with diverse transmission types and bandwidth demands. To meet user-specific quality-of-service (QoS) requirements, the power and spectrum allocated to each user should lie inside a power/spectral-shape bounded region in order to be meaningful for the intended application. Most existing DSA methods aim at enhancing the total system utility. As such, spectrum wastage may arise when the system-wide optimal allocation falls outside individual users' desired regions for QoS provisioning. In this work, novel QoS-aware DSA algorithms are developed for both non-cooperative and cooperative users in cognitive radio (CR) networks. The algorithms maximize the "useful utilities" to the users, and minimize the power consumption and mutual interference within the CR network. In addition, the proposed algorithms can be used with a Frequency Agile Waveform Adaption (FAWA) framework, where generalized signal expansion functions can not only represent physical-layer radio resources but also synthesize the transmitter and receiver waveforms. The FAWA framework in combination with the notion of useful utilities, two procedures that are currently carried out separately, provides a joint solution of QoS-aware Dynamic Resource Allocation with waveform adaptation.

8739-26, Session 8

Spatial-proactive routing algorithm (SPRA) algorithms for IP-based satellite networks

Wei Yu, Sixiao Wei, Guobin Xu, Chao Lu, Towson Univ. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh D. Pham, Erik P. Blasch, Air Force Research Lab. (United States)

The defense satellite communication system (DSCS) seeks to provide worldwide high-volume and secure communication infrastructure for supporting real-time voice and data communication. Nevertheless, the lack of network resources in satellite networks is a major issue for supporting a large number of war-fighting users, who seek to transmit imagery data, provide networking for navigation, and support secure data communications for mission critical applications.

To address this issue, we introduce a unique framework and develop novel IP routing algorithms over satellite networks, which link user preferences and network conditions to improve end-to-end performance. Our proposed framework adopts a cross-layer design and considers the characteristics of satellite networks (e.g., heterogeneity on satellite nodes, interferences of satellite links, and others). We propose a Spatial-Proactive Routing Algorithm (SPRA) on satellite networks that allow users to bargain based on the traffic priority, flow characteristics, and satellite link quality. For SPRA, we consider both the Single-Path

Spatial-Proactive Routing Algorithm (SP-SPRA) and the Multiple-Path Spatial-Proactive Routing Algorithm (MP-SPRA), which can be formalized as an integer multi-commodity flow problem. SP-SPRA can guarantee the flow arrived at the destination is in sequence, while MP-SPRA can increase network throughput and resource utilization. We also develop the Multilevel Precedence and Preemption Service (MLPP) at both packet and flow levels in satellite networks to conduct bandwidth guarantee for transmitting data demanded by urgent needs. Via the combination of theoretical analysis and simulation study, we evaluate of our proposed routing algorithms for enhanced DSCS performance.

8739-28, Session 8

On effectiveness of digital signal processing and image-based intrusion detection techniques for cyber security situation awareness

Wei Yu, Xiao Wei Shi, Guobin Xu, Chao Lu, Towson Univ. (United States); Misty Blowers, Erik P. Blasch, Khanh D. Pham, Air Force Research Lab. (United States); Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Networking technologies are growing explosively to meet worldwide social, business, military, and commercial communication needs. Because networks are vulnerable to various types of attacks, there is an urgent call for cyber security methods. To conduct cyber security situation awareness including both situation assessment and attack mitigation, we investigate both digital signal processing and image processing detection techniques to accurately track anomalies in network traffic.

Our contributions in this paper are listed below. First, we develop the digital signal processing technique to detect stealth attacks, which dynamically manipulate attack traffic. Using collected real-world traffic data and simulated representative attacks, test scenarios are created. Based on mixture traffic, a discrete wavelet transform (DWT)-based detection algorithm is compared with a network traffic volume (NTV)-based detection algorithm. Second, we develop algorithms to transform real-world network traffic information (i.e., IP source and detection addresses) into images and develop the image-based detection to effectively learn the pattern of attacks and predict future attacks. To highlight the critical information in the image, a novel gray-scale image representation uses luminance to highlight the intensity of traffic anomaly. The image-based toolset provides an intelligent user a top-down systems-level perspective of traffic anomalies. Third, we present algorithms to identify the attack patterns in images based on the correlation of source and destination addresses. Our experimental data show that our cyber image-based intrusion detection (CI2D) techniques can detect stealthy attacks, including worm/malware propagation denoted as many-to-many attacks, distributed denial-of-service threats denoted as many-to-one attacks, and scan threats denoted as one-to-many attacks.

8739-29, Session 8

RSD-WSN: remote source-level debugger for rapid application development in wireless sensor networks

Mohammad Mozumdar, California State Univ., Long Beach (United States); Weiyuan Bian, Politecnico di Torino (Italy); Jose Perez, California State Univ., Long Beach (United States); Luciano Lavagno, Politecnico di Torino (Italy)

The landscape of Wireless Sensor Network (WSN) applications has been extending rapidly in many fields such as factory and building automation, environmental monitoring, security systems and in a wide variety of commercial and military areas. Developing and verifying of WSN applications is very challenging, because most of the available sensor nodes on the market (such as MicaZ, TelosB, Tmote Sky, etc.) only provide a few on-board blinking LEDs as debug aids. This makes code development on the actual platform virtually impossible. Although Hardware-In the Loop (HIL) debugging has been commonly used for debugging single embedded device, but it cannot be applied to WSNs easily. Because WSN nodes could be located in multi-hops distance, and hence direct physical connection to node is not feasible. In RSD-WSN framework, we propose a framework that connects wirelessly with a multi-hop distance node and synchronizes clock to debug application behavior in real time. This framework allows a programmer to develop an application using high level abstractions (Finite State Machine) and then automatically generate code for target platforms. The complied generated code could be then directly mounted on sensor nodes and the RSD-WSN framework provides interfaces by which an application developer can bind execution sequences of a remote sensor node with a virtual simulated node, so that the developer can monitor node behavior and refine the application in case of unexpected behavior.

8739-30, Session 9

Multiple sensor estimation using high-degree cubature information filter

Jia Bin, Columbia Univ. (United States); Ming Xin, Mississippi State Univ. (United States); Khanh D. Pham, Erik Blasch, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

In this paper, high-degree cubature information filter is proposed for multiple sensor estimation. The statistical linear error propagation method is used to incorporate the high-degree cubature rules into the framework of the extended information filter. The new proposed information filter is more flexible to use due to the fact that a different number of points and accuracy levels can be chosen to achieve arbitrarily higher estimation accuracy than the extended information filter and the unscented information filter. In addition, the high-degree cubature information filter can achieve a close performance to the highly accurate Gauss-Hermite information filter. However, it does not suffer the curse of dimensionality problem existing in the Gauss-Hermite information filter since the cubature points only increase polynomially with the dimension. Therefore, it is computationally more efficient to obtain arbitrary degree of accuracy. The performance and robustness of this new information filter is compared with other information filters via a target tracking problem. The high-degree cubature information filter is shown to be the best in terms of both estimation accuracy and computational efficiency.

8739-31, Session 9

The Doppler wind and temperature sounder: enabling next-generation weather and space weather forecasts

Martin J. McHugh, Larry L. Gordley, David F. Fritts, GATS, Inc. (United States); Wayne F. J. Evans, NorthWest Research Associates (United States); Benjamin T. Marshall, GATS, Inc. (United States)

Over the last decade it has been established that medium to long range weather patterns are significantly affected by stratospheric events. However, existing observations of the dynamical atmosphere above the tropopause are sparse and irregular, and remote measurements of upper atmospheric winds have historically proved challenging. Current numerical models must rely on data from widely separated land-based instruments and satellite observations with modest precision and coverage. Even less plentiful are observations of the neutral atmosphere above 100 km, despite the high potential impact of space weather on global navigational and electrical systems. We present here a new instrument concept, the Doppler Wind and Temperature Sounder

(DWTS) that will enable global daily measurements of temperature and horizontal wind fields from 15 to 250 km. The measurement concept leverages the high spectral resolution inherently available with gas-filter correlation radiometry. By exploiting the Doppler shifts resulting from a limb-viewing low Earth orbit satellite, DWTS spectrally resolves large ensembles of atmospheric emission features. From this, we extract kinetic temperature and horizontal wind vectors with unprecedented precision. We review the measurement concept, present simulation results, and conclude by describing a low-cost operational system that would quantify atmospheric dynamics from the lower stratosphere into the mid thermosphere for the first time.

8739-32, Session 9

A highly sensitive multi-element HgCdTe e-APD detector for IPDA lidar applications

Jeff Beck, DRS RSTA, Inc. (United States); Mark Skokan, Richard Scritchfield, DRS Sensors & Targeting Systems, Inc. (United States); Chris Kamilar, Terry Welch, James M. McCurdy, DRS RSTA, Inc. (United States); Pradip Mitra, DRS Technologies, Inc. (United States); Xiaoli Sun, James Abshire, NASA Goddard Space Flight Ctr. (United States); Kirk Reiff, Analog Digital Integrated Circuits (United States)

The HgCdTe electron avalanche photodiode (e-APD) is a unique APD that provides visible to IR sensitivity with high gain. This device is notable due to that fact that the gain is “noiseless” (excess noise factor near unity) and very uniform. The fact that it provides photon level sensitivity from the visible to the IR opens up a range of active electro-optics systems applications.

NASA Goddard Space Flight Center (GSFC) is currently developing CO2 LIDARs at 1.57µm wavelength for the Active Sensing of CO2 Emission over Days, Nights, and Seasons (ASCENDS) mission. One of the major technical challenges is photodetectors that must operate in the short wave infrared wavelength region with photon level sensitivity requirements. A HgCdTe e-APD approach is being developed which promises significant improvements in current technology, and extended response out to 1.65 µm for CH4 detection. The HgCdTe APD SWIR detector assembly is expected to improve the receiver sensitivity of the CO2 LIDAR by at least a factor of two with high dynamic range.

A 4x4 APD array, ROIC, Dewar, and support electronics were designed for an ASCENDS demonstration sub-system. The APD arrays met the dark current specification in all pixels and the goal dark current in the center 4 pixels. For example, one representative APD had a specification compliant gain of 170 and gain normalized dark current of 4.5 fA. The ROIC provides a 10 MHz bandwidth with low noise and 21 selectable gains. Performance of the detector, ROIC, and integrated system will be presented.

8739-33, Session 9

Designing optimized lightweighted a 700mm diameter mirror and structures made of sic for spaceborne EO/IR telescope

Haengbok Lee, Agency for Defense Development (Korea, Republic of)

Silicon carbide(SiC) is a new type of telescope material developed in recent years for space applications due to its attractive properties such as high stiffness, low density, low CTE, high thermal conductivity, big special heat, long term stability against varying thermal loads and potential cost and schedule. The combination of its high stiffness, low CTE, low density and good thermal conductivity, make SiC one of the more appropriate material for the space opto-mechanical applications.

In this paper, we address a design trade studies that explores the structural views for the lightweight primary mirror was fabricated by both reaction bonded (RB)sic, sintered sic and chemical vapor deposition (CVD) sic process as well as the metering structure in sub-metric GSD class spaceborne EO/IR telescope.

8739-34, Session 9

Engineered plasma interactions for geomagnetic propulsion of ultra-small satellites

Jeremy A. Palmer, System Planning Corp. (United States); Thomas P. Hughes, Jeremiah J. Boerner, Guy R. Bennett, Sandia National Labs. (United States)

Previous astrophysical studies have explained the orbital dynamics of particles that acquire a high electrostatic charge. In low Earth orbit, the charge collected by a microscopic particle or an ultra-small, low-mass satellite referred to here as an attosat, interacts with the geomagnetic field to induce the Lorentz force which, in the ideal case, may be exploited as a form of propellantless propulsion whereby Earth’s rotational kinetic energy is indirectly converted to useful work. In specific orbits, an attosat consisting of a multi-chip module with mass not exceeding 0.01 kg may realize Lorentz augmented orbits by modulating electrostatic charge, the magnitude of which is impacted by its mass, materials, geometry; and interactions with the ionosphere’s neutral magnetized plasma. Efficient mechanisms for negative and positive electrostatic charging of an attosat are proposed considering material, geometry, and emission interactions with the ionosphere’s neutral plasma with characteristic Debye length. A novel model-based plasma physics study was undertaken to optimize the positive charge mechanism quantified by the system charge-to-mass ratio. In the context of the practical system design considered, a positive charge-to-mass ratio on the order of 1.9?10-9 C/kg is possible with maximum spacecraft potential equal to the sum of the kinetic energy of electrons from active field emission (+43V) and less than +5V from passive elements. The maximum positive potential is less than what is possible with negative electrostatic charging due to differences in thermal velocity and number density of electronic and ionic species. These insights are the foundation of a practical system design.

8739-36, Session 9

Long-integration star tracker image processing for combined attitude-attitude rate estimation

Brad Sease, University of Central Florida (United States); Ryan Koglin, The Univ. of Akron (United States); Brien Flewelling, Air Foce Research Lab. (United States)

Typical star trackers require the precise centroid information of multiple stars for attitude determination.

In fact, as rotation rates increase for a fixed exposure, star tracker attitude accuracy necessarily decreases. The proposed algorithm utilizes streaked star camera information contained in a single image to provide past and present attitudes, as well as rate estimation. Streaked star camera images are generated from a pinhole camera model applied to the Hipparcos star catalog. Morphological image processing reduces noise inherent to the camera system as well as low SNR streaks, and centroiding identifies contiguous areas of interest. Endpoints of individual star streaks are localized through traditional corner detection methods. Multiple corner detection methods are implemented and compared, including the Harris Corner Detector, the Minimum Eigenvalue Method, and the Trajkovic 4- and 8- Neighbor methods [1, 2]. Discovered endpoints are grouped according to time of occurrence by considering a least-squares solution for the center of rotation as projected into the image plane. Each set is identified against the reference catalog as in a typical star tracker [3]. Preliminary Monte Carlo simulation results indicate rate estimates within 2% of actual. Single endpoint attitude accuracies for various methods and camera boresight orientations with respect to rotation axis are shown below. The algorithm has potential to be used in conjunction with or as an alternative to satellite systems' IMU components.

Future work will focus on reducing computation cost for continuous operation as well as feedback in closed-loop attitude control systems.

8739-35, Session 10

A color component texture approach to locate a vehicle license plate

Jianjun Gao, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Erik P. Blasch, Khanh D. Pham, Air Force Research Lab. (United States)

License plate recognition is popular for highway monitoring and robust methods would enable future options such as toll-payment primary lane user validation, and parking validation to enable smoother traffic flows. To locate the vehicle license plate is the first key problem to solve in automatic vehicle license recognition within an image. Based on color composition analysis, this paper provide a novel approach of color component texture location. As we know the ordinary vehicle license plates have fixed colors for the letters and a known background picture. The color of the plate base is the background which seeks to have a distinguishing color contrast with the letters. The most common approach is to decompose the license plate into sub-blocks, and every block in the plate consists of one or two of the plate colors within a block. This method involves heavy calculations which results in low efficiency. Considering the two base colors of block is the co-existing color texture of license plate, we only need to recognize the two colors as adjacent colors based on edges. The calculation of this method is shown to have lower computational costs versus the common approach and thus is higher cost effective. The experiment with 200 plate pictures in various conditions shows 98.5% location rate. Integrated with a the neural network to recognize the license plate colors, NN functions from OpenCV are used to calculate the color edge detections, and denoise calculations. The approach shows high accuracy and robustness even in skew, blurred , noisy, and various lighting conditions.

8739-37, Session 10

A fuzzy-logic based approach to color segmentation

Wei Li, Tianjin Univ. (China) and California State Univ., Bakersfield (United States); Yunyi Li, Duke Univ. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Quoxing Zhao, Qinghao Meng, Tianjin Univ. (United States)

Image segmentation is a fundamental issue in image processing and computer vision. Especially, color images can provide much more information than gray-level, so algorithms for color image segmentation have attracted more and more attention. A number of image segmentation techniques have been proposed in past decades. However, most of the proposed techniques provide a crisp segmentation of images, where each pixel is classified into a unique subset. This classification may not reflect an understanding of images by human very well, as the image segmentation problem is basically one of psychophysical perception, and therefore not susceptible to a purely analytical solution.

This paper presents an approach to segmenting colors in an image using fuzzy logic. Its basic idea is to use a color extractor (FCE) to measure color similarity for segmentation. In this study, colors in an image are described in the RGB space, where colors are represented by their red, green, and blue components in an orthogonal Cartesian space. The color of each pixel is processed to separate its red, green, and blue components. The FCE extracts a cluster of colors based on the color component differences between the pixel and a defined color pattern CPRGB. A color segmentation algorithm iteratively applies the FCE to segment the entire image. The experiments demonstrate the effectiveness and robustness of the proposed algorithms.

8739-38, Session 10

A holistic image segmentation framework for cloud detection and extraction

Dan Shen, Intelligent Fusion Technology, Inc. (United States); Haotian Xu, Temple Univ. (United States); Erik P. Blasch, Khanh D. Pham, Gregory Horvath, Air Force Research Lab. (United States); Zhonghai Wang, Intelligent Fusion Technology, Inc. (United States); Haibin Ling, Temple Univ. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Clouds are a commonly encountered phenomena associated with aerial or or space-borne visual tracking with electro-optical sensors. Generally clouds are difficult to detect and extract/segment because they are complex in shape and vary with the lighting conditions. In this paper, we propose a clustering game-theoretic image segmentation (CGIS) based approach to detect, identify, and segment clouds. In our framework, the first step is to decompose a given image containing clouds. We consider the problem of image segmentation as a "clustering game". Within the clustering game context, the notion of a cluster turns out to be equivalent to a classical equilibrium concept from game theory, as the game equilibrium reflects both the internal and external cluster conditions. To obtain the evolutionary stable strategies, we explore three evolutionary dynamics: fictitious play, replicator dynamics, and infection and immunization dynamics (InImDyn). As for the second step, we use the shape and color features of known cloud types (e.g., cirrus, stratus, and cumulus) to refine the cloud segments and lower the false alarm rate. In the third step, we will remove cloud-like objects (such as glaciers or white buildings) based on the paring of clouds and shades (which are also segments extracted in the first step). We demonstrate our cloud detection framework on a video clip and obtain supportive results. We also apply the segmentation results for cloud region inpainting using region replication approaches. The results support all-weather full-motion video tracking.

8739-39, Session 10

Infrared target tracking using multiple instance learning with adaptive motion prediction and spatially template weighting

Xinchu Shi, Institute of Automation (China) and Temple Univ. (United States); Weiming Hu, Institute of Automation (China); Yun Cheng, Hunan University of Humanities, Science and Technology (China); Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Jingjing Ji, Temple University (United States); Haibin Ling, Temple Univ. (United States)

In this paper, we formulate the problem of infrared target tracking as a binary classification task and extend the online multiple instance learning tracker (MILTracker) for the task. Compared with many color or texture based tracking algorithms, the MILtracker highlights the difference between the target and the background or similar objects, and is thus suitable for infrared target tracking which undergoes serious textual information loss. To address the specific challenges in the infrared sequences, we extend the original MILtracker from two aspects. Firstly, an adaptive motion prediction procedure is integrated in to enhance the efficiency of the tracker. This step helps discriminate disturbing objects that are visual very similar to the target under tracking. Secondly, a spatial weight mask is introduced into the target representation to augment its robustness against similar background clutters, especially distracters. We apply the proposed approach on several challenging IR sequences. The experimental results clearly validate the effectiveness of our method with encouraging performances.

Conference 8740: Motion Imagery Technologies, Best Practices, and Workflows for Intelligence, Surveillance, and Reconnaissance (ISR), and Situational Awareness

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8740-1, Session 1

Overcoming ISR data challenges

David Bottom, National Geospatial-Intelligence Agency (United States)

The accelerating growth in motion imagery and other ISR data presents a major challenge to Information Technology (IT) organizations. This paper will exam those challenges as relates to the NGA mission and strategic objectives. The paper will focus on creating an open IT environment that will facilitate tools that provide the GEOINT analysts with an integrated workspace to perform their evolving role. It will also look at how this environment can support the use of motion imagery and other ISR data to support activity based intelligence.

8740-2, Session 1

The convergence of GEOINT and ISR

Michael G. Lee, Blue Canopy Group, LLC (United States)

This paper will address the integration of FMV into the larger GEOINT enterprise and how industry can support this objective. When FMV is paired with other technology it can be a major source for persistent surveillance. The paper will compare traditional GEOINT and persistent imagery surveillance. FMV fills a number of gaps in the GEOINT enterprise and these are things industry can help with. The paper will elaborate on these and provide some Do's and Don'ts to be considered.

8740-3, Session 1

Activity based intelligence

Collin Agee, U.S. Army (United States)

Activity Based Intelligence (ABI) is a neophyte sub-discipline of intelligence. In the past decade, there have been significant advances in collection in the form of Wide Area Persistent Surveillance (WAPS) and advanced analytics, its operational employment is in the nascent stage. This presentation will provide an operational perspective, setting the stage by reviewing the evolution of Wide Area Surveillance (WAS), looking at both collection and Processing, Exploitation and Dissemination (PED), and discussing the applications from the past decade of conflict. It will posit the tremendous potential of ABI, as the logical maturation of WAS, but also as an integrating analytical approach to Multi-INT Intelligence. It will examine the explosive growth in collection, which some have characterized as "swimming in sensors, drowning in data," which necessitates some combination of data compression and data reduction. And it will consider the relevance of ABI to meet future challenges, beyond the immediacy of the COIN challenge that has driven early development.

8740-4, Session 1

Uses of motion imagery in activity-based intelligence

Tom Lash, SAIC (United States)

No abstract available.

8740-5, Session 1

Low-power multi-camera system and algorithms for automated threat detection

David J. Huber, Deepak Khosla, Yang Chen, Darrel J. Van Buer, Kevin Martin, HRL Labs., LLC (United States)

A key to any robust automated surveillance system is continuous, wide field-of-view sensor coverage and high accuracy object-of-interest (i.e., target) detection algorithms. Newer systems typically employ an array of multiple fixed cameras that provide individual data streams, each of which is managed by its own processor. This array can continuously capture the entire field of view, but actual data collection and back-end detection algorithm processing consumes additional power and increases the Size, Weight, and Power (SWaP) of the package. This is often unacceptable, as many potential surveillance applications have strict system SWaP requirements.

In this paper, we present a wide field-of-view video system that employs multiple fixed cameras and exhibits SWaP similar to a single-camera system without compromising the detection rate. To do this, we cycle through the sensors, fetch a fixed number of frames from each, and process them through a modified target detection algorithm. During this time the other sensors remain powered-down. Since we don't process all of the sensors simultaneously, we reduce both the number of processors required for detection and the power requirements of the system. We show that the small gaps in coverage and irregular frame rate from the method do not affect the detection rate of the underlying detection algorithms. With this approach, we were able to reduce the power of a ten-camera system by approximately 10x compared to the baseline normal operation. This work was applied to Phase 2 of DARPA Cognitive Technology Threat Warning System (CT2WS) program and used during field testing.

8740-6, Session 1

Delivering FMV in tactical (low bandwidth) environments

John Snevely Jr., U.S. Dept. of Defense (United States)

Mr. Snevely will present a paper on the challenges and opportunities for delivering Full Motion Video (FMV) in tactical (low bandwidth) environments. He will discuss the current and planned Military Service posture for access and dissemination of motion imagery through the Department's Distributed Common Ground/Surface Systems (DCGSs). Mr Snevely will also examine the considerations and limitations for Motion Imagery in this constrained environment.

8740-7, Session 2

Transporting live video over high packet loss networks

Dave Werdin, Superior Access Solutions (United States)

Deep Packet Recovery (DPR) Technical Overview

DPR technology provides correction to network induced issues including Jitter, Out of Order Packets, Dropped Packets, and Burst Loss. DPR is designed to provide much broader and stronger protection than traditional Forward Error Correction techniques enabling transport of live video across severely impaired networks.

The DPR packet recovery mechanism is essentially a buffer

management system that is based on a Negative Acknowledgment with Retransmission. The video packet stream runs continuously from source to destination with the DPR process monitoring the packet arrival characteristics at the destination end of the link.

Packets are de-jittered and re-ordered at the destination end as necessary. If the system discovers missing or corrupt packets, a request to retransmit the missing packets is sent to the source end of the link. The missing packets are then sent from the source to the destination end and inserted into the egress buffer of the system. The retransmission request and the retransmitted packets flow over unique UDP ports across the same physical connection as the video. The system has the ability to request and retransmit missing packets several times as the network may also drop retransmitted packets. The ability to attempt retransmission multiple times is required in high packet loss networks.

The DPR system process and algorithm is fully adjustable enabling the DPR to be optimized for particular expected impairments and for latency requirements.

8740-8, Session 2

Intelligent video surveillance communication systems

Eric P. McCulley, Christopher M. Durso, Vislink US Billerica (United States)

Recent advances in video encoding and transport technologies can greatly improve the reliability and expansion of Public Safety Command and Control Communication Systems. The need for shared communication resources between public safety agencies has never been greater. The tragic terrorist events of September 11, 2001 underscored the importance of reliable and secure shared communication resources between disparate public safety agencies. Such communications solutions require a high degree of synergy across multiple collection and delivery mediums.

Video delivery systems employing IP packet-based architectures have become essential to the successful sharing of interagency communication systems. This digital format medium allows for multiple workflows to transpire simultaneously and for mission critical video, audio and data to be strategically deployed.

Software Defined Surveillance (SDS) platforms featuring web-based software interfaces help to mitigate concerns of interoperability and premature equipment obsolescence. They make it easier for the user to manage the system technology after deployment and facilitate a level of customization and product specialization unique to the specific requirements of the end user. Further, SDS platforms provide a key element for the seamless expansion of high-performance video communication systems as public safety needs evolve.

8740-9, Session 2

Increased efficiency for beyond line-of-sight in airborne ISR operations

Koen Willems, Newtec (Belgium); Slava Frayter, Newtec (United States)

Airborne platforms are increasingly being used as vehicles to capture intelligence data for defense, state and civil applications. The aerial vehicles are equipped with technology for both video and data collection; the data is then sent to a ground command center for further processing. When airborne platform is outside the reach of direct data relay due to distance or environment, satellite communications is used for beyond line of sight (BLoS) communication.

Key requirement for the satellite link in ISR operations is to get as much data and video as possible through the available bandwidth. The satellite link also needs to be available at all times during operations to insure mission critical communications and not endanger ground operations. Only using robust satellite technology the demand for more data and highest efficiency can be satisfied while keeping OPEX costs under control.

This presentation will highlight both technical and practical challenges of operators in the airborne ISR missions, going from technical requirements to efficiency-driven solutions and final results in the field when transmitting ISR data and video from the airborne platform over satellite in highly adaptive environments. The existing qualified and deployed BLoS airborne solution already achieves over 20Mbps from the aircraft to the ground in active operations, but requirements and capabilities continue to increase as more comprehensive ISR data is being transmitted.

The first part of presentation will be focusing on current trends and technical solutions for ISR operations over satellite. Second part will cover practical challenges and the results achieved during previous missions.

8740-11, Session 2

A results-based process for evaluation of diverse visual analytics tools

Gary Rubin, David H. Berger, System Planning Corp. (United States)

With the pervasiveness of still and full-motion imagery in commercial and military applications, the need to ingest and analyze these media has grown rapidly in recent years. Additionally, video hosting and live camera websites provide a near real-time view of our changing world with unprecedented spatial coverage. To take advantage of these controlled and crowd-sourced opportunities, sophisticated visual analytics (VA) tools are required to accurately and efficiently convert raw imagery into usable information. Whether investing in VA products or evaluating algorithms for potential development, it is important for stakeholders to understand the capabilities and limitations of visual analytics tools.

Visual analytics algorithms are being applied to problems related to Intelligence, Surveillance, and Reconnaissance (ISR), facility security, and public safety monitoring, to name a few. The diversity of requirements means that a one-size-fits-all approach to performance assessment will not work. We present a process for evaluating the efficacy of algorithms in real-world conditions, thereby allowing users and developers of video analytics software to understand software capabilities and identify potential shortcomings. The results-based approach described in this paper uses an analysis of end-user requirements and Concept of Operations (CONOPS) to define Measures of Effectiveness (MOEs), test data requirements, and evaluation strategies. We define metrics that individually do not fully characterize a system, but when used together, are a powerful way to reveal both strengths and weaknesses. We provide examples of data products, such as frame heat maps, target trails, detection timelines, and rank-based probability of detection curves.

8740-12, Session 2

Full motion video optical navigation targeting (FMV ON-target)

Scott D. Robbins, The MITRE Corp. (United States)

No Abstract Available.

8740-13, Session 3

Video quality across the defense intelligence information enterprise (DI2E)

Kevin West, U.S. Dept. of Defense (United States)

Mr. West will present a paper on the challenges of ensuring Video Quality across the Defense Intelligence Information Enterprise (DI2E). He will discuss the challenges and on-going activities that Department of Defense (DoD) is considering to define a repeatable method for implementing video quality metrics across the DI2E.

8740-14, Session 3

Improving geolocation performance for ISR

Michael J. Lenihan, Todd E. Johanesen, National Geospatial-Intelligence Agency (United States)

The presentation will provide the audience with a high-level overview of the critical role geopositioning plays into turning full motion video into actionable intelligence. The value of implementing a core geospatial framework, based on the science of photogrammetry, will be shown as a key enabler for a myriad of on-going operational missions including detection, identification, location determination, and video analytics. This foundational capability transcends all phase of the traditional intelligence production cycle and includes improvements to the sensor to enable wide-area motion imagery and activity based intelligence capabilities; it also covers changes to upstream and downstream processing architectures; and lastly the implementation of rigorous geopositioning capabilities at the users level - national, theater, tactical, or forward-deployed.

8740-15, Session 3

Foreground estimation in motion imagery using multiframe change detection techniques

Andrew Lingg, Brian D. Rigling, Wright State Univ. (United States)

Using multi-frame change detection methods, we are able to estimate which pixels include objects that are in motion relative to the background. We utilize both a sequential statistical change detection method and a sparsity-based change detection method. We are able to perform foreground estimation in videos in which the background is static as well as in images in which apparent background motion is induced by camera motion. We show the results of our techniques on the background subtraction data set from the Statistical Visual Computing Lab at the University of California, San Diego.

8740-16, Session 3

Gaze interaction in UAS video exploitation

Jutta E. Hild, Stefan T. Bruestle, Norbert F. Heinze, Elisabeth Peinsipp-Byma, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

A frequently occurring interaction task in UAS video exploitation is the marking or selection of objects of interest in the video. If an object of interest is visually detected by the video analyst, its selection for further exploitation, documentation and communication with the team is a necessary task. Today, object selection is usually performed by mouse interaction. As due to sensor motion all objects in the video move, object selection can be rather challenging. Particularly, if strong and fast ego-motions are present, e.g., with small airborne sensor platforms, objects of interest are sometimes not long enough visible to enable the analyst to reliably select them using mouse interaction. To address this issue, we propose an eye tracker as input device for object selection. As the eye tracker provides continuously the gaze position of the analyst on the monitor, it is intuitive to use the gaze position for pointing at an object. The selection is then actuated by pressing a button. We integrated this gaze-based object selection into Fraunhofer IOSB's exploitation station ABUL using a Tobii X60 eye tracker and a standard keyboard for the button press. Representing the selected objects in a spatial relational database, ABUL enables the video analyst to efficiently query the video data for these objects with respect to their geographical and other properties in a post processing step. In this contribution, an experimental evaluation is presented, comparing the gaze-based interaction technique with mouse interaction in the context of object selection in UAS videos.

8740-20, Session 3

Smart systems, dumb data: impact on ISR operations

Gregory Creech, U.S. Dept. of Defense (United States)

Just as we face a global environment where the latest technology is most needed by DoD and the IC, we find ourselves hindered by the lack of smart, useful data that our intelligent systems and workforce can fully exploit. The resulting impact on ISR operations is detrimental, if not catastrophic. Consider the ISR Enterprise "system of systems." Our inability to properly populate metadata fields for making data discoverable and useful is as harmful to system performance as putting low-grade fuel in a race car. In order for our downstream ISR Enterprise systems (and analysts) to achieve their full performance potential, we must take measures upstream to make the data stream smart. This paper will examine the challenges and propose solutions that will benefit analysts at all echelons.

8740-18, Session 4

InnoVision's focus areas for motion imagery R&D

Kenneth E. Rice, National Geospatial-Intelligence Agency (United States)

Exploiting the volumes of Full Motion Imagery (FMV) and Wide Area Motion Imagery (WAMI) hereto referred to collectively as "Motion Imagery", is the focus of a tremendous amount of research and development (R&D) across the Department of Defense and Intelligence Community (DoD/IC). The National Geospatial Intelligence Agency (NGA) is the DoD/IC Functional Manger for Motion Imagery and the research and development arm of NGA, InnoVision, is the functional manager for R&D for Motion Imagery. While there has been tremendous progress in exploiting Motion Imagery, there are still opportunities for improvement. InnoVision's charter is to enable and focus R&D efforts across the DoD/IC with the goal of extracting the most information as efficiently as possible from Motion Imagery in all phases of exploitation. This paper outlines the specific focus areas and objectives of InnoVision.

8740-19, Session 4

Reel-to-real

William Craig, WiSC Enterprises LLC (United States)

Reel-to-Real addresses the challenges of achieving an Integrated Intelligence Environment (IIE) with emphasis on emerging GEOINT information; and, posits a two-pronged way-ahead through: 1) the concepts of capability-based interoperability and conformance, performance and operational evaluations; and, 2) changes to the acquisition process

8740-21, Session 4

Standards for efficient employment of wide-area motion imagery (WAMI) sensors

Scott Randall, Booz Allen Hamilton Inc. (United States); Paul Maenner, Exelis Visual Information Solutions (United States)

Airborne Wide Area Motion Imagery (WAMI) sensors provide the opportunity for continuous high-resolution surveillance of geographic areas covering tens of square kilometers. This is both a blessing and a curse. Data volumes from “gigapixel-class” WAMI sensors are orders of magnitude greater than for traditional “megapixel-class” video sensors. The amount of data greatly exceeds the capacities of downlinks to ground stations, and even if this were not true, the geographic coverage is too large for effective human monitoring. Although collected motion imagery is recorded on the platform, typically only small “windows” of the full field of view are transmitted to the ground; the full set of collected data can be retrieved from the recording device only after the mission has concluded. Thus, the WAMI environment presents several difficulties: (1) data is too massive for downlink; (2) human operator selection and control of the video windows may not be effective; (3) post-mission storage and dissemination may be limited by inefficient file formats; and (4) unique system implementation characteristics may thwart exploitation by available analysis tools. To address these issues, the National Geospatial-Intelligence Agency’s Motion Imagery Standards Board (MISB) is developing relevant standard data exchange formats: (1) moving target indicator (MTI) and tracking metadata to support tipping and cueing of WAMI windows using “watch boxes” and “trip wires”; (2) control channel commands for positioning the windows within the full WAMI field of view; (3) 3D model-based compression to address downlink bandwidth and storage capacity limitations; and (4) a full field of view spatiotemporal tiled file format for efficient storage, retrieval, and dissemination. The authors previously provided an overview of this suite of standards. This paper describes the latest progress, with specific concentration on a detailed description of the spatiotemporal tiled file format.

8741-1, Session 2

Aerial robot experimental design for decentralized visual SLAM

Alexander G. Cunningham, Kyel Ok, Jason Antico, Vadim Indelman, Frank Dellaert, Georgia Institute of Technology (United States)

This paper presents an analysis of real-world experimental design for multi-robot decentralized simultaneous localization and mapping (SLAM) algorithm evaluation algorithms using small, teleoperated, off-the-shelf quadrotor platforms equipped with visual and inertial sensing. We present data from field experiments collected at a military urban training site in Camp Lejeune, NC, which simulates multi-robot reconnaissance.

Because of the inherent complexity of the multi-robot problem, we consider three core subproblems across the design of different scenarios. The first is multi-robot loop closure, which is when robots split up and rendezvous at a new location, a multi-robot mapping algorithm should be able to treat this as a loop closure from a single-robot mapping scenario. The second is using between-robot observations, in which one robot acts as a “spotter” for another robot exploring a more cluttered environment, which can help overcome the limited field of vision on individual robots. Finally, we control robots to improve mapping because monocular SLAM is relatively challenging, particularly in the robust calculation feature correspondences, and were careful to use trajectories that would avoid data association failure cases.

This paper details the design of these experiments, with both “mission”-oriented scenarios, as well as testing scenarios varying size and complexity. Finally, this paper presents results from visual and inertial SLAM techniques applied to this dataset, with additional analysis on its impact on decentralized SLAM techniques.

8741-2, Session 2

Visual template tracking based MAV localization for hovering over low-textured surfaces

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This paper introduces a new vision aided localization method for micro air vehicle (MAV) position estimation in low textured GPS-denied environments with a minimal sensor suite (camera, IMU, sonar altimeter). The approach uses images from a downward looking camera to perform full image template tracking for lateral MAV motion estimation with the assumption of a ground plane in view. Tracked frames are sub-sampled and aligned horizontally based on IMU attitude information. The lateral displacement is calculated with a fast, ESM type, iterative algorithm in a key frame approach. Sonar height measurements are used for altitude estimation and to regain metric scale. The algorithm runs in real-time on-board a MAV with a frame rate of up to 60Hz. Results demonstrate stable MAV hovering-in-place over surfaces with very low unique texture content (new concrete, uniform carpet, grass) where conventional feature-based tracking approaches have significant difficulties.

8741-3, Session 2

Dynamic, cooperative multi-robot patrolling with a team of UAVs

Charles E. Pippin, Georgia Tech Research Institute (United States); Henrik I. Christensen, Georgia Institute of Technology (United States); Lora G. Weiss, Georgia Tech Research Institute (United States)

The multi-robot patrolling task has practical relevance in surveillance, search and rescue, and security applications. In this task, a team of robots must repeatedly visit areas of interested in the environment, minimizing the time in-between visits to each. A team of robots can perform this task efficiently; however, challenges remain related to team formation and task assignment.

Conventional strategies for performing this task assume that the robots will perform as expected and do not address situations in which some team members patrol inefficiently. However, reliable performance of team members may not always be a valid assumption. This paper presents an approach for monitoring patrolling performance and dynamically adjusting the task assignment function based on these observations. Experimental results demonstrate that robots that model team member performance using this approach can dynamically and more efficiently distribute tasks in a multi-robot patrolling application.

In this paper, a patrolling scenario is presented with multiple UAVs patrolling areas of interest. The UAVs on the patrol team have different performance characteristics. The teaming and task partitioning approach is adjusted using both centralized and decentralized approaches to partitioning the patrol areas based on observed UAV performance. Multiple dimensions of task performance are presented for evaluating team member performance, along with monitoring approaches. Each team member uses a reputation model that is updated through repeated interactions. Finally, the approach is demonstrated through experiments performed in realistic simulations of a patrolling scenario using a UAV platform.

8741-4, Session 2

Vegetation versus man-made object detection from imagery for unmanned vehicles in off-road environments

Josh Harguess, Jacoby Larson, Space and Naval Warfare Systems Ctr. Pacific (United States)

There have been several major advances in autonomous navigation for unmanned ground vehicles in recent years in controlled urban environments. However, off-road environments still pose several perception and classification challenges. This paper addresses two of these challenges: detection and classification of vegetation vs. man-made objects. In order for a vehicle or remote operator to traverse cross-country terrain, automated decisions must be made about obstacles in the vehicle’s path. The most common obstacle is vegetation, but some vegetation may be traversable, depending on the size of the vehicle and the type of vegetation. However, man-made objects should generally be detected and avoided in navigation. We present a solution to vegetation and man-made object detection which fuses several recent advances in computer vision, focusing our efforts in the visible spectrum. Vegetation and man-made objects are detected and identified by fusing the information discovered from image segmentation with Markov random fields, visual saliency and natural scene statistics. Each of the methods are compared and contrasted along with our fusion approach. Experimental results are presented on several images and video taken from a small unmanned ground vehicle.

8741-5, Session 2

Landing spot selection for UAV emergency landing

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During UAV emergency landings safety is one of the top priorities. Detection of human activity near the UAV is a key element in improving the safety.

We present a robust method for moving object detection to be used for UAV emergency landings. The method uses a downward facing camera, either visual or infrared. The method is simple enough to allow real-time implementation on a UAV system and is at the same time robust against camera motion and noise. The method is able to detect objects in the presence of camera movement and motion parallax. Other approaches to activity detection are optic flow, keypoint trajectory analysis and static object detection. In the paper we compare our method for detecting human presence against these other approaches. We show that our method is more suitable for this application than the other methods. At the end of the paper we discuss selection of suitable landing areas, based on the results of moving object detection and other detection results.

8741-45, Session 2

Feature detection and SLAM on embedded processors for micro-robot navigation

Paul Robinette, Thomas R. Collins, Georgia Tech Research Institute (United States)

The drive to create smaller, man-portable robots has lead to a conflict between increasingly resource hungry algorithms for mapping and efficient but less capable processors onboard. The Surveyor SRV-1 robot is uniquely suited to address this conflict as a micro-scale robot with Blackfin processors and considerable payload capabilities for additional electronics. We have developed an algorithm to perform feature detection on images and calculate localization at approximately one hertz. While this is considerably slower than many existing systems, our system is limited by the onboard embedded processing power.

Our system uses the SRV-1 with SVS (two cameras, each with a Blackfin BF537 processor) and an onboard Gumstix Overo. We start by taking an image with each camera and performing FAST corner detection. Thresholding is set such that approximately 100 corners are detected. The appropriate threshold can be calculated using a binary search with little additional time per frame. FAST detection takes 0.06 seconds per frame on the Blackfin processor. Using the scoring function built into FAST, we then find the ten best features in each image. Descriptors are calculated for each feature using the SURF descriptor calculation. Each descriptor requires 0.07 seconds of calculation on the Blackfin, so 0.7 seconds per frame. Finally, these features and their descriptors are sent to the Gumstix so that the GTSAM algorithm can calculate the most likely position of both the SRV-1 and the landmarks.

8741-7, Session 3

Robot mapping in large-scale mixed indoor and outdoor environments

John G. Rogers III, Georgia Institute of Technology (United States); Jason M. Gregory, Stuart H. Young, U.S. Army Research Lab. (United States); Henrik I. Christensen, Georgia Institute of Technology (United States)

Tactical situational awareness in unstructured and mixed indoor/ outdoor scenarios is needed for urban combat as well as rescue operations. Two of the key functionalities for utilization of robot systems is the ability to estimate the position of a platform and to generate a map, a representation of the environment.

With the introduction of a wider variety of sensors that can generate dense point clouds, it is of interest of provide mapping systems that can utilize these sensors for generation of detailed maps and to utilize the extra information to solve challenging problems such as loop closing. We present a strategy to build dense maps and to do automatic loop closing.

The system is designed to have two parallel threads, one building a map and the other detecting potential loop closures. The approach has been integrated into a new mapping module named emph{Omni_Mapper}. The system can utilize a variety of different sensors such as the Velodyne 32E, Kinect style cameras, or a Hokuyo sensor mounted on a nodding pan-tilt unit such as the Direct Perception PTU-46.

The system has been tested for use in office buildings, at military training facilities and in large scale mixed in-and-out-door environments. We will present both the underlying system, the implementation, and experimental results from a variety of difficult, real-world environments.

8741-8, Session 3

Cooperative mobile agents search using beehive partitioned structure and Tabu Random search algorithm

Saba Ramazani, Rastko R. Selmic, Delvin Jackson, Louisiana Tech Univ. (United States)

In search and surveillance operations, deploying a team of mobile agents provides a robust solution that has multiple advantages over using a single agent in efficiency and minimizing exploration time. This paper addresses the challenge of identifying a target in a given environment when using a team of mobile agents by proposing a novel method of mapping and movement of agent teams in a cooperative manner. The approach consists of two parts. First, the region is partitioned into a hexagonal beehive structure in order to provide equidistant movements in every direction and to allow for more natural and flexible environment mapping. Additionally, in search environments that are partitioned into hexagons, mobile agents have an optimized travel path while performing searches due to this partitioning approach. Second, we use a team of mobile agents that move in a cooperative manner and utilize the Tabu Random algorithm to search for the target.

Due to the ever-increasing use of robotics and Unmanned Aerial Vehicle (UAV) platforms, the field of cooperative multi-agent search has developed many applications recently that would benefit from the use of the approach presented in this work, including: search and rescue operations, surveillance, data collection, and border patrol. In this paper, the increased efficiency of the Tabu Random Search algorithm method in combination with hexagonal partitioning is simulated, analyzed, and advantages of this approach are presented and discussed.

8741-9, Session 3

Cognitive patterns: giving autonomy some context

Danielle A. Dumond, Webb Stacy, Alexandra Geyer, Jeffrey Rousseau, Mike Therrien, Aptima, Inc. (United States)

Today's robots require a great deal of control and supervision, and are unable to intelligently respond to unanticipated and novel situations. Interactions between an operator and even a single robot take place exclusively at a very low, detailed level, in part because no context information about a situation is conveyed or utilized to make the interaction more effective and less time consuming. Moreover, the robot control and sensing systems do not learn from experience and, therefore, do not become better with time or apply previous knowledge to new situations.

With human-robot teams, human operators, in addition to managing the low-level details of navigation and sensor management while operating the robot, are also required to maintain mission situational awareness. To make the most use of robots in combat environments, it will be necessary to have the capability to assign new missions (including providing them context information), and to have them report information about the environment they encounter as they proceed with their mission.

The Cognitive Patterns Knowledge Generation system (CPKG) has the ability to connect to various knowledge-based models, multiple sensors, and a human operator. The CPKG system comprises three major internal components: Pattern Generation, Perception/Action, and Adaptation, enabling it to create situationally-relevant abstract patterns, match sensory input to a suitable abstract pattern in a multilayered top-down/bottom-up fashion similar to the mechanisms used for visual perception in the brain, and generate new abstract patterns. The CPKG allows the operator to focus on things other than the operation of the robot(s).

8741-11, Session 3

Real-time adaptive off-road vehicle navigation and terrain classification

Urs Muller, Net-Scale Technologies, Inc. (United States); Lawrence Jackel, North-C Technologies, Inc (United States); Yann LeCun, New York Univ. (United States); Beat Flepp, Net-Scale Technologies, Inc. (United States)

We are developing a complete, self-contained autonomous navigation system for mobile robots that learns quickly, uses commodity components, and has the added benefit of emitting no radiation signature. It builds on the autonomous navigation technology developed by Net-Scale and New York University during the DARPA LAGR program (Learning Applied to Ground Robots) and takes advantage of recent scientific advancements achieved during the DARPA Deep Learning program. In this paper we will present our approach and algorithms, show results from our vision system, discuss lessons learned from the past, and present our plans for further advancing vehicle autonomy.

8741-12, Session 3

Multi-robot exploration strategies for tactical tasks in urban environments

Carlos P. Nieto, John G. Rogers III, Henrik I. Christensen, Georgia Institute of Technology (United States)

Projects like the ARL MAST CTA seek to introduce the application of large numbers of inexpensive and simple mobile robots for situational awareness in urban military and rescue operations. Human operators are required to teleoperate the current generation of mobile robots for this application; however, teleoperation is increasingly difficult as the number of robots is expanded. In the multi-robot scenario, resources are distributed amongst a team of robots instead of concentrated on one large and expensive machine. The distributed team is able to continue its mission even if some of the robots are disabled or destroyed. A single robot can only explore or monitor at one location at a time; however, the multi-robot team can provide situational awareness in many locations at once. Unless the single robot is able to move much faster than the multi-robot agents, the lone robot will be slower in performing the exploration and mapping task. These advantages are taken for a multi-robot team at the cost of increased complexity in communication and coordination.

The coordination strategy used by the members of a mobile robot team can have a big impact on the team's performance. We have developed a set of coordination strategies which consist of various degrees of cooperation and noninterference. On one extreme, the Reserves strategy keeps team members at the starting area until they are needed to explore a branching intersection. On the other extreme, the Divide and Conquer strategy allocates all robots and splits the team into two when a branching intersection is reached.

This paper will present experiments conducted with teams of mobile robots exploring and mapping in a military training facility. Each coordination strategy is evaluated in several types of building shape scenarios to determine which is most effective in terms of mapping speed and completion time.

8741-13, Session 3

Semantic data association for planar features in outdoor 6D-SLAM using lidar

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Simultaneous Localization and Mapping (SLAM) is a fundamental problem of the autonomous systems in GPS (Global Navigation System) denied environments. The traditional probabilistic SLAM methods uses point features as landmarks and hold all the feature positions in their state vector in addition to the robot pose. The bottleneck of the point-feature based SLAM methods is the data association problem, which are mostly based on a statistical measure. The data association performance is very critical for a robust SLAM method since all the filtering strategies are applied after a known correspondence. For point-features, two different but very close landmarks in the same scene might be confused while giving the correspondence decision when their positions and error covariance matrix are solely taking into account. Planar features can be considered as an alternative landmark model in the SLAM problem to be able to provide a more consistent data association. Planes contain rich information for the solution of the data association problem and can be distinguished easily with respect to point features. In addition, planar maps are very compact since an environment has only very limited number of planar structures. The planar features does not have to be large structures like building wall or roofs; the small plane segments can also be used as landmarks like billboards, traffic posts and some part of the bridges in urban areas. In this paper, a probabilistic plane-feature extraction method from 3D-LiDAR data and the data association based on the extracted properties (semantic) of the planar features is introduced. The experimental results show that the semantic data association provides very satisfactory result in outdoor 6D-SLAM.

8741-14, Session 5

Robust leader tracking from an unmanned ground vehicle

Camille Monnier, Stan German, Andrey Ost, Charles River Analytics, Inc. (United States)

While many leader-follower technologies for robotic mules have been developed in recent years, the problem of reliably tracking and re-acquiring a human leader through cluttered environments continues to pose a challenge to widespread acceptance of these systems. Recent approaches to leader tracking rely on leader-worn equipment that may be damaged, hidden from view, or lost, such as radio transmitters or special clothing, as well as specialized sensing hardware such as high-resolution LIDAR. We present a vision-based approach for robustly tracking a leader using a simple monocular camera. The proposed method requires no modification to the leader's equipment, nor any specialized sensors on board the host platform. The system learns a discriminative model of the leader's appearance to robustly track him or her through long occlusions, changing lighting conditions, and cluttered environments. We evaluate the system's tracking performance on a publicly available benchmark dataset, as well as in representative scenarios captured using a small unmanned ground vehicle (SUGV).

8741-15, Session 5

Multimodal interaction for human-robot teams

Dustin Burke, Nathan Schurr, Jeanine Ayers, Jeffrey Rousseau, John Fertitta, Alan Carlin, Aptima, Inc. (United States); Danielle Dumond, Aptima, Inc (United States)

Unmanned ground vehicles have the potential for supporting small dismounted teams in mapping facilities, maintaining security in cleared

buildings, and extending the team's reconnaissance and persistent surveillance capability. In order for such autonomous systems to integrate with the team, we must move beyond current interaction methods using heads-down teleoperation which require intensive human attention and affect the human operator's ability to maintain local situational awareness and ensure their own safety.

Within this work, we designed and developed a multimodal interaction system that incorporates naturalistic human gestures, voice commands, and a ruggedized tablet interface. By providing multiple, partially redundant interaction modes, our system degrades gracefully in complex environments and enables the human operator to robustly select the most suitable interaction method given the situational demands. For instance, the human can silently use arm and hand gestures for commanding a team of robots when it is important to maintain stealth. Uniquely, our system utilizes the physical presence of the human with respect to the robot systems within a common map frame to enable the human to utilize pointing to objects within the environment, including the robots as well as sensed objects, for commanding intents. The tablet interface provides an overhead situational map allowing waypoint-based navigation for multiple ground robots in beyond-line-of-sight conditions. Using lightweight, wearable motion sensing hardware either worn comfortably beneath the operator's clothing or integrated within their uniform, our non-vision-based approach enables an accurate, continuous gesture recognition capability without line-of-sight constraints. To reduce the training necessary to operate the system, we designed the interactions around familiar arm and hand gestures.

8741-16, Session 5

An intuitive graphical user interface for small UAS

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Thousands of small UAVs are in active use by the US military and are generally operated by trained but not necessarily skilled personnel. The user interfaces for these devices often seem to be more engineering-focused than usability-focused, which can lead to operator frustration, poor mission effectiveness, reduced situational awareness, and sometimes loss of the vehicle. In addition, coordinated control of both air and ground vehicles is a frequently desired objective, usually with the intent of increasing situational awareness for the ground vehicle. The Space and Naval Warfare Systems Center Pacific (SSCPAC) is working under a Naval Innovative Science and Engineering project to address these topics. The UAS currently targeted are the Raven/Puma/Wasp family of air vehicles as they are small, all share the same communications protocol, and are in wide-spread use. The stock ground control station (GCS) consists of a hand control unit, radio, interconnect hub, and laptop. The system has been simplified to an X-box controller, radio and a laptop, resulting in a smaller hardware footprint, but most importantly the number of personnel required to operate the system has been reduced from two to one. The stock displays, including video with text overlay on one and FalconView on the other, are replaced with a single, graphics-based, integrated user interface, providing the user with a much improved situational awareness. The SSCPAC government-developed GCS (the Multi-robot Operator Control Unit) already has the ability to control ground robots and this is leveraged to realize simultaneous multi-vehicle operations including autonomous UAV over-watch for enhanced UGV situational awareness.

8741-17, Session 5

Evaluating the presentation of autonomous mapping algorithm results

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Currently fielded small unmanned ground vehicles (SUGVs) are operated via teleoperation. This method of operation requires a high level of operator involvement within line of sight of the robot. As advances are made in autonomy algorithms, capabilities such as automated mapping can be developed to allow SUGVs to be used to provide situational awareness with an increased standoff distance while simultaneously reducing operator involvement.

In order to realize these goals, it is paramount the data produced by the robot is not only accurate, but also presented in an intuitive manner to the robot operator. The focus of this paper is the evaluation of how to effectively present map data produced by a SUGV in order to drive the design of a future user interface. The effectiveness of several 2D and 3D mapping capabilities was evaluated by presenting a collection of pre-recorded data sets of a (SUGV) mapping a building in an urban environment to a user panel of Soldiers. The data sets were presented to each Soldier in several different formats in order evaluate multiple factors, including update frequency and presentation style. Once all of the data sets were presented, a survey was administered. The questions in the survey were designed to gage the overall usefulness of the mapping algorithm presentations as an information generating tool. In this paper the development of this test protocol along with the results of the survey are presented.

8741-18, Session 5

Evolution of a radio communication relay system

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Providing long-distance non-line-of-sight control for unmanned ground robots have long been recognized as a problem, considering the nature of the required high-bandwidth radio links. In the early 2000s, the DARPA Mobile Autonomous Robot Software (MARS) program funded the Space and Naval Warfare Systems Center (SSC) Pacific to demonstrate a capability for autonomous mobile communication relaying, implemented on a number of Pioneer laboratory robots. This effort also resulted in the development of ad hoc networking radios and software that were later leveraged in the development of a more practical and logistically simpler system, the Automatically Deployed Communication Relays (ADCR). Funded by the Joint Ground Robotics Enterprise and internally by SSC Pacific, several generations of ADCR systems introduced increasingly more capable hardware and software for automatic maintenance of communication links through deployment of relay nodes from mobile robots. This capability was finally tapped in 2010 to fulfill an urgent need from theater. Two hundred and forty-three kits of ruggedized, robot-deployable communication relays were produced and sent to Afghanistan to extend the range of EOD and tactical ground robots in 2012. This paper provides a summary of the evolution of the radio relay technology at SSC Pacific, then focuses on the latest two stages, the manually-deployed communication relays and the latest attempt at automating the deployment of these ruggedized and fielded relay nodes.

8741-52, Session 5

Multilateral haptics-based immersive teleoperation for improvised explosive device disposal

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Of great interest to industry, academia, and military is the development of effective improvised explosive device (IED) disposal technology to aid in activities such as mine field clearing and bomb disposal, while at the same time minimizing risk to personnel. This paper presents new

results in the research and development of a next generation mobile immersive teleoperated explosive ordnance disposal system. This system incorporates elements of 3D vision, multilateral teleoperation for high transparency haptic feedback, immersive augmented reality operator control interfaces, and a realistic hardware in the loop (HIL) 3D simulation environment incorporating vehicle and manipulator dynamics for both operator training and algorithm development. In the past year, new algorithms have been developed to facilitate incorporating COTS robotic hardware into the teleoperation system. In particular, a real-time numerical inverse position kinematics algorithm that can be applied to a wide range of manipulators has been implemented, an IMU-based attitude stabilization system for manipulators has been developed and experimentally validated, and a voice-operated manipulator control system has been developed and integrated into the operator control station. The integration of these components into a vehicle simulation environment with half-car vehicle dynamics has also been successfully carried out. A physical half-car plant is currently being constructed for HIL integration with the simulation environment.

8741-20, Session 6

Position-adaptive MAV in emitter localization mission using RSSI and Path Loss Exponent metrics

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We consider a Micro-Aerial Vehicle (MAV), in conjunction with static nodes, in a mission of detection and localization of a hidden Electromagnetic (EM) emitter. This paper, submitted to SPIE Intelligent Behaviors session, explores the position adaptation segment of the Position Adaptive Direction Finding (PADF) concept by providing an algorithmic framework for MAVs to reposition themselves to avoid obstructions or locations that may disrupt the propagation of the emitter, hence reducing the accuracy of the receivers' combined emitter location estimation. Given the cross Path Loss Exponents (PLEs) between the static and mobile nodes, we propose a cost function for MAVs' position adjustments that is based on the combination of cross PLEs and Received Signal Strength Indications (RSSI). The mobile nodes adjust algorithmically by minimizing a gradient descent cost function such that the average PLE is minimized while maximizing RSSI, thereby, minimizing the inconsistency of the environment, and reducing the echo and multipath disturbances. In the process, MAVs find a more uniform measuring environment that increases localization accuracy. In addition to using cross PLEs, we propose to study the complex cepstrum between mobile nodes and the hidden emitter as a metric for MAV control. Complex cepstrum is correlated with a received echo in EM signals; therefore, reducing the cepstrum leads to improving measurement and estimation in an environment (similar to phenomenon in biological species with built-in cepstrum minimization and detection, or echo reduction, capabilities that allow movement away from large objects/animals). We propose to embed such capabilities and functionalities into MAV control algorithms.

8741-21, Session 6

Learning consensus in adversarial environments

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Due to the highly uncertain and dynamic nature of military conflict, enabling autonomous agents to gracefully adapt to mission and environmental changes is a very challenging task. These capabilities are necessary in the asymmetric battles waged against insurgencies, where enemy combatants quickly adapt to Army strategies and tactics. The United States Army, Air Force, and Navy have recently shown interest in the cyber security aspect of UAVs and UAGs, which rely heavily on their on-board autopilots and controllers to function. Most of the currently available autopilot systems were built without cyber security considerations, and are thus vulnerable to cyber attacks. This research provides knowledge to the problem of commanding multiple tactical assets in military and adversarial environments, attending Army's expectations that networked teams will perform in a reliable manner especially when being attacked by advanced and persistent threats.

This work presents a game theory-based consensus problem for leaderless multi-agent systems in the presence of adversarial inputs that are corrupting the measurements. Given the presence of enemy components and the possibility of malicious cyber attacks compromising the security of networked teams, a velocity and position agreement must be reached by the networked mobile team based on environmental changes. The problem is addressed under a distributed decision making framework that is robust to possible cyber attacks, which has an advantage over centralized decision making in the sense that a decision maker is not required to access information from all the other decision makers. The proposed framework derives three tuning laws for every agent; one associated with the cost, one associated with the controller, and one with the adversarial input.

8741-22, Session 6

Stable structures of coalitions in competitive and altruistic military teams

Muhammad Aurangzeb, The Univ. of Texas at Arlington (United States); Dariusz G. Mikulski, Gregory R. Hudas, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); Frank L. Lewis, The Univ. of Texas at Arlington (United States); Edward Y. Gu, Oakland Univ. (United States)

Battlefield teams are generally heterogeneous coalitions consisting of interacting humans, ground sensors, and unmanned airborne (UAV) or ground vehicles (UGV). In these teams relations are based on direct local interactions, yet information is conveyed along a chain of command. The balance between coalitional and individual objectives forms the basis for the internal topological structure of coalitions. In this paper, the coalitional structure is studied by presenting a novel graphical coalitional game (GCG), with Positional Advantage (PA). PA is based on Shapley value strengthened by the Axioms of value. Axioms of valve are based on its connectivity properties within the coalition. Under the Axioms of Value the GCG is convex, fair, cohesive, and fully cooperative. Three measures of the contributions of agents to a coalition are introduced: marginal contribution (MC), competitive contribution (CC), and altruistic contribution (AC).

Moreover, the paper examines the dynamic team effects such as the formation of teams by adding agents, the destruction of teams by defection of agents, and other issues involving sequential decisions by agents to join, leave, or form teams. To study the dynamic team effects, three online sequential decision games are defined. These sequential decision games are based on the three contributions MC, CC, and AC. It is shown that the stable graphs under the objective of maximizing the MC are any connected graph. The stable graphs under the objective of maximizing the CC are the complete graph. The stable graphs under the objective of maximizing the AC are any tree.

8741-23, Session 6

Adaptive neural network consensus-based control for mobile robot formations

Haci Mehmet Guzey, Jagannatan Sarangapani, Missouri Univ. of Science and Technology (United States)

In this paper, an adaptive optimal consensus based control scheme is derived for mobile robot formation in the presence of uncertain dynamics and reduced communication. First, it is shown that uncertain agent dynamics, if unaccounted for, can make the overall formation unstable

when utilizing consensus-based control. Next, an optimal adaptive consensus scheme for such agents with uncertain dynamics is proposed in the presence of full communication capability. Subsequently, an algorithm to reduce communication among the agents using consensus based formation control scheme is introduced. This proposed optimal adaptive scheme is designed to minimize not only the control effort and formation error but also maximizes the time interval between two communication periods. It is shown that the propagation of formation errors between any two communication periods remains in a predefined bound. In addition, the optimal control law ensures the desired performance by maintaining the formation. Lyapunov method is used to prove stability of the overall consensus-based formation control. Finally, Simulation results are given to verify theoretical claims.

8741-24, Session 6

Maintaining robust connectivity in heterogeneous robotic networks

Patricio J. Cruz, Rafael O. Fierro, The Univ. of New Mexico (United States); Wenjie Lu, Silvia Ferrari, Duke Univ. (United States); Thomas A. Wettergren, Naval Undersea Warfare Ctr. (United States)

The scenario envisioned in this paper is intended for surveillance and search operations and concerns the exploration of hazardous buildings, caves and collapsed structures. In these situations, the use of heterogeneous systems made up of aerial and ground robotic agents would maximize the probability to efficiently and successfully accomplish the mission. For instance, aerial vehicles have the capability to cover an area faster but cannot have a detailed view of caves or buildings where line-of-sight is lost. On the other hand, multi-legged robotic platforms can only explore a limited area, but do so with much more accuracy. In addition, maintaining wireless connectivity is an important factor to be considered when dealing with multi-agent systems. Due to several limitations in the communication channel, especially when the transmission is through the air medium, complications such as shadow effects and secondary reflections arise. These phenomena create a variety of constrains on the possible relative positions of the heterogeneous agents. Thus, we are interested in developing strategies to enhance connectivity of the network of robots while exploring an area of interest as quickly as possible. To be more specific, we describe a search algorithm for a ground mobile sensor network by relaxing the assumption of network connectivity and introduce specialized aerial relay agents to the network which are better equipped to communicate over longer distances. Furthermore, we present an approximate dynamic programming (ADP) algorithm based on potential navigation functions for vehicle control under a two-component communication constraint: range and line-of-sight. Numerical simulations validate the proposed methodologies.

8741-44, Session PSThu

An open-source scheduler for small satellites

Donovan Torgerson, Jeremy Straub, The Univ. of North Dakota (United States); Atif Mohammad, Christoffer Korvald, Dayln Limesand, University of North Dakota (United States)

The limited power generation capabilities of small satellites, such as CubeSats, dictate the need for robust scheduling software. Limited communications windows drive a need for this scheduling to be performed onboard the spacecraft. The scheduling needs include long-term planning and near-real-time response capabilities. The scheduling approach must be power-conservative as attempting to run all onboard systems concurrently would, generally, far exceed the power generation capabilities and result in a brownout condition. This paper presents an autonomous, onboard scheduling approach for small satellites. It considers subsystem inter-dependency (where co-operation is required, desirable or prohibited), operational requirements and ground communication windows. It examines an optimal way of scheduling tasks for autonomous operation (which is required for scheduling when not in communication with ground controllers and desirable at all times during the mission). It compares a genetic algorithm-based approach, an exhaustive search-based approach and a heuristic-based approach. A data-driven requirement conflict resolution mechanism is also discussed. The benefits and detriments of these techniques are presented. The techniques are compared and performance maximization is considered (in light of both decision-making time-cost and reducing activity time-cost). The automatic fault-recovery techniques and payload/operating software separation implemented on the OpenOrbiter Spacecraft are also discussed.

8741-46, Session PSThu

Human and tree classification based on its model using 3D ladar in GPS-denied environment

Kuk Cho, Univ. of Science & Technology (Korea, Republic of); Seung-Ho Baeg, SangDeok Park, Korea Institute of Industrial Technology (Korea, Republic of)

This paper describes a method for a human and a tree classification based on their 3D geometric models in GPS-denied environment. To cooperate an unmanned ground vehicle (UGV) with a human, a leader should sequentially provide a local target position to the UGV without a human interference. The one of methods is that a trajectory of the leader becomes the local target position to the UGV. In a wooded mountain, the UGV needs to recognize a leader during both movements. However, the feature of a human and a tree are unclear to distinguish using a vision sensor and a 2D LRF sensor. Our approach makes a human and a tree models with 3D measurement and estimates them by a statistical classifier: kinematic B-spline model and neural network. For a human, the algorithm decomposes a human body into its main composition parts: a head, two arms, two legs, and a trunk. In case of a tree, it is constructed a stem, several branch, and some bush. Each part is a resource of a model and the composition of the objects is the feature for its classification. In conclusion, we show how to implement efficient human and tree detection and classification and how to track a leader.

8741-47, Session PSThu

Universal framework for unmanned systems penetration testing

Philip Kobezak, Sam Abbot-McCune, Virginia Polytechnic Institute and State Univ. (United States); Joseph Tront, Randy Marchany, Alfred Wicks, Virginia Tech (United States)

Multiple industries, from defense to medical, are increasing their use of unmanned systems. Today, many of these systems are rapidly designed, tested, and deployed. To aid the quick turnaround, commercially available subsystems and embedded components are often used. These components may introduce security vulnerabilities particularly if the designers do not fully understand their functionality and limitations. Because of this, there is a need for thorough testing of unmanned systems for security vulnerabilities, which includes all subsystems. Using a penetration testing framework would help find these vulnerabilities across different unmanned systems applications. The framework should encompass all of the commonly implemented subsystems including but not limited to, wireless networks, CAN buses, passive and active sensors, positioning receivers, and data storage devices. By looking at the unique characteristics of these subsystems, potential attacks and vulnerabilities can be identified. The framework will clearly outline the attack vectors as they relate to each subsystem. If any vulnerabilities exist, a mitigation plan can be developed prior to the completion of the design phase. Additionally if the vulnerabilities are known in advance of deployment, monitoring can be added to the design to alert operators of any attempted or successful attacks.

The proposed framework will help evaluate security risks quickly and consistently to ensure new unmanned systems are ready for deployment. Verifying that a new unmanned system has passed a comprehensive security evaluation will ensure greater confidence in its operational effectiveness.

8741-48, Session PSThu

The need for alternative munition integration on unmanned aircraft systems in order to bypass the identification problem

Mehmet Durkan, Ozgur Otkun, Ugur Uzunoglu, Turkish Air Force Academy (Turkey)

Hardships and obstacles on the identification phase of security operations are the most challenging problems for security decision makers. Due to changing nature of threats, security forces cannot exactly distinguish friend and foe. Furthermore, some detected groups can be a mixture of friend, foe and unidentified people. Because of these facts and problems, the decision process before using hard power on detected but unidentified groups is too complicated and results with late decision, wrong decision or no decision at all. From other glance, when the risk level is high and uncertainties are a lot, decision makers at medium level expect approval from upper level managers. Occasionally, security forces cannot use initiative and ask political seniors for their decision. To sum up; threat analysis is often difficult even impossible, the decision process is not timely and using initiative is not plausible in that kind of environment.

Air force has dynamic, flexible, agile and rapid effects on operational domain. If decision makers cannot decide to use this kind of force timely, it will not be effective as thought to be. In other words, identification problems decrease the core abilities of air power. As world market roadmaps show that unmanned aircraft systems will take the place of manned systems, air force executives should solve the above-mentioned problem in order to use UASs in security operations. In this study, the problem mentioned above is discussed widely and a solution is defined from the perspective of users.

8741-50, Session PSThu

A perspective of applications of unmanned systems in asymmetric warfare

Saban Adana, Isa Haskologlu, Ali Kemel Duzgun, Alper Alparslan Eker, Harp Akademileri Komutanligi (Turkey)

The history of war witnessed several technological innovations that fundemantally changed the battlefield. The ones who could adapt and improvise acccordingly dominated the others and became superpowers. (spear-arrow-horse-rifle-artillery-tanks-balistic missiles- computer Technologies-unmanned Technologies and cyber..) with this, asymmetric threats are increasingly beacoming a reality of our today's operating environment and most of the time technology does not seem to be the answer. Conventional armies need to adopt certain measures to counteract these threats that do not bind themselves with any kind of law. In this study, we will provide some insights on one of the measures, Unmanned technologies, and how they can be synchronized in to the overall operational planning."

8741-25, Session 7

Common world model for unmanned systems

Robert Dean, General Dynamics Robotic Systems (United States)

The Robotic Collaborative Technology Alliance (RCTA) seeks to provide adaptive robot capabilities which move beyond traditional metric algorithms to include cognitive capabilities. Key to this effort is the Common World Model, which moves beyond the state-of-the-art by representing the world using metric, semantic, and symbolic information. It joins these layers of information to define objects in the world. These objects may be reasoned upon jointly using traditional geometric, symbolic cognitive algorithms and new computational nodes formed by the combination of these disciplines. The Common World Model must understand how these objects relate to each other. Our world model includes the concept of Self-Information about the robot. By encoding current capability, component status, task execution state, and their histories we track information which enables the robot to reason and adapt its performance using Meta-Cognition and Machine Learning principles. The world model also includes models of how aspects of the environment behave which enable prediction of future world states. To manage complexity, we have adopted a phased implement approach to the world model. We discuss the design of "Phase 1" of this world model, discuss interfaces for metric, symbolic and meta-cognition by tracing perception data through the system from source to the meta-cognitive layers provided by ACT-R and SS-RICS, and close with lessons learned from implementation and how the design relates to Open Architecture.

8741-26, Session 7

Using expectations to monitor robotic progress and recover from problems

Unmesh Kurup, Christian Lebiere, Anthony Stentz, Martial Hebert, Carnegie Mellon Univ. (United States)

How does a robot know when something goes wrong? Our research answers this question by leveraging expectations – predictions about the immediate future – and using the mismatch between the expectations and the external world to monitor the robot's progress. We use the cognitive architecture ACT-R to learn the associations between the current state of the robot and the world, the action to be performed in the world, and the future state of the world. These associations are used to generate expectations that are then matched by the architecture with the next state of the world. A significant mismatch between these expectations and the actual state of the world indicate a problem possibly resulting from unexpected consequences of the robot's actions, unforeseen changes in the environment or unanticipated actions of other agents. When a problem is detected, the recovery model can suggest a number of recovery options. If the situation is unknown, that is, the mismatch between expectations and the world is novel, the robot can use a recovery solution from a set of heuristic options. When a recovery option is successfully applied, the robot learns to associate that recovery option with the mismatch. When the same problem is encountered later, the robot can apply the learned recovery solution rather than using the heuristics or randomly exploring the space of recovery solutions. We present results from execution monitoring and recovery performed during an assessment conducted at the Combined Arms Collective Training Facility (CACTF) at Fort Indiantown Gap.

8741-27, Session 7

Terrain identification for RHex-type robots

Camilo Ordonez, Jacob Shill, The Florida State Univ. (United States); Aaron M. Johnson, Univ. of Pennsylvania (United States); Jonathan Clark, Emmanuel G. Collins Jr., The Florida State Univ. (United States)

Terrain identification is a key enabling ability for generating terrain adaptive behaviors that assist both robot planning and motor control. This paper considers running legged robots from the RHex family, which the military plans to use in the field to assist troops in reconnaissance tasks. Important terrain adaptive behaviors include the selection of gaits, modulation of leg stiffness, and alteration of steering control laws that minimize slippage, maximize speed and/or reduce energy consumption. These terrain adaptive behaviors can be enabled by a terrain identification methodology that combines multiple proprioceptive sensors already available in RHex-type robots. The proposed classification

approach is based on the characteristic frequency signatures of data from leg encoders, motor current sensors, and the recently developed leg observers, which combine current sensing with a dynamic model of the leg motion. The leg observers are utilized here as an effective “software” sensor that filters out expected changes in motor current readings due to transitions between the flight and stance phases of the legs. The paper analyzes the classification accuracy obtained using both a single leg and groups of legs (i.e., leg tripods) on different outdoor terrains such as asphalt, grass, gravel, and dirt. Additionally, it investigates the robustness of the classification methodology to gait and speed changes.

8741-28, Session 7

An architecture for online semantic labeling on UGVs

Arne Suppe, Carnegie Mellon Univ. (United States); Luis Navarro-Serment, Carnegie Mellon University (United States); Daniel Munoz, Drew Bagnell, Martial Hebert, Carnegie Mellon Univ. (United States)

We describe an architecture to provide online semantic labeling capabilities to field robots operating in urban environments. At the core of our system is the stacked hierarchical classifier developed by Munoz et al., which classifies regions in monocular color images using models derived from hand labeled training data. The classifier is trained to identify buildings, several kinds of hard surfaces, grass, trees, and sky. When taking this algorithm into the real world, practical concerns with difficult and varying lighting conditions require careful control of the imaging process. First, camera exposure is controlled by software, examining all of the image’s pixels, to compensate for the limitations of the rudimentary algorithm used on the camera. Second, by merging multiple images taken with different exposure times, we are able to synthesize images with higher dynamic range than the ones produced by the sensor itself. The sensor’s limited dynamic range makes it difficult to, at the same time, properly expose areas in shadow along with high albedo surfaces that are directly illuminated by the sun. Texture is a key feature used by the classifier, and under/over exposed regions lacking texture are a leading cause of misclassifications. Finally, we present techniques to recover classification performance despite image artifacts produced in cases where the sun is imaged directly. The results of the classifier are shared with higher-level elements operating in the UGV in order to perform tasks such as building identification from a distance and finding traversable surfaces.

8741-29, Session 7

Features and representations for first-person human activity recognition

Michael S. Ryoo, Larry H. Matthies, Jet Propulsion Lab. (United States)

In this paper, we discuss human activity recognition methodologies to analyze videos obtained from a robot’s perspective. The objective is to enable recognition of dangerous and suspicious activities targeted to the robot (e.g., attacking the robot) from its first-person viewpoint, and provide it activity-level situation awareness for protection and more intelligent interactions. This paper compares various types of video features and representations for recognizing multiple categories of friendly, neutral, and hostile human activities. Together with baseline classifiers, features designed to capture global/local motion information of first-person videos are quantitatively evaluated, illustrating which feature/representation/classifier benefits the analysis of first-person videos most.

More specifically, we test several types of local spatio-temporal features and global motion features on our first-person video dataset obtained while humans are interacting with the robot. These activities include a negative interaction of ‘a person throwing an object to the robot’ and a neutral interaction of ‘two people having a conversation in front of a robot’. Histogram based representations (bag-of-words) of each feature type as well as their combinations to better represent these videos will be discussed and evaluated. The experimental results will enable explicit comparison of suitability of motion features for understanding first-person videos.

8741-30, Session 8

Performance of a scanning laser line striper in outdoor lighting

Christoph Mertz, Carnegie Mellon Univ. (United States)

For search and rescue robots and reconnaissance robots it is important to detect objects in their vicinity. We have developed a scanning laser line striper (C. Mertz et al.) that can produce dense 3D images using active illumination. The scanner consists of a camera and a MEMS-micro mirror based projector. It can also detect the presence of optically difficult material like glass and metal. The sensor can be used for autonomous operation or it can help a human operator to better remotely control the robot. In this paper we will evaluate the performance of the scanner under outdoor illumination, i.e. from operating in the shade to operating in full sunlight. We report the range, resolution and accuracy of the sensor and its ability to reconstruct objects like grass, wooden blocks, wires, metal objects, electronic devices like cell phones, RPG and other explosive devices. Furthermore we evaluate its ability to detect the presence of glass and polished metal objects. Lastly we report on a user study that shows a significant improvement in a grasping task. The user is tasked with grasping a wire with the remotely controlled hand of a robot. We compare the time it takes to complete the task using the 3D scanner with using a traditional video camera.

8741-31, Session 8

Visual and tactile interfaces for bi-directional human robot communication

Daniel J. Barber, Stephanie Lackey, Lauren Reinerman-Jones, Univ. of Central Florida (United States); Irwin Hudson, U.S. Army Research Laboratory, Simulation and Training Technology Center (United States)

Seamless integration of unmanned and systems and Soldiers in the operational environment requires robust communication capabilities. Multi-Modal Communication (MMC) facilitates achieving this goal due to redundancy and levels of communication superior to single mode interaction using auditory, visual, and tactile modalities. Visual signaling using arm and hand gestures is a natural method of communication between people. Visual signals standardized within the U.S. Army Field Manual and in use by Soldiers provide a foundation for developing gestures for human to robot communication. Emerging technologies using Inertial Measurement Units (IMU) and Electromyography (EMG) enable classification of arm and hand gestures for direction communication with a robot without the requirement of line-of-sight needed by computer vision techniques. These devices improve the robustness of interpreting gestures in noisy environments and are capable of classifying signals relevant to operational tasks. Closing the communication loop between Soldiers and robots necessitates them having the ability to return equivalent messages. Existing visual signals from robots to humans typically require highly anthropomorphic features not present on military vehicles. Tactile displays tap into an unused modality for robot to human communication. Typically used for hands-free navigation and cueing, tactile displays previously delivered equivalent visual signals from the U.S. Army Field Manual. This paper describes ongoing research into developing interfaces for classification of visual signals and communication with Soldiers using tactile displays, including examples involving live and virtual robotic platforms.

8741-32, Session 8

Dynamic whole-body robotic manipulation

Yeuhi Abe, Benjamin Stephens, Michael P. Murphy, Alfred A. Rizzi, Boston Dynamics (United States)

Using legs to augment and enhance manipulation capabilities of mobile robots has the potential to increase overall performance of robots in the field. In particular, lower limbs can be used to increase the strength, velocity, and workspace of the robot if used in coordination with manipulator arms, as we have shown previously on the BigDog platform with static foot placements. This increase in performance can be further extended by utilizing stepping motions in addition to leg forces to inject additional body momentum into a manipulated object, as well as to recover from a dynamic task and maintain balance, similar to how a discus thrower or baseball pitcher uses steps to maximize throwing performance. We present techniques and results of whole body dynamic manipulation on the BigDog platform with the task of throwing a 16kg cinder block. The challenge to a whole-body dynamic manipulation strategy is the coordination of the high degree of freedom system. This is especially challenging when operating at the limits of stability, where maximum performance is often achieved, because control authority on one or more degrees of freedom may be reduced due to actuator saturation, kinematic state, or stability requirements. We generate dynamic throwing behaviors by optimizing feed-forward inputs to the robot offline and then using feedback control schemes online to reject disturbances and overcome modeling errors. Videos of the real robot performing these behaviors are available.

8741-33, Session 8

Leaping experiments with a power-autonomous, compliant-spined quadruped

Jason L. Pusey, U.S. Army Research Lab. (United States); Jeffrey Duperret, Univ. of Pennsylvania (United States); G. Clark Haynes, National Robotics Engineering Ctr. (United States); Ryan Knopf, Daniel E. Koditschek, Univ. of Pennsylvania (United States)

We document initial experiments with Canid, a free-standing, power-autonomous quadrupedal robot equipped with an actuated compliant spine. Research into robotic bounding and galloping platforms holds scientific and engineering interest because it can both probe biological hypotheses regarding bounding and galloping mammals and also provide the engineering community with a new class of rapidly-locomoting legged robots. We very briefly review the biological literature concerning properties of high-speed mammalian runners and equally briefly compare Canid to a number of contemporary bounding robotic quadrupeds by way of identifying its specific distinguishing hypotheses regarding bioinspired compliant-spine locomotion. We then detail the design features of Canid that promote our goals in a relatively cheap, conventionally prototyped power-autonomous platform. Finally we present initial joint motor, inertial and motion capture data taken from Canid's initial leaps into regimes of high kinetic energy and large accelerations.

8741-34, Session 9

Collaborative experiments of small autonomous systems at the SOURCE ATO capstone experiment

Jason M. Gregory, David Q. Baran, U.S. Army Research Lab. (United States)

Autonomous systems operating in military-relevant environments are valuable assets due to the increased situational awareness that they provide to the Warfighter. To further progress the current state of these systems, a collaborative experiment was conducted as part of the Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments (SOURCE) Army Technology Objective (ATO). We present the findings from this large-scale experiment which spanned several research areas, including 3D mapping and exploration, communications maintenance, visual intelligence, platform characterization, and quadrotor development.

For 3D mapping and exploration, the evaluated capabilities encompassed loop closure using Iterative Closest Point (ICP), object classification-driven exploration, autonomous, outdoor exploration, collaborative mapping using ground robots, and collaborative mapping using off-the-shelf quadrotors. To improve current communications systems, the limitations of an existing mesh network were analyzed and a distributed state information sharing system using the Dandelion protocol was tested. Further, an algorithm to map pairwise radio connectivity during exploration of indoor environments was evaluated. Using a Point Grey Chameleon camera, data was collected to assess the performance of existing visual localization algorithms and experimental semantic filtering algorithms. Similarly, camera data from a Microsoft Kinect was used to test autonomous stairway detection and modeling algorithms. A platform-specific model was created so that empirically-determined predictions of slip conditions could be added to the control loop for more reliable control. Finally, the current state of station-keeping and waypoint navigation capabilities wer assessed using quadrotors. This paper will detail the experiment procedure and the preliminary results for each of these tests.

8741-35, Session 9

Achieving integrated convoys: Cargo Unmanned Ground Vehicle development and experimentation

Noah Zych, Oshkosh Corp. (United States); David Silver, David Stager, Carnegie Mellon Univ. (United States); Colin Green, Thomas Pilarski, Robotics Institute, Carnegie Mellon Univ. (United States); Jacob Fischer, Oshkosh Corp. (United States)

The Cargo UGV project was initiated in 2010 with the aim of developing and experimenting with advanced autonomous vehicles capable of being integrated unobtrusively into manned logistics convoys. The intent was to validate two hypotheses in complex, operationally representative environments: first, that unmanned tactical wheeled vehicles provide a force protection advantage by creating standoff distance to warfighters during ambushes or improvised explosive device attacks; and second, that these UGVs serve as force multipliers by enabling a single operator to control multiple unmanned assets.

To assess whether current state-of-the-art autonomous vehicle technology was sufficiently capable to permit resupply missions to be executed with decreased risk and reduced manpower, and to assess the effect of UGVs on customary convoy tactics, the Marine Corps Warfighting Laboratory and the Joint Ground Robotics Enterprise sponsored Oshkosh Defense and the National Robotics Engineering Center to equip two standard Marine Corps cargo trucks for autonomous operation.

This paper details the system architecture, hardware implementation, and software modules developed to meet the vehicle control, perception, and planner requirements compelled by this application. Additionally, the design of a custom human machine interface and an accompanying training program are described, as is the creation of a realistic convoy simulation environment for rapid system development.

Finally, results are conveyed from a warfighter experiment in which the effectiveness of the training program for novice operators was assessed, and the impact of the UGVs on convoy operations was observed in a variety of scenarios via direct comparison to a fully manned convoy.

8741-36, Session 9

Mobile dexterous manipulator for material handling and shipping box loading and unloading

Yi-Je Lim, John Hu, Jayson Ding, Robert Hsiung, 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 and military ISO containers, operate safely around humans, with dexterity sufficient to unlock and open cargo doors. In this presentation we will discuss the technology and application challenges of Hstar's 'a mobile Dexterous Manipulator (D-Man) project, and describe a solution architecture that we believe will prove applicable to a wide range of uses.

The Hstar D-Man product line brings an 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 compliance arm, strength to pick up and move up to 300 pound objects, and a holonomic mobile platform with robotic navigation control, augmented by semi-autonomous container door opening, and dexterous manipulation of shipping boxes. D-Man incorporates innovative compliant actuation technology, an advanced robotic hand and robust perception sensors.

This presentation will highlight the diverse challenges relating to designing and implementing a robust, autonomous freight handling system, including system architecture for telepresence and direct control; human-safe, 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.

8741-37, Session 9

MTRS-scale combat engineer vehicle mechanisms, behaviors and capabilities

Gary Witus, Wayne State Univ. (United States); Douglas C. MacKenzie, Todd A. Kappauf, Mobile Intelligence Corp. (United States)

This paper describes the design and performance of MTRS-scale manipulators modeled after combat engineer vehicle mechanisms for obstacle breaching and terrain improvement. The manipulators were implemented as attachments for a "Badger" robot platform. The manipulators include a 3-degree-of-freedom front loader with a grapple bucket (used TARDEC's Canine competition) and a 3-degree-of-freedom excavator arm with pick and shovel. The front loader can be modified, with different motion patterns, to act as a fork lift. The capture behavior with the front loader was modeled after a canine animal behavior pattern: lower head with open mouth, run forward to scoop up the object while closing the mouth, then raise the head. The excavator arm is also capable of self-extrication of mobile robot stuck in a ditch, at a vertical obstacle, or high centered. This paper describes the engineering design and performance envelopes.

8741-38, Session 9

Development of a non-contextual model for determining the autonomy level of intelligent unmanned systems

Phillip J. Durst, Wendell Gray, U.S. Army Engineer Research and Development Ctr. (United States); Michael Trentini, Defence R&D Canada - Suffield (Canada)

A simple, quantitative measure for encapsulating the autonomous capabilities of intelligent unmanned systems (UMS) has yet to be established. Several models for measuring a UMS's autonomy level have been proposed, most notably the Autonomy Levels for Unmanned Systems (ALFUS), but these models require extensive, operational level testing of the UMS and provide a means for assessing the autonomy level for a specific mission/task and operational environment. A more robust technique for quantifying autonomy using component level testing of the UMS platform alone, outside of mission and environment context, is desirable. In search of such a technique, a generic, high-level model of UMS architectures defining the UMS's hardware and software systems was developed. Using this high level framework for UMS architectures, a new model for determining UMS level of autonomy was developed. The model uses a combination of developmental and component level testing for each aspect of the UMS architecture to define a non-contextual autonomous potential (NCAP). The NCAP provides an autonomy level, ranging from fully non-autonomous to fully autonomous, in the form of a single numeric parameter describing the UMS's performance capabilities. It defines a predictive measure of an autonomous UMS's potential performance as opposed to a retroactive measure of autonomous performance. Presented in this paper are the UMS architecture model developed, the NCAP model for determining autonomy level, a comparison between the NCAP and the ALFUS, some example applications of the NCAP to several commercially available UMS, and plans for future development and refinement of the NCAP.

8741-39, Session 9

Simple but novel standards for quantitatively comparing robot mapping algorithms, using SLAM and dead reckoning as controls

Neil S. Davey, Haris Godil, National Institute of Standards and Technology (United States)

Storage and retrieval of goods in banks, military arsenals, or factories could be made much more efficient and error-free with the use of autonomous robots. A system for robotically retrieving and storing goods requires accurate map-making. Map-making algorithms in the past have been analyzed by comparing the map of an area generated by an algorithm to a ground truth map, an actual blueprint map of an area. This method does not show which parts of the algorithm are more accurate and how much more accurately the algorithm performs in a specific aspect of mapping. We created a new method for evaluating map-making algorithms by separating mapping into five main base-case scenarios and comparing the effectiveness of all algorithms at each scenario. In our experiments, we used the P3DX, a skid-based turning robot, and tested ROS's (Robot Operating System) SLAM (Simultaneous Localization and Mapping) algorithm by comparing it to a standard Dead Reckoning algorithm. The data indicated that SLAM was overall a better map-making algorithm than Dead Reckoning, as it excelled in a majority of the base-case scenarios. With improved mapping, robots can be used in a multitude of environments to store and retrieve goods.

8741-49, Session 9

Development of a spherical aerial vehicle for urban search

Kang Hou, Hanxu Sun, Qingxuan Jia, Beijing Univ. of Posts and Telecommunications (China)

SAV (small aerial vehicle) is one of the hottest research fields in robotics because of its low cost, operational environment, and small size. It is a kind of person-portable aircraft which has flexible movement in the relatively small areas. Spherical aerial vehicle is a new and novel kind of small aerial vehicles in the last few years. Compared with other conventional small aerial vehicles, spherical air vehicle has significant advantages due to its special structure. It has a spherical hollow shell to protect the propeller, motor systems, all control circuits, and power supply devices inside. And the spherical shell should be made to result in little loss of rotor system aerodynamic efficiency. Due to the characteristics of its structure, the spherical air vehicle can effectively protect its inner parts with the spherical shell when the vehicle lands on the ground in any posture. In this paper, the spherical aerial vehicle and its aerodynamics model is presented and studied. Firstly, the unique structure and features of spherical aerial vehicle are introduced in detail. And then the aerodynamics theory based on this vehicle's structure is analyzed, and the equations of force and moment acting on the spherical aerial vehicle were deduced. Due to the above analysis, the aerodynamics model based on the unique structure features of spherical aerial vehicle is established and derived to get the relationship between the aircraft physical parameters and the aerodynamics parameters. At last, the simulations and experimental results are provided to confirm the feasibility of the spherical aerial vehicle's aerodynamics theory and model.

8741-40, Session 10

Robust speech recognition and speaker identification in noisy environments

Ranga Narayanaswami, Raman K. Mehra, Scientific Systems Co., Inc. (United States)

Speech recognition is of primary importance in several applications including, robot control and interaction, unattended ground vehicles (UGV), automatic call routing and answering systems, and audio-based search of databases and data mining. Speech recognition and speaker identification are both challenging problems, particularly with respect to robustness, which arises from environmental noise, reverberation, channel distortion, computational limitations on small form factor devices such as mobile phones and tablets.

We present our recent research on Speaker Identification and Speech Recognition using beamforming with multiple microphones. The beamformer approach has two significant advantages in this context. First, it can significantly improve the signal to noise ratio (SNR), second, it can be used for delay estimation as an additional input in estimating the direction of the sound source, speaker identification and speaker tracking, and identifying a new speaker. Both single channel (spectral subtraction, cepstral mean normalization) as well as multichannel algorithms (beamforming, blind source separation) are applied for robustness. We perform Speaker identification using Gaussian Mixture Models (GMM) as well as delay estimation from the beamformer, which gives better results than only relying on the speech signal. Speech recognition is done through speech recognition toolkits (PocketSphinx and HTK).

We present our results on speaker identification and speech recognition with multiple speakers at a conference table. Speaker identification is performed using a combination of delay estimation, online building of GMM models for a speaker and pitch tracking. Speech recognition is performed using the PocketSphinx/HTK speech recognition engines with SNR improvement from the beamformer.

The research results indicate that a multi microphone beamforming approach is feasible for small handheld devices and offers a robust method for audio based control of robots, UGV and teleoperated vehicles. Our direction of ongoing research and discussion includes:

Development of Compact Beamformer

- Shrink to small form factor for use with a hand-held device as a clip on device

- Try to be as close to a COTS system as possible

- Suitable electronics for data acquisition and hardware based beamforming

Robustness of Beamformer

- Provide tilt and accelerometer sensors to keep track of hand-held orientation when moved

- Voice Training on Beamformer

Train speech recognition engine on beamformer

- Develop better microphone adaptation algorithms

- Develop better speaker adaptation algorithms

Environmental Robustness

- Consider frequency invariant beamforming as well as noise cancellation by spectral subtraction, echo and reverberation cancellation

Microphone adaptation

- Consider microphone adaptation techniques for robust speech recognition

Speaker ID

- Implement speaker tracking by beamforming and GMM models for

speaker ID

User Interface

- Develop graphical layouts and user interface for audio-based control, transcription, Speaker ID

8741-41, Session 10

A preliminary cyber-physical security assessment of the robot operating system (ROS)

Jarrod McClean, Harvard Univ. (United States); Christopher J. Stull, Charles R. Farrar, David L. Mascarenas, Los Alamos National Lab. (United States)

Over the course of the last few years, the Robot Operating System (ROS) has become a highly popular software framework for robotics research. ROS has a very active developer community and is widely used for robotics research in both academia and government labs. The prevalence and modularity of ROS cause many people to ask the question, "What prevents ROS from being used in commercial or government applications." One of the main problems that is preventing the use of ROS in these applications is the question of characterizing its security. In the summer of 2012, a crowd-sourced cyber-physical security contest was launched at the cyber-security conference DEFCON-20 to begin the process of characterizing ROS. A small-scale, car-like robot was configured as a cyber-physical security research honeypot running ROS. DEFFCON-20 attendees were invited to find exploits and vulnerabilities in the robot while data on network traffic was collected. The results of this experiment provided some interesting insights and opened up many security questions pertaining to deployed robotic systems. The Federal Aviation Administration is tasked with opening up the civil airspace to commercial drones by September 2015 and driverless cars are already legal for research purposes in a number of states. Given the integration of these robotic devices into our daily lives, the authors pose the following question: "What security exploits can a motivated person with little-to-no experience in cyber security execute, given the wide availability of free cyber security penetration testing tools such as Metasploit. This research focuses on applying common, low-cost, low-overhead, cyber-attacks on a robot featuring ROS. This work documents the effectiveness of those attacks.

8741-42, Session 10

UGV: security analysis of subsystem control network

Sam Abbott-McCune, Philip Kobezak, Virginia Polytechnic Institute and State Univ. (United States); Al Wicks, Joseph Tront, Randy Marchany, Virginia Tech (United States)

Unmanned Ground vehicles (UGVs) are becoming prolific in the heterogeneous superset of robotic platforms. The sensors which provide odometry, localization, perception, and vehicle diagnostics are fused to give the robotic platform a sense of the environment it is traversing. The automotive industry CAN bus has dominated the industry due to the fault tolerance and the message structure allowing high priority messages to reach the desired node in a real time environment. UGVs are being researched and produced at an accelerated rate to preform arduous, repetitive, and dangerous missions that are associated with a military action in a protracted conflict. The technology and applications of the research will inevitably be turned into dual-use platforms to aid civil agencies in the performance of their various operations. Our motivation is security of the holistic system; however as subsystems are outsourced in the design, the overall security of the system may be diminished. We will focus on the CAN bus topology and the vulnerabilities introduced in UGVs and recognizable security vulnerabilities that are inherent in the communications architecture. We will show how data can be extracted from an add-on CAN bus that can be customized to monitor subsystems. The information can be altered or spoofed to force the vehicle to exhibit unwanted actions or render the UGV unusable for the designed mission. The military relies heavily on technology to maintain information dominance, and the security of the information introduced onto the network by UGVs must be safeguarded from vulnerabilities that can be exploited.

8741-43, Session 10

The characteristics of future UAVs against asymmetric threats

Ugur Uzunoglu, Mehmet Durkan, Turkish Air Force Academy (Turkey)

Countries threat perceptions have changed after the Cold War. During last 20-30 years, a conventional war has been occurred in few regions. Nowadays, asymmetric threats such as terrorism, illegal formations, insurgency, counterinsurgency etc. become the biggest national security problem. Countries use their national forces against asymmetric threats in different ways. The countries have airpower as a unique asymmetric power against these kind of threats. Afghanistan and Libya operations are validating this argument.

Air power have been using unmanned aircraft vehicles (UAVs) against asymmetric threats at attack and ISR functions. Different UAVs will be produced in the future. When we think the future operational environments, the UAVs should have artificial intelligence for evaluation and decision making. With the help of this kind of UAVs, we can have force structure with that ISR, C2, attack and evaluation functions can be made at the same time.

In this study, characteristics of such UAVs are described and modelled with the help of value focused thinking method.

8742-2, Session 1

Context-rich semantic framework for effective data-to-decisions in coalition networks

Keith Grueneberg, Geeth de Mel, IBM Thomas J. Watson Research Ctr. (United States); David Braines, IBM United Kingdom Ltd. (United Kingdom); Seraphin Calo, Xiping Wang, IBM Thomas J. Watson Research Ctr. (United States); Tien Pham, - (United States)

IIn a coalition environment, data fusion involves combining soft data (e.g., field reports, intelligence reports) and hard data (e.g., acoustic sensory data, imagery) such that the resulting output provides a richer basis for making decisions than what would have been possible if the data were taken individually. However, due to the lack of explicit semantics attached with such data, it is difficult to automatically disseminate and put the right contextual data in the hands of the decision makers. In order to understand the data, explicit meaning needs to be added by means of categorizing and/or classifying the data in relationship to each other from base reference sources.

In this paper, we present a semantic framework that provides automated mechanisms to expose real-time raw data effectively by presenting appropriate information needed for a given situation so that an informed decision could be made effectively. The system utilizes controlled natural language capabilities provided by the ITA (International Technology Alliance) Controlled English (CE) toolkit. CE provides a human-friendly semantic representation language that is directly processible in human/machine hybrid environments. The semantic enrichment service adds relevant contextual information to raw data streams from domain knowledge bases using declarative rules. The rules define how the added semantics and context information are derived and stored in a semantic knowledge base. The software framework exposes contextual information from a variety of hard and soft data sources in a fast, reliable manner so that an informed decision can be made using semantic queries in intelligent software systems.

8742-3, Session 1

A system architecture for decision-making support on ISR missions with stochastic needs and profit

Nan Hu, Thomas F. LaPorta, The Pennsylvania State Univ. (United States); Diego Pizzocaro, Alun D. Preece, Cardiff Univ. (United Kingdom)

In this paper, we propose a system architecture for decision-making support on ISR (i.e. Intelligence, Surveillance, Reconnaissance) missions via optimizing resource allocation. We model a mission as a graph of tasks, each of which often requires exclusive access to some resources. Our system guides users through refinement of their needs through an interactive interface. To maximize the chances of executing new missions, the system searches for pre-existent information collected on the field that best fit the needs. If this search fails, a set of new requests representing users' requirements is considered to maximize the overall benefit constrained by limited resources. If an ISR request cannot be satisfied, feedback is generated to help the commander further refine or adjust their information requests in order to still provide support to the mission. In our work we model both demands for resources and the importance of the information retrieved realistically in that they are not fully known at the time a mission is submitted and may change overtime during execution. The amount of resources consumed by a mission may not be deterministic; i.e., a mission may last slightly longer or shorter than expected, or more of a resource may be required to complete a task. Furthermore, the benefits received from the mission, which we call profits, may also be non-deterministic; e.g. successfully localizing a vehicle might be more important than expected for accomplishing the entire operation. Therefore, when satisfying ISR requirements we take into account both constraints on the underlying resources and uncertainty of demands and profits.

8742-5, Session 2

The terra harvest open software environment: remote interface

Kevin Klawon, Kristen M. Bachman, Joshua Gold, Univ. of Dayton Research Institute (United States)

The DIA wants to create an UGS controller that is interoperable across all controller platforms, capable of easily adding new sensors, radios, and processes, etc., as well as backward compatibility with existing UGS systems. To achieve this, a Terra Harvest controller was created that used Java JRE 1.6 and an OSGI platform, name Terra Harvest Open Software Environment (THOSE). OSGI is an extensible framework that provides a modularized environment that allows functionality to be deployed in "bundles". These bundles can publish, discover, and share services available from other bundles or bundles provided by the controller core. A nature step was then to correct a common remote interface that allows 3rd party real-time interaction with the controller.

This paper will give you architectural overview of the remote interface, including how to interact with the controller via the remote interface including an overview of the ICD for the remote interface.

8742-6, Session 2

How to use the terra harvest open software environment (THOSE): GUI

Kevin Klawon, Nicholas Marcucci, David Humeniuk, Univ. of Dayton Research Institute (United States)

The DIA wants to create an UGS controller that is interoperable across all controller platforms, capable of easily adding new sensors, radios, and processes, etc., as well as backward compatibility with existing UGS systems. To achieve this, a Terra Harvest controller was created that used Java JRE 1.6 and an OSGI platform, name Terra Harvest Open Software Environment (THOSE). OSGI is an extensible framework that provides a modularized environment that allows functionality to be deployed in "bundles". These bundles can publish, discover, and share services available from other bundles or bundles provided by the controller core. The next step the project was to create a GUI interface that interacts with the THOSE.

This paper will give you architectural overview and then show you how to use the THOSE GUI to deploy a bundle for your asset, communications device, or algorithms; plan missions, configure assets and communication devices real-time; command and control of assets, and viewing of operations of the various assets, etc.

8742-7, Session 2

Development of terra harvest compliant plug-ins for McQ unattended ground sensors (UGS)

Brent W. Roeder, Robert C. Fish, McQ, Inc. (United States)

The Army Research Lab (ARL) in collaboration with the Defense Intelligence Agency (DIA) and representatives from industry recently validated the feasibility of the Terra Harvest architecture by successfully integrating dozens of Intelligence, Surveillance, and Reconnaissance (ISR) assets at the Trident Spectre 12 (TS12) exercise in Fort Story, VA. Based on the exercise, it is evident that Terra Harvest will greatly simplify the process of integrating disparate ISR systems. By reducing this complexity, Terra Harvest will increase the variety of devices U.S. soldiers have at their disposal giving them a greater technological advantage over their adversaries than ever before. This paper describes McQ's effort to develop Terra Harvest compliant plug-ins for its UGS and the results of their demonstration.

8742-41, Session 2

Using advanced manufacturing to produce unmanned aerial vehicles

Michael A. Balazs, Jonathan Rotner, The MITRE Corp. (United States); Steven Easter, Jonathan Turman, Dave Sheffler, Univ. of Virginia (United States)

No Abstract Available.

8742-42, Session 2

UGS SWG and terra harvest overview *(Invited Paper)*

No Abstract Available.

8742-8, Session 3

Slew to cue of persistent imagers using ground sensors

Thomas W. Walker, Nino Srour, U.S. Army Research Lab. (United States)

No abstract available.

8742-9, Session 3

ISR information: new paradigms, priorities and interoperability…everything your mother was afraid to tell you *(Invited Paper)*

Michael A. Kolodny, U.S. Army Research Lab. (United States)

No abstract available.

8742-11, Session 3

Demonstration of the terra harvest controller architecture

Gary H. Stolovy, U.S. Army Research Lab. (United States)

This paper will discuss the integration and demonstration of multiple sensor assets into the Terra Harvest controller architecture for Unattended Ground Sensors (UGS).

8742-12, Session 4

U.K. MoD land open system architecture and coalition interoperability with the U.S.

Gavin Pearson, Defence Science and Technology Lab. (United Kingdom); Michael A. Kolodny, U.S. Army Research Lab. (United States); Tien Pham, - (United States)

The UK Land Open System Architecture (LOSA) is an open, service-based architecture for systems integration and interoperability in the land environment. It is being developed in order to deliver coherent and agile force elements at readiness to operations. LOSA affects planning, delivery and force generation, and supports Future Force 2020.

LOSA aims to combine the progress made with the Generic Vehicle Architecture (GVA, DefStan 23-09), Generic Base Architecture (GBA, DefStan 23-13) and Generic Solider Architecture (23-12)

This paper will review the objectives of LOSA and the progress made to date; before focusing on the Oct 2012 experimental period undertaken in the UK at Caerwent by a combined MoD (Ministry of Defence) and Industry team. This experiment focused on data and power interoperability across the LOSA pillars of Soldiers, Vehicles and Bases.

8742-13, Session 4

Practical experience in deploying and controlling the data sharing interoperability layer at the UK land open systems architecture (LOSA) field trials in October 2012

Flavio Bergamaschi, Dave Conway-Jones, IBM United Kingdom Ltd. (United Kingdom); Gavin Pearson, Defence Science and Technology Lab. (United Kingdom)

In October 2012 the UK MoD sponsored a multi-vendor field integration exercise in support of its Land Open Systems Architecture (LOSA), an open, service based architecture for systems integration and interoperability which builds on the progress made with the Generic Vehicle Architecture (GVA, DefStan 23-09), Generic Base Architecture (GBA, DefStan 23-13) and the Generic Soldier Architecture (DefStan 23-12) programs.

The aim of this exercise was to experiment with a common data and power interoperability across and in support of the Soldier, Vehicles and Bases domains.

This paper presents an overview of the field exercise and discusses in details how the ITA Information Fabric, technology originated in the US and UK International Technology Alliance program, was extended to support the control of the data interoperability layer across various data bearers. This includes:

- interoperability and information sharing across multiple stove piped and legacy solutions,

- command and control and bandwidth optimization of streamed data (e.g. video) over a peer-to-peer ad-hoc network across multiple domains

- integration of disparate sensor systems,

- integration with DDS based C2 systems.

8742-14, Session 4

Future interoperability of camp protection systems (FICAPS)

Sylvie Caron, Direction Générale de l'Armement (France); Rainer Gündisch, Wehrtechnische Dienststelle für Schutz- und Sondertechnik (Germany); Karl-Hermann Stahl, Rheinmetall

Defence Electronics GmbH (Germany); Alain Marchand, TDA Armements S.A.S. (France)

The FICAPS Project has been established as a Project of the European Defence Agency based on an initiative of Germany and France.

Goal of this Project was to develop Interoperability Guidelines in terms of operational and technical requirements and definitions to allow:

· Real-time information exchange between equipments and systems of different suppliers and nations,

· Quick and easy replacement of equipments at run-time in the field by means of plug and play capability,

· Enhancement of system capabilities in the field by adding new equipments with new capabilities,

· Remote control of a system with its equipments by another system.

The guide lines have defined the IP-based Data Distribution Service (DDS) standardised by the OMG as basis for any information exchange between equipments and systems.

Different sensors and effectors have been defined. Detailed data models have been developed for EO/IR-Sensors and for Directional Effectors, both on Pan/Tilt-Platform, and for the Information exchange between Systems.

To allow integration of legacy equipments “Interoperability Adapter” have been foreseen to convert proprietary interfaces to standardised interface definition.

To prove the Guidelines, a French and a German Demonstration System have been prepared (based on legacy equipments).

Demonstrations have been performed. The required interoperability functionality was shown successfully.

Even if the focus of the FICAPS project was on camp protection, the solution found is also appropriate for other force protection and ISR tasks not only due to its flexibility but also due to the chosen interfacing.

8742-15, Session 4

Coalition warfare program (CWP) project on policy controlled information query and dissemination

Andrew Toth, U.S. Army Research Lab. (United States); Todd Karr, NATO Intelligence Fusion Ctr. (United Kingdom); Graham A. Bent, Dominic Harries, IBM United Kingdom Ltd. (United Kingdom)

In 2006, the US Army Research Laboratory (ARL) and the UK Ministry of Defence (MoD) established a collaborative research alliance with academia and industry, called the International Technology Alliance (ITA) to address fundamental issues concerning Network and Information Sciences. Under the ITA research program, a US-UK transition project on “ITA Policy Controlled Information Query & Dissemination” was funded in 2011 by OSD’s Coalition Warfare Program (CWP). The goal of this CWP project is to develop an extensible capability of performing distributed federated query and information dissemination across a coalition network of distributed disparate data/information sources with access control policies.

The CWP project is lead by US Army Research Laboratory (ARL) and UK Defence Science Technology Laboratory (Dstl) with software development by IBM UK and IBM US. The CWP project exploits two key technology components developed within the ITA, namely the Gaian Database and integrated Access Policy Decision and Enforcement mechanisms. The Gaian Database (GaianDB) is a Dynamic Distributed Federated Database (DDFD) that addresses a need to share information among coalition members by providing a means for policy-controlled access to data across a network of heterogeneous data sources. GaianDB implements a SQL-compliant Store-Locally-Query-Anywhere (SLQA) approach providing software applications with global access to data from any node in the database network via standard SQL queries. Security policy is stored locally and enforced at the database node level, reducing potential for unauthorized data access and waste of network bandwidth.

The paper discusses the CWP project and the two key technologies (Gaian Database and integrated Access Policy Decision and Enforcement mechanisms) developed within the US-UK ITA research program. Also covered are the CWP technology demonstration at the NATO Intelligence Fusion Centre (NIFC) in January 2013, extensions to the Kerberos protocol necessary for integration into the NIFC, source data parsing for Analysts, and future plans for the program.

References:

G. Bent, P. Dantressangle, D. Vyvyan, A. Mowshowitz and V. Mitsou. “A dynamic distributed federated database.” Second Annual Conference of ITA, Imperial College, London, September 2008.

A. Toth, T. Pham, T. Karr, G. Bent, and D. Harries. “Coalition Warfare Program (CWP) Project on Policy Controlled Information Query & Dissemination.” NATO IST112/SET813 Symposium on “Persistent Surveillance: Networks, Sensors, Architecture”, April 2012.

G. Bent, D. Harries, and A. Toth. “Extending the Kerberos Protocol for Distributed Data as a Service.” Annual Conference of the ITA, September 2012.

8742-16, Session 4

Flexible procedural interoperability across security and coalition boundaries using rapidly re-configurable boundary protection definitions

Nicholas Peach, 2IC Limited (United Kingdom)

Existing configuration of boundary protection devices, which validate the content and context of information crossing between security domains, uses a set of accreditor-agreed steps individually agreed for every situation. This has traditionally been a slow and exacting process of negotiation between integrators and accreditors. The Decentralised Operation Procedure (DOP) technique allows interoperability definitions of system interactions to be created as XML files and deployed across the battlefield environment. By extending the security information definitions within the DOP technique, the additional information will allow boundary protection devices to utilise a DOP XML file and apply the required standards of security. This allows boundary devices to be updated simultaneously with the deployment of new DOP definitions to exploit coalitional capabilities having crossed security boundaries.

The paper describes an open and published boundary definition to support the aims of the MOD 23-13 Generic Base Architecture Defence Standard when working with coalition partners. The research aims are; a) to identify each element within a DOP that require security characteristics to be described; b) create a means to define security characteristics using XML; c) determine whether external validation of an approved DOP requires additional authentication; d) determine the actions that end users will have to perform on boundary protection devices in support of these aims.

The paper will present the XML security extensions and the results of a proof of concept implementation extending the functionality of an existing accredited barrier device.

8742-17, Session 5

The science of autonomy: integrating autonomous systems with the ISR enterprise

Gregory Creech, U.S. Dept. of Defense (United States)

Consider a future where joint, unmanned operations are the norm. A fleet of autonomous airborne systems conducts overwatch and surveillance for their land and sea brethren, accurately reporting adversary position and aptly guiding the group of autonomous land and sea warriors into position to conduct a successful takedown. Sounds a bit like science fiction, but reality is just around the corner. The DoD ISR Enterprise has evolved significantly over the past decade and has learned many a harsh lesson along the way. Autonomous system operations supporting the warfighter have also evolved, arguably to a point where integration into the broader ISR Enterprise is a must, in order to reap the benefits that these highly capable systems possess. Achieving meaningful integration, however, is not without its challenges. The ISR Enterprise, for example, is still plagued with "stovepipe" efforts – sufficiently filling a niche for an immediate customer need, but doing little to service the needs of the greater enterprise. This paper will examine the science of autonomy, the challenges and potential benefits that it brings to the ISR Enterprise and recommendations that will facilitate smooth integration of emerging autonomous systems with the mature suite of traditional manned and unmanned ISR platforms.

8742-18, Session 6

NATO SET battlefield acoustics sensing activities *(Invited Paper)*

Michael V. Scanlon, U.S. Army Research Lab. (United States)

Acoustic sensing and networked multimodal sensor fusion have been ongoing areas of research within the NATO Sensors & Electronic Technology (SET) Task Groups. The US Army Research Laboratory has led numerous SET groups over the years, and the successful international collaborations have helped advance the state-of-the-art in networked acoustic sensing. The presentation will include descriptions and experiments from the current SET-189 on "Battlefield Acoustic Sensing, Multi-modal Sensing and Networked Sensing for ISR Applications," and previous SET-142 on "Acoustics & Autonomous Sensing for ISR Applications" (2009-12), SET-093 on "Advanced Concepts of Acoustic & Seismic Sensor Technology" (2005-08), and SET TG-25 "Sniper Detection and Unattended Ground Sensors" (Early 2000's). Current SET-189 participants include NATO, Partners-for-Peace, and Mediterranean Dialogue countries.

8742-19, Session 6

Hostile fire indicator threat data collection for helicopter-mounted applications

Pierre Naz, Sebastien De Mezzo, Sébastien Hengy, Institut Franco-Allemand de Recherches de Saint-Louis (France)

This paper briefly describes the set-up of the sensors and the instrumentation deployed by the French-German Research Institute of Saint-Louis (ISL) during the last NATO/ACG3/SG2 HFI Threat Data Collection (Trial PROTEUS which has been conducted during the summer 2012 in Slovenia). The main purpose of this trial was the measurements of weapon and ammunition signature for threat warning / hostile fire indicator (HFI) system development. Weapons vary from small caliber rifles to anti-tank rockets in ground-to-ground shooting configurations. For the ISL team, the objectives consisted in measuring the acoustic signals for detection and localization of weapon firing events. Experimental results of sound waves obtained using ground based sensors are presented and analyzed for snipers shots obtained in various conditions.

This work is included in national/international efforts for the development of Hostile Fire Indicator for helicopters taking into account small caliber guns, RPG, rockets or missiles. For small caliber weapons, acoustic detection may provide valuable and complementary data to increase the protection capabilities of helicopters. On the other hand the integration on such a platform is challenging due to flow noise, engine and rotor noise. This paper briefly describes the main constrains for such an application.

8742-21, Session 6

River as a part of ground battlefield

Miodrag S. Vracar, Ivan P. Pokrajac, Predrag Okiljevic, Military Technical Institute (Serbia)

The rivers are in some circumstances part of ground battlefield. Elastically deformations of the riverbed and ground at the river surrounding might be consequence of the military activities (military ground transports, explosions, troop's activities, etc). Vibrations of those fluid-solid structures are modeled in terms of solid displacement and fluid pressure. This time varying fluid pressure in river, which originates from ground vibrations, is possible measure with hydrophones. Therefore, hydroacustic measurements in rivers enable detecting, identification and localization of various military activities at the ground (ground vibrations) as and those, which originate in river water (hydrodynamics of water flow, wind, waves, river vessels, etc). In this paper are presented river ambient noise measurements of the three great rivers: the Danube, the Sava and the Tisa, which flows in north part of Serbia in purpose to establish limits in detection of the ground vibrations in relatively wide frequency range from zero to 20 kHz. Parallel analysis of the ground vibrations induced by military vehicle is performed experimentally by geophone placed in ground and hydrophone in the river. Event classification is based on poly spectral analysis.

8742-22, Session 7

Air route selection for improved air-to-ground situation assessment

Marc Oispuu, Massimo Sciotti, Alexander Charlish, Fraunhofer FKIE (Germany)

Situation Assessment from airborne platforms implies collecting information on the entities (e.g., people, vehicles) evolving in the scenario, and inferring the relations among them and with the surrounding environment. Well-established Ground Moving Target Indication (GMTI) techniques provide positional/kinematics data, and estimates of target features/identity. These reports are inputs for higher inference techniques devoted to Situation and Impact Assessment (JDL Data Fusion Level 2-3). Consequently, the estimated "Situation/Impact" can be seen as an error-affected estimate of the "ground truth", hence subject to improvement by properly steering the data acquisition process.

Specifically, we consider the selection of the aircraft route on the basis of long-term prediction of the tactical picture, i.e., the "Situation" inferred at Level-2. Our target state is composed by positional, kinematics and behavioral components, as estimated from GMTI reports, context information (e.g., streets, tunnels, buildings), and observed target relationships. The optimization problem is solved globally, by taking into account all sources of uncertainty. Specifically, we model the processing scheme through a context-aided Particle Filter with feedback from a Bayesian Network, devoted to inferring target behavior. The optimization goal is to maintain the required accuracy on the long-term predicted target state. This implies predicting the accuracy of each track in advance, as a function of the environment (e.g., sensor obstructions), and the likely paths followed by the target. Taking inspiration from Cramér-Rao-Bound (CRB) based optimization techniques, the best observation geometry is calculated iteratively over discrete time intervals, hence identifying the aircraft route with highest payoff.

8742-23, Session 7

Integrating UAV and UGS for persistent ISR

James Morrison, McQ, Inc. (United States)

McQ Inc. is a leading provider of high performance, advanced technology unattended ground sensor (UGS) systems. Our research spans two decades of investigating technologies suitable for automatically detecting, classifying, identifying, imaging, and tracking targets in remote

regions. In this program, we developed an UGS system specifically tailored for integration with existing and planned UAV ISR systems. Our investigations and engineering have lead to an operational prototype system. The UGS system can be integrated with and demonstrated with a UAV imaging system. The system demonstrates the ability of integrated systems to effectively detect, classify, identify, image and track targets within the airborne imagery using UGS systems with very long life.

UAV systems are valuable ISR assets, but are in high demand for missions support and do not have the numbers or endurance to provide persistent surveillance at numerous areas of interest. Long life UGS distributed over these numerous points of interest provide persistent surveillance without requiring continuous monitoring by UAV pilots or data analysts. This capability allows large geographic areas to be patrolled by fewer UAVS that can immediately respond to target reports at areas of interest. This technology offers an efficient application of UAV technology to support the Warfighter over large regions by supplying timely target position information.

8742-24, Session 7

Clustering of estimated spatial locations in networked sensors

Miodrag S. Vracar, Ivan P. Pokrajac, Predrag Okiljevic, Military Technical Institute (Serbia)

Multisensor data fusion combines data from multiple sensors to overcome interferences that may not be possible from a single sensor or source alone. In military application data fusion can be used to integrate the individual sensor data into common operational picture of the battlefield. However, there is still possibility to improve quality of the individual sensor. Improving of accuracy in estimation of spatial location is investigated in this paper. Some novel methods and algorithms for estimation of spatial location are compared such as Discrete Probability Density (DPD) method, fusion of multiple bearing lines and mean-square distance algorithm. These methods for estimation of spatial location use two-step positioning technique (indirect technique) based on estimation of a specified parameter such as angle of arrival (AOA). In the network where is possible to provide multiple spatial locations from the spatially close sources, clustering of estimated spatial location is very important. The estimated spatial locations that correspond to a source are spatially close to one another will have a larger likelihood than those estimated spatial locations that are not correspond to the source. In this paper methods and algorithms for estimation of spatial location are compared where it is multiple spatial locations, for the same sources spatially close. Clustering has been performed based on estimated spatial locations and appropriates the covariance matrix.

8742-25, Session 7

Application of inexpensive, low-cost, low-bandwidth silhouette profiling UGS systems to current remote sensing operations

Feng Jin, Brimrose Corp. of America (United States); Emir Y. Haskovic, Sterling Walsh III, Brimrose Technology Corp. (United States); Glenn Cloud, Brimrose Corp. of America (United States)

Traditional surveillance technology development has been focused on increasing the sensitivity and accuracy of a system at the expense of high production cost and power consumption. However, the increased need for surveillance in remote environments (such as Iraq, Afghanistan and the US border) has heightened the demand for inexpensive, low power and low bandwidth sensor systems. With military missions sometimes requiring up to 6 months of constant surveillance in remote and dangerous areas it has become increasingly prohibitive to deploy more traditional surveillance equipment, which often rely on human supervision and a large power source. Advancements in high-efficiency/low production-cost sensors and embedded systems has allowed for the development of L3B (low bucks, batteries, bandwidth) unattended ground surveillance systems to fill this growing demand.

The primary advantage of L3B UGS is their field-deployment scalability, which allows them to suit a wide range of surveillance applications. L3B UGS can also be utilized as effective tripwires for more sophisticated sensors in situations where a high level of scene detail is needed but power consumption is a factor. Newer image profilers offer event classification directly on the unit, which considerably reduces the system's bandwidth as well as the level of human supervision required. A mix-and-match scheme of deploying various types of L3B UGS can increase the robustness of event detection and discrimination. This paper discusses the capability of L3B UGS, specifically linear and 2D profilers such as Brimrose's SPOT system, to address growing industry demands.

8742-26, Session 8

A key management scheme for tiered wireless sensor network with self-healing capability

Maoyu Wang, Communications Research Ctr. Canada (Canada); Helen Y. Tang, Defence Research and Development Canada, Ottawa (Canada); F. Richard Yu, Carleton Univ. (Canada)

Wireless sensor network (WSN) has promising future in many civil and military applications such as environment monitoring and border surveillance , etc. Communication Research Centre designed and implemented a novel WSN, called Self-healing Autonomous Sensor Network (SASNet) that has a tiered networking architecture with self-healing capability. The tiered architecture of SASNet is implemented as follows. Sensor nodes (SN) in tier-1 communicate in a multi-hop fashion to reach a fusion node, fusion nodes (FN) forms an ad hoc network in tier-2. Some fusion nodes provide long-haul connectivity to backend command and control stations, called management node.

Self-healing capability, which allows the network to re-configure without operator intervention if some nodes ceased working, is a highly desired feature to provide robust and persistent communication. In SANSet, when any fusion node stops working, the sensor nodes that formed a cluster with that fusion node can re-associate with another fusion node autonomously. To the best of our knowledge, SASNet is the first WSN to provide the self-healing feature which makes it suitable to be deployed in unattended and adversarial environments to offer agile surveillance services.

SANSNet also has a very strong security mechanism. The security emphasis is put on how to control a SN's or a FN's participation and then how to assure the collected data is coming from a reliable source. Besides SN's or FN's participation, any unauthorized user are not allowed to query/task the system. To protect SASNet against various security attacks, we designed a novel key management scheme which can also be applied to other tiered WSNs. Our key management scheme supports the cluster membership and the self-healing features through re-keying when joining a new cluster. The security analysis demonstrates the proposed scheme is effective and efficient with respect to communication, computation and memory overhead for operation in a hostile environment.

8742-27, Session 8

A data collection decision-making framework for a multi-tier collaboration of heterogeneous orbital, aerial and ground craft

Jeremy Straub, The Univ. of North Dakota (United States)

This paper presents an algorithm for the autonomous identification of and tasking to collect additional data that is required to complete an experimental or surveillance goal. This goal, which is stated as an assertion (e.g., 'a given element is present in a region of a planet' or 'enemy forces are not present along a given route') is decomposed by the autonomous control software into an initial set of data collection

tasks. Once these are completed, information gaps may exist or new information collection requirements may be identified. These needs can, prospectively, be satisfied in numerous different ways with different data collection activities.

A utility-maximization, as a function of cost, metric is applied to assign follow-on tasks. The utility value is computed based upon heuristics that are utilized to estimate the value of each class of data that could be collected towards validating or refuting the assertion. The heuristic considers the value of previous data (of a given type) collected in proximity to a potential target, the value of exploring unexplored areas (or alternate data type collection in explored areas) and the potential for change occurring during collection (thus, the value of validation). Cost is estimated based on a combination of localized historical movement cost and task performance time-cost estimates.

This decision making process is performed at every (applicable) level of the hierarchy, decomposing large-scale needs into progressively smaller group, sub-group and individual craft task assignments. The utility of this control approach is assessed for persistent surveillance and planetary science applications.

8742-28, Session 9

On-line data validation in distributed data fusion

Jurgo Preden, Tallinn Univ. of Technology (Estonia); James Llinas, Univ. at Buffalo (United States); Galina L. Rogova, Encompass Consulting (United States); Raido Pahtma, Leo Motus, Tallinn Univ. of Technology (Estonia)

Data acquisition and data fusion systems are becoming increasingly complex, being in fact system of systems, where every component may be an autonomous system by itself. Possible changes in system configuration by entities joining or being removed from the system make the system design even more complex. As synchronous operation cannot be expected in such a system configuration the temporal and spatial correctness of data must be achieved via other means.

The paper presents the concept of mediated interactions as a method for ensuring correctness of computation in a distributed system. The mediator associated with each computing entity is responsible for online checking of the data both before it is sent out at the sender side and before it is received at the receiver side, ensuring that only data satisfying the validity constraints of the data processing algorithm is used in computation. This assumes that each data item is augmented with temporal and spatial validity information which enables online data validation. The mediator is able to cope with the unknowns that occur at runtime and are not predictable, such as channel delay, jitter of clocks, changes in processing delay (especially a factor in multi tasking systems and in configurations when a computing entity may have to process a variable number of parallel streams of data).

Both the middleware architecture using mediators and a simulation case study of a distributed data fusion scenario are presented in the paper.

8742-29, Session 9

Dynamically allocated virtual clustering management system

Kelvin M. Marcus, U.S. Army Research Lab. (United States); Jess A. Cannata, Dynamics Research Corp. (United States)

In our current experimentation environment, our researchers need to be able to run clusters of heterogeneous nodes to model emulated wireless tactical networks where each node could contain a different operating system, application set, and physical hardware. To complicate matters, most experiments require the researcher to have root privileges. Our previous solution of using a single shared cluster of statically deployed virtual machines did not sufficiently separate each user's experiment due to undesirable network crosstalk, thus only one experiment could be run at a time. In addition, the cluster did not make efficient use our servers and physical networks.

To address these concerns, we created the Dynamically Allocated Virtual Clustering management system. This system leverages existing open-source software to create private clusters of nodes that are either virtual or physical machines. These clusters can be utilized for software development, experimentation, and integration with existing hardware and software. The system uses the Grid Engine job scheduler to efficiently allocate virtual machines to idle systems and networks. The system deploys stateless nodes via network booting. The system uses 802.1Q Virtual LANs to prevent experimentation crosstalk and to allow for complex, private networks eliminating the need to map each virtual machine to a specific switch port. The system monitors the health of the clusters and the underlying physical servers. The system maintains cluster usage statistics for historical trends. Users can start private clusters of heterogeneous nodes with root privileges for the duration of the experiment. Users also control when to shutdown their clusters.

8742-31, Session 9

Low Frame Rate Video Target Localization and Tracking Testbed

Pu Pang, Temple Univ. (United States); Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Pengpeng Liang, Temple University (United States); Khanh D. Pham, Erik P. Blasch, Air Force Research Lab. (United States); Zhonghai Wang, Intelligent Fusion Technology, Inc. (United States); Haibin Ling, Temple Univ. (United States)

Traditional tracking frameworks are challenged with low frame rate scenarios because the appearances and locations of the target may change drastically in consecutive frames. We present a Low Intensity and Frame Rate (LiFR) framework to deal with such scenario and demonstrate it in our robot testbed. First, we use median filter to construct a background of the scene and apply background subtraction to every new frame to decide the potential target positions. Using the target dynamics, obtained through communication, target positions are projected to the image space so as to further narrow down the search range in the current frame. With the help of markers on the target (e.g., robots), a gradient direction voting algorithm is designed to detect the likely target locations. Finally, a template matching with branch pruning is used to obtain the finer estimation of the target position. To make the track-by-detection LiFR framework stable, we further introduce the temporal and spatial association constratints using previous detected target positions . Our experiments in the robot testbed show that the proposed method can achieve a very stable tracking result and outperform some general trackers such as meanshift, MIL, TLD etc. With all techniques used in our LiFR framework, we are also able to make our algorithm real-time under the low frame rate and low image quality (i.e., intensity) requirement.

8742-32, Session 10

Acoustic network event classification using swarm optimization

Jerry A. Burman, Intelligent Recognition Systems (United States)

An acoustic event classifier uses particle swarm optimization to perform a flexible time correlation of a sensed acoustic signature to reference data. In order to mitigate the effects of sound interference such as multipath, the classifier fuses signatures from multiple sensors to form a composite sensed acoustic signature and then automatically matches the composite signature with reference data. The approach is applicable to classify all types of acoustic events but is particularly well suited to classify explosive events such as gun shots, mortar blasts and improvised explosive devices that produce an acoustic signature having a shock wave component that is aperiodic and non-linear. The classifier was applied to field data and yielded excellent results in terms of reconstructing degraded acoustic signatures from multiple sensors and in classifying disparate events.

8742-33, Session 10

Virtual GEOINT Center: C2ISR through an avatar's eyes

Sanjay Kumar Boddhu, MetaCarta, a Div. of Qbase (United States); Robert L. Williams, Air Force Research Lab. (United States); Mark Seibert, Wright State Univ. (United States)

No Abstract Available.

8742-34, Session 10

Characterization and definition of a software stack for a reference experimental framework

Andrew Toth, U.S. Army Research Lab. (United States); Flavio Bergamaschi, IBM United Kingdom Ltd. (United Kingdom)

In 2006, the US Army Research Laboratory (ARL) and the UK Ministry of Defence (MoD) established a collaborative research alliance with academia and industry, called the International Technology Alliance (ITA) to address fundamental issues concerning Network and Information Sciences. Research performed under the ITA was extended through a collaboration between ARL and IBM UK to characterize and define a software stack and tooling that will become the reference framework for network science experimentation.

A key element to the success and validation of ITA theoretical research is experimentation in a controlled environment that can, as best as possible, emulate the real world conditions and context. Experimental validation in a network emulation environment contributes to the validation of theoretical concepts and algorithms, the investigation of more complex scenarios that span multiple research areas, exposing gaps in the theory that may need special attention, identifying additional areas where the research might focus and develop, and reproducible experimentation, which enables and facilitates the comparison of results from multiple executions of the same experiment. To accomplish these experimentation goals, the framework needs to foster the collaboration across multiple disciplines and facilitate the sharing of existing and new assets in a common emulation environment. The framework also needs to be extensible for the integration of new features, emulation models, monitoring, and integration with real, external assets that can be linked to any given experiment.

The paper discusses the experimentation framework resulting from the ARL/IBM UK collaboration. It describes the characterization and definition of a software stack and tooling that has become the reference experimental framework that builds on the goals stated above. The experimentation framework makes use of open source technologies, namely the Common Open Research Emulator (CORE) and the Extendable Mobile Ad-hoc Network Emulator (EMANE). Additional ITA assets such as Controlled English (CE) Store, Declarative, the ITA Services Composition Framework, the ITA Distributed State Machine are integrated into the framework and available as core infrastructure for experimentation.

8742-35, Session 10

Managing ISR sharing policies at the network edge using Controlled English

Christos Parizas, Diego Pizzocaro, Alun D. Preece, Cardiff Univ. (United Kingdom); Petros Zerfos, IBM Thomas J. Watson Research Ctr. (United States)

In domains such as emergency response and military operations the sharing of Intelligence, Surveillance and Reconnaissance (ISR) assets among different coalition partners is regulated through policies. Traditionally, policies are created at the center of a coalition's network by high-level decision makers and expressed in low-level policy languages (e.g. Common Information Model SPL) by technical personnel, which makes them difficult to be understood by non-technical users at the edge of the network. Moreover, policies must often be modified by negotiation among coalition partners, typically in rapid response to the changing operational situation. Commonly, the users who must cope first with situational changes are those on the edge, so it would be very effective if they were able to create and negotiate policies themselves. We investigate the use of Controlled English (CE) as a means to define a policy representation that is both human-friendly and machine processable. We show how a CE model can capture a variety of policy types, including those based on a traditional asset ownership model, and those defining team-based asset sharing across a coalition. The use of CE is intended to benefit coalition networks by bridging the gap between technical and non-technical users in terms of policy creation and negotiation, while at the same time being directly processable by a policy-checking system without transformation to any other technical representation.

8742-36, Session 10

Diagnosing Degradation of Services in Hybrid Wireless Tactical Networks

Srikar Tati, The Pennsylvania State Univ. (United States); Petr Novotny, Imperial College London (United Kingdom); Bong Jun Ko, IBM Thomas J. Watson Research Ctr. (United States); Alexander L. Wolf, Imperial College London (United Kingdom); Thomas F. LaPorta, The Pennsylvania State Univ. (United States)

In this paper, we consider a diagnosis problem related to service deployment and management in tactical military networks. In tactical networks, performance degradation in services could prove fatal, so it must be diagnosed quickly. Performance of services can be affected due to various reasons that span across different layers of networks. The causes of network disconnectivity could be inferred using known service relationships and partial deployment information. In this paper, we provide a network model for hybrid wireless networks in military tactical scenarios and a monitoring model of services, whose infrequent updates are used to generate service layer dependency graphs. We then discuss techniques that could be used to infer the causes of the degradation .

8742-37, Session 11

A collaborative smartphone sensing platform for detecting and tracking hostile drones

Sanjay Kumar Boddhu, MetaCarta, a Div. of Qbase (United States); Robert L. Williams, Air Force Research Lab. (United States); Matt Macarthny, Wright State University (United States)

In recent years, not only United States Armed Services but other Law-enforcement agencies have shown increasing interest in employing drones for various surveillance and reconnaissance purposes. Further, the recent advances in drone control technology has led to completely autonomous and self-sustaining drones that can be pre-programmed with mission requirements devoid of any traditional necessity for human-in-the-loop control. These autonomous drone technology advancements have tremendously increased the geographic extent of the drone based missions beyond the traditional line-of-sight control coverage without any sophisticated requirement of data links to control them remotely, proving to be tremendously reliable and effective for security personnel (and soldiers) operating in hostile environments. But, these autonomous drones can prove to be hostile, when acquired by anti-social groups who can target the property and life in urban settlements. To further escalate the issue, the traditional detection techniques like RADARs, RF data link signature scanners, etc..., prove futile as the drones are smaller in size to evade successful detection by a RADAR based system in urban environment and being autonomous have capability of operating without an active data link (RF) that can be traced. Hence, a research team at AFRL's Tec^Edge Labs has developed a highly scalable, geographically

distributable and easily deployable smartphone-based collaborative platform that can aid in detecting and tracking hostile drones in an urban environment. In its current state this collaborative platform, built on the paradigm of "Human-as-Sensors", mainly consists of intelligent Smartphone application that leverages appropriate sensors on the device to capture a drone's attributes in a semi-automated fashion with real-time collaboration capabilities thru a highly composable sensor cloud architecture and an intelligent processing module that can estimate the possible flight of the hostile drone based on the multiple observation data points and provide real-time alerting mechanism for the personnel in the field to avert or subdue the damages caused by the detect hostile drones.

8742-38, Session 11

Smartphones for distributed multimode sensing: biological and environmental sensing and analysis

Sanjay Kumar Boddhu, MetaCarta, a Div. of Qbase (United States); Robert L. Williams, Air Force Research Lab. (United States); Tyler Feitshans, Ohio Northern Univ. (United States)

Active and Agile Environmental and Biological sensing are becoming obligatory to generate prompt warnings for the troops and law enforcements conducting missions in hostile environments. The traditional static sensing mesh networks which provide a coarse-grained (far-field) measurement of the environmental conditions like air quality, radiation , CO2, etc … would not serve the dynamic and localized changes in the environment, which requires a fine-grained (near-field) sensing solutions. Further, sensing the biological conditions of (healthy and injured) personnel in a contaminated environment and providing a personalized analysis of the life-threatening conditions in real-time would greatly aid the success of the mission. In this vein, under SATE and YATE programs, the research team at AFRL Tec^Edge Discovery labs had demonstrated the feasibility of developing Smartphone applications , that employ a suite of external environmental and biological sensors, which provide fine-grained and customized sensing in real-time fashion. In its current state, these smartphone applications leverage a custom designed modular standalone embedded platform (with external sensors) that can be integrated seamlessly with Smartphones for sensing and further provides connectivity to a back-end data architecture for archiving, analysis and dissemination of real-time alerts. Additionally, the developed smartphone applications have been successfully tested in the field with varied environmental sensors to sense humidity, CO2/CO, wind, etc…, ; and with varied biological sensors to sense body temperature and pulse with apt real-time analysis.

8742-39, Session 11

Context-aware event detection smartphone application for first responders

Sanjay Kumar Boddhu, MetaCarta, a Div. of Qbase (United States); Robert L. Williams, Air Force Research Lab. (United States)

The rise of social networking platforms like Twitter, Facebook, etc…, have provided seamless sharing of information (as chat, video and other media) among its user community on a global scale. Further, the proliferation of the smartphones and their connectivity networks has powered the ordinary individuals to share and acquire information regarding the events happening in his/her immediate vicinity in a real-time fashion. This human-centric sensed data being generated in "human-as-sensor" approach is tremendously valuable as it delivered mostly with apt annotations and ground truth that would be missing in traditional machine-centric sensors, besides high redundancy factor (same data thru multiple users). Further, when appropriately employed this real-time data can support in detecting localized events like fire, accidents, shooting, etc…, as they unfold and pin-point individuals being affected by those events. This spatiotemporal information, when made available for first responders in the event vicinity (or approaching it) can greatly assist them to make effective decisions to protect property and life in a timely fashion. In this vein, under SATE and YATE programs, the research team at AFRL Tec^Edge Discovery labs had demonstrated the feasibility of developing Smartphone applications, that can provide a augmented reality view of the appropriate detected events in a given geographical location (localized) and also provide an event search capability over a large geographic extent. In its current state, the application thru its backend connectivity utilizes a data (Text & Image) processing framework, which deals with data challenges like; identifying and aggregating important events, analyzing and correlating the events temporally and spatially and building a search enabled event database. Further, the smartphone application with its backend data processing workflow has been successfully field tested with live Twitter feed.

8742-40, Session 11

Smartphone citizen sensors for urban ground tracking

Sanjay Kumar Boddhu, MetaCarta, a Div. of Qbase (United States); Robert L. Williams, Air Force Research Lab (United States); Michael Fox, Wright State Univ. (United States)

No abstract available.

8743-1, Session 1

The remarkable success of adaptive cosine estimator in hyperspectral target detection *(Invited Paper)*

Dimitris G. Manolakis, MIT Lincoln Lab. (United States); Eric Truslow, Northeastern Univ. (United States); Michael L. Pieper, MIT Lincoln Lab. (United States); Thomas Cooley, Michael Brueggeman, Steven J. Lipson, Air Force Research Lab. (United States)

A challenging problem of major importance in hyperspectral imaging applications is the detection of subpixel targets of military and civilian interest. The background clutter surrounding the target, acts as an interference source that simultaneously distorts the target spectrum and reduces its strength. Two additional limiting factors are the spectral variability of the background clutter and the spectral variability of the target. Since a result in applied statistics is only as reliable as the assumptions from which it is derived, it is important to investigate whether the basic assumptions used for the derivation of matched filter (MF) and adaptive cosine estimator (ACE) algorithms are a reasonable description of the physical situation. Careful examination of the linear signal model used to derive the MF and ACE algorithms and the replacement signal model, which is a more realistic model for subpixel targets, reveals a serious discrepancy between modeling assumptions and the physical world. Contrary to this discrepancy and additional mismatches between assumed and actual signal and clutter models, the ACE algorithm shows an "amazing effectiveness" in practical target detection applications. The objective of this paper is an attempt to explain this unbelievable effectiveness using a combination of classical statistical detection theory, geometrical interpretations, and a novel realistic performance prediction model for the ACE detector.

8743-2, Session 1

Extending continuum fusion to create unbeatable detectors

Alan P. Schaum, U.S. Naval Research Lab. (United States)

Amongst the many versions of continuum fusion (CF) algorithm, one flavor has been shown to produce the uniformly most powerful solution to any detection problem that admits one. It was hoped, therefore, that the flexibility in design afforded by CF principles would permit one to find with them solutions to any reasonably defined optimization problem. The class of unbeatable algorithms solve one such problem category. However, for many discrete composite hypothesis problems, unbeatable detectors are known that elementary CF methods cannot produce. Here we generalize the CF methodology in a way that converts any discrete fusion problem into a continuous one. Continuum fusion algorithms produced in this way generate the entire class of unbeatable detectors. We discuss further the concept of undesirable unbeatable detectors, and we describe methods for avoiding them.

8743-3, Session 1

A hyperspectral anomaly detector based on partitioning pixel into adjacent components

Edisanter Lo, Susquehanna Univ. (United States)

An algorithm for detecting anomaly in hyperspectral imaging is presented. The algorithm is based on partitioning the pixel into groups of adjacent components of the pixel and partialling out the main background structure from each group of adjacent components. Some adjacent components of the pixel are known to be significantly correlated and this correlation can be exploited to improve anomaly detection. The Mahalanobis distance of the resulting residual is defined as the anomaly detector. Experimental results show that the anomaly detector has a substantial improvement in detection than the conventional anomaly detectors.

8743-4, Session 1

False alarm mitigation techniques for hyperspectral target detection

Michael L. Pieper, Eric Truslow, Dimitris G. Manolakis, MIT Lincoln Lab. (United States)

A challenging problem of major importance in hyperspectral imaging applications is the detection of subpixel targets of military and civilian interest. High false alarm thresholds are required to detect subpixel targets due to the large amount of surrounding background clutter. These high false alarm rates are unacceptable for military purposes, requiring the need for false alarm mitigation (FAM) techniques to weed out the targets of interest. The objective of this paper is to provide a comparison of the implementation of these FAM techniques and their inherent benefits. One method of FAM works in the whitened detection space. The widely utilized matched filter (MF) and adaptive cosine estimator (ACE) are both based on a linear mixing model (LMM) between a background and target class. The matched filter approximates the target abundance, and the ACE measures the model error. Each of these measurements provides inadequate target separation alone. By using both the target abundance and model error, the targets can be separated from the false alarms. A second method studies detection hits in the physical spectral space using a LMM. The target background is estimated from the local surroundings, and subtracted from the pixel of interest. The resulting target component is then used to identify the pixel. Variations of the above FAM techniques will also be discussed.

8743-5, Session 1

Image change detection via ensemble learning

Benjamin W. Martin, The Univ. of Tennessee Knoxville (United States); Ranga R. Vatsavai, Oak Ridge National Lab. (United States)

The concept of geographic change detection is relevant in many areas. Changes in geography can reveal much information about a particular location. For example, analysis of changes in geography can identify regions of population growth, change in land use, and potential environmental disturbance. A common way to perform change detection is to use a simple method such as differencing to detect regions of change. Though these techniques are simple, often the application of these techniques is very limited. Recently, machine learning methods such as neural networks for change detection has been explored with great success.

In this work, we explore the use of ensemble learning methodologies for detecting changes in bitemporal synthetic aperture radar (SAR) images. Ensemble learning uses a collection of weak machine learning classifiers to create a stronger classifier which has higher accuracy than the individual classifiers in the ensemble. The strength of the ensemble lies in the fact that the individual classifiers in the ensemble create a "mixture of experts" in which the final classification made by the ensemble classifier is calculated from the outputs of the individual classifiers. Our

methodology leverages this aspect of ensemble learning by training collections of weak decision tree based classifiers to identify regions of change in SAR images collected of a region in the Staten Island, New York area during Hurricane Sandy. Preliminary studies show that the ensemble method has approximately 11.5% higher change detection accuracy than an individual classifier.

8743-6, Session 2

Material classification for unmanned ground vehicles using multispectral cameras

David Chambers, Marc Alban, William C. Flannigan, Southwest Research Institute (United States)

In this paper, we present a real-time material classification system for assessing terrain for an off-road autonomous vehicle. The system utilizes data from a forward-facing camera array consisting of 8 sub-megapixel cameras. The camera array is composed of a stereo pair (one monochrome camera on each end), an rgb camera, and 5 cameras with purpose-selected color filters (a multispectral array). This work describes both a specialized method for selecting spectral filters which are optimal for classifying the selected set of materials and the implementation of a real-time pixel-by-pixel classification system which utilizes features from stereo-based segmentation, image texture, and the multispectral camera array. We demonstrate the fusion of these features in a single classifier and discuss a customized decision-tree classifier which provides a reliable confidence estimate. We discuss algorithm performance on our training and testing datasets, which cumulatively contain more than 2000 frames and 25 million labeled samples. We also show the relative importance of all of our features for material classification on an overall basis as well as a class-by-class basis.

8743-8, Session 2

Spectral unmixing applied to desert soils for the detection of sub-pixel disturbances

Jessica L. Stuart, U. S. Dept. of Defense (United States); Fred A. Kruse, Naval Postgraduate School (United States)

Desert areas cover approximately one-fifth of the Earth's surface. These areas are extremely sensitive and highly responsive to environmental and man-made impacts, thus it is important to be able to detect and understand surface disturbances. Remote sensing technology can be used to detect and characterize these both literally (visually) and non-literally (analytically). Even when no disturbances are apparent in individual images or color composites, non-literal approaches may allow detection of anthropogenic-related surface disturbances that are not visible through image interpretation. This is achievable through analytical detection and identification of spectral reflectance and absorption feature changes caused by both chemical and biological differences among similar soil components. Previous research suggests that surface disturbances cause alteration of soil properties, making it feasible to detect variation in spectral signatures. This research utilizes field spectroscopy and hyperspectral imagery analysis to provide additional confirmation that disturbance-related changes do have unique spectral characteristics and that these are detectable, even at the sub-pixel level. Case histories utilizing Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data demonstrate that detection, identification, and mapping of surface disturbance are possible using library spectra, extrapolation of site-specific field spectral measurements, and even using spectral endmembers from geographically different yet geologically similar regions. The results have implications for environmental monitoring and other civilian and military applications.

8743-9, Session 2

An advanced algorithm suite for wide-field of view multispectral threat warning systems

Joel B. Montgomery, Marjorie Montgomery, M&M Aviation (United States)

Threat warning, including Man Portable Air Defense (MANPADS) and medium-large machine gun fire is a critical component for airborne assets to survive in hostile airspace. To provide situational awareness for the pilot, cued defense and countermeasures, and proactive engagement requires extremely high probability of detection coupled very low false alarm rates. Historically, false alarm rates have driven the threat warning at a system level due to a multitude of factors including unintended expenditure release resulting in requirement of the system to be disabled. Better spectral discrimination in the mid-infrared helps, but the high costs of these systems, including acquisition and maintenance, have limited fielding to very few aircraft. M&M Aviation has been working on perfecting Spectrally Independent Mappable Algorithms for Clutter (SIMAC) for over 7 years and has been used in several wide-field systems that were flown and tested against multiple missile and gun based threats. This algorithm suite allows for a wide range of applications including use in the near-IR (NIR) and visible domains as well as the mid-infrared. Additionally, SIMAC has been updated to include short-timeline threat signatures to detect and declare Hostile Fire Intent (HFI) and energetic events (grenades, exploding bombs, IEDs) on airborne platforms. This output is coupled to a geo-fusion engine for location and identification of less than 2m. This paper will give an overview of the current SIMAC algorithm implementation including real-time operations, results from various clutter flights and threat systems, system based received operating characteristic (ROC) curves, and finally conclude with future work and direction.

8743-85, Session 2

Hyperspectral imaging for detection and identification of blood stains at the crime scene

Gerda Edelman, Academic Medical Center (Netherlands); Ton G van Leeuwen, Univ. van Amsterdam (Netherlands) and Academic Medical Center (Netherlands); Maurice C.G. Aalders, Academic Medical Center (Netherlands)

Blood stains are an important source of information in forensic investigations. Extraction of DNA may lead to the identification of victims or suspects, while the blood stain pattern may reveal useful information for the reconstruction of a crime. Consequently, techniques for the detection and identification of blood stains are ideally non-destructive in order not to hamper both DNA and the blood stain pattern analysis. Currently, forensic investigators mainly detect and identify blood stains using chemical or optical methods, which are often either destructive or subject to human interpretation.

We demonstrated the feasibility of hyperspectral imaging of the crime scene to detect and identify blood stains remotely. Blood stains outside the human body comprise the main chromophores oxy-hemoglobin, methemoglobin and hemichrome. Consequently, the reflectance spectra of blood stains are influenced by the composite of the optical properties of the individual chromophores and the substrate. Using the coefficient of determination between a non-linear least squares multi-component fit and the measured spectra blood stains were successfully distinguished from other substances visually resembling blood (e.g. ketchup, red wine and lip stick) with a sensitivity of 100 % and a specificity of 85 %.

The custom-made hyperspectral imaging system used in this study is portable and wireless, and can be transported to the crime scene to record large samples or even the entire crime scene. The practical applicability of this technique was demonstrated at a mock crime scene, where blood stains were successfully identified automatically.

8743-10, Session 3

Bayesian information criteria for material identification in hyperspectral imagery

William Basener, Rochester Institute of Technology (United States) and Exelis Visual Information Solutions (United States); Daniel W. Czirjak, U.S. Army (United States)

Over the recent decades, much attention has been placed on building more effective target detection algorithms for hyperspectral imagery. Much of this work is based on signal processing methods, locating a known signal spectra out of a background image. While methods are available for detection of a known target, these methods output high scores for both target objects and correlated confusers.

In this paper we develop a method for target identification based on Bayesian Information Criteria (BIC) for the identification of the material in a pixel. Bayesian information is particularly well suited for this task because it enables averaging over multiple spectra and outputs results that can more readily be interpreted in a Bayesian framework for decision making. We compare results using BIC to identification metrics used previously in the literature on HYDICE Forest Radiance data.

8743-11, Session 3

Undercomplete learned dictionaries for land cover classification in multispectral imagery of Arctic landscapes using CoSA: clustering of sparse approximations

Daniela I. Moody, Steven P. Brumby, Joel C. Rowland, Chandana Gangodagamage, Los Alamos National Lab. (United States)

Techniques for automated feature extraction, including neuroscience-inspired machine vision, are of great interest for landscape characterization and change detection in support of global climate change science and modeling. We present results from an ongoing effort to extend machine vision methodologies to the environmental sciences, using state-of-the-art adaptive signal processing, combined with compressive sensing and machine learning techniques. We use a Hebbian learning rule to build undercomplete spectral-textural dictionaries that are adapted to the data. We learn our dictionaries from millions of overlapping multispectral image patches and then use a pursuit search to generate classification features. Land cover labels are automatically generated using our CoSA algorithm: unsupervised Clustering of Sparse Approximations. We demonstrate our method using multispectral Worldview-2 data from three Arctic study areas: Barrow, Alaska; the Selawik River, Alaska; and a watershed near the Mackenzie River delta in northwest Canada. Our goal is to develop a robust classification methodology that will allow for the automated discretization of the landscape into distinct units based on attributes such as vegetation, surface hydrological properties (e.g., soil moisture and inundation), and topographic/geomorphic characteristics. To interpret and assign land cover categories to the clusters we both evaluate the spectral properties of the clusters and compare the clusters to both field- and remote sensing-derived classifications of landscape attributes. We compare our technique to standard remote sensing algorithms as well as a supervised genetic algorithm. Our work suggests that neuroscience-based models are a promising approach to practical pattern recognition problems in remote sensing.

8743-12, Session 3

Security inspection through anomaly detection using hyperspectral imaging technology

Javier Rivera, Fernando L. Valverde, Manuel Saldana, Vidya B. Manian, Univ. de Puerto Rico Mayagüez (United States)

Applying technology in port security applications is crucial for the detection of possible threats or illegal activities. One of the most common problems that cargo suffers is tampering. This represents a danger to society because it creates a channel to smuggle illegal and hazardous products. If a cargo is altered, security inspections of that cargo should contain anomalies that reveal the nature of the tampering. Hyperspectral images can detect anomalies by gathering information through multiple electromagnetic bands. The spectrums extracted from these bands can be used to detect surface anomalies from different materials. Based on this technology, a scenario was built in which a hyperspectral camera was used to inspect the cargo for any surface anomalies. The spectrum of items, altered by different materials that can be used to conceal illegal products, is analyzed and classified in order to provide information about the tampered cargo. The image is analyzed with a variety of techniques such as multiple features extracting algorithms, autonomous anomaly detection, and target spectrum detection. The results will be exported via Bluetooth to a mobile device to implement an easy-to-use interface. This process could enhance the current capabilities of security systems that are already implemented, providing a more complete approach to detect threats and illegal cargo.

8743-13, Session 3

A multistage framework for dismount spectral verification in the VNIR

Dalton S. Rosario, U.S. Army Research Lab. (United States)

A multistage algorithm suite is proposed for a specific target detection/verification scenario, where a visible/near infrared hyperspectral (HS) sample is assumed to be available as the only cue from a reference image frame. The target is a suspicious dismount. The suite first applies a biometric based human skin detector to focus the attention of the search. Using as reference all of the bands in the spectral cue, the suite follows with a Bayesian Lasso inference stage designed to isolate pixels representing the specific material type cued by the user and worn by the human target (e.g., hat, jacket). In essence, the search focuses on testing material types near skin pixels. The third stage imposes an additional constraint through RGB color quantization and distance metric checking, limiting even further the search for material types in the scene having visible color similar to the target color. Using the proposed cumulative evidence strategy produced some encouraging range-invariant results on real HS imagery, dramatically reducing to zero the false alarm rate on the example dataset. These results were in contrast to the results independently produced by each one of the suite's stages, as the spatial areas of each stage's high false alarm outcome were mutually exclusive in the imagery. These conclusions also apply to results produced by other standard methods, in particular the kernel SVDD (support vector data description) and Matched Filter, as shown in the paper.

8743-14, Session 3

LWIR hyperspectral change detection for target acquisition and situation awareness in urban areas

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This paper studies change detection of LWIR (Long Wave Infrared) hyperspectral imagery. Goal is to improve target acquisition and situation awareness in urban areas. Hyperspectral data were collected during the DUCAS (*) trials in Zeebrugge, Belgium, in June 2011. Additional high-resolution airborne imagery and ground truth data were collected simultaneously. LWIR data were acquired using the ITRES Thermal Airborne Spectrographic Imager TASI-600 that operates in the spectral range of 8-11.5 μm. Chosen was for the 32 band configuration with 109.5

nm spectral width (FHWM). Acquisition of the images was around noon. To reduce the number of false alarms due to diurnal changes, the time interval between the images was less than 2 hours. Local co-registration adjustment was applied to compensate for small misregistration errors. The targets in the data that will be analysed in this paper are different kinds of vehicles. To investigate the performance of LWIR hyperspectral change detection, the following algorithms were applied and evaluated: Euclidean distance, Mahalanobis distance (RX), Chronochrome (CC), Covariance Equalisation (CE), Hyperbolic Anomalous Change Detection (HACD), and Spectral Angle Mapper (SAM). Evaluation is based on Receiver Operator Characteristics (ROC). Conclusion is that HACD and Euclidean distance show the best results. The contrast of gone vehicles in this period is generally larger than of new vehicles due to its thermal shadow on the ground. (*) Detection in Urban scenario using Combined Airborne imaging Sensors, EDA project arrangement no. B 0294 IAP3 GC

8743-15, Session 4

The SHARE 2012 data collection campaign

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A multi-modal (hyperspectral, multispecral, and LIDAR) imaging data collection campaign was conducted at the Avon Driving Park in Avon, NY on September 20, 2012 by the Rochester Institute of Technology (RIT) in conjunction with SpecTIR, LLC, the Air Force Research Lab (AFRL), the Naval Research Lab (NRL), and MITRE. The campaign was a follow on from the SpecTIR Hyperspecral Airborne Rochester Experiment (SHARE) from 2010. Data was collected in support of thirteen simultaneous experiments. The airborne imagery was collected over four different sites with hyperspectral, multispectral, and LIDAR sensors. The sites for data collection included Avon, NY, Conesus Lake, Hemlock Lake and forest, and a nearby quarry. Experiments included topics such as target unmixing, subpixel detection, LIDAR fusion, material identification, forest health, and in-water target detection. An extensive ground truthing effort was conducted in addition to airborne imagery. The ultimate goal of the data collection campaign is to provide the remote sensing community with a shareable resource to support future experiments. This paper details the experiments conducted and the data that was collected during this campaign.

8743-16, Session 4

SHARE 2012: large edge targets for hyperspectral imaging applications

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Spectral unmixing is a type of hyperspectral imagery (HSI) sub-pixel analysis where the pure materials and abundances within the pixel are identified. However, validating the results obtained from spectral unmixing is very difficult due to a lack of real-world data and ground-truth information associated with these real-world images. Real HSI data are preferred for validating spectral unmixing, but when there are no HSI truth-data available then validation of spectral unmixing algorithms relies on user-defined synthetic images which can be generated to exploit the benefits (or hide the flaws) in the new unmixing approaches. Here we introduce a new dataset (SHARE 2012: large edge targets) for the validation of spectral unmixing algorithms. The SHARE 2012 large edge targets are uniform 9m by 9m square regions of a single material (grass, sand, black felt, or white TyVek®). The spectral profile and the GPS of the corners of the materials were recorded so that the heading of the edge separating any two materials can be determined separately from the imagery. An estimate for the abundance of two neighboring materials along a common edge can be calculated geometrically by identifying the edge which spans multiple pixels. These geometrically calculated abundances can then be used as validation of spectral unmixing algorithms. The size, shape, and spectral profiles of these targets also make them useful for radiometric calibration, atmospheric adjacency effects, and sensor MTF calculations. The imagery and ground-truth information are presented here.

8743-17, Session 4

SHARE 2012: subpixel detection and unmixing experiments

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The quantitative evaluation of algorithms applied to remotely sensed hyperspectral imagery require data sets with known ground truth. A recent data collection known as SHARE 2012, conducted by scientists at the Rochester Institute of Technology together with several outside collaborators, acquired hyperspectral data with this goal in mind. Several experiments were designed, deployed, and truthed to support algorithm evaluation.

In this paper, we describe two experiments that addressed the particular needs for the evaluation of subpixel detection and unmixing algorithms. The subpixel detection experiment involved the deployment of dozens of nearly identical subpixel targets in a random spatial array. The subpixel targets were pieces of wood painted either green or yellow. They were sized to occupy about 25% of the 1 m pixels if they fell entirely within a single pixel.

The unmixing experiment used novel targets with prescribed fractions of different materials based on a geometric arrangement of subpixel patterns. These targets were made up of different fabrics with various colors. Whole pixel swatches of the same materials were also deployed in the scene to provide in-scene endmembers. Alternatively, researchers can use the unmixing targets alone to derive endmembers from the mixed pixels.

Initial results have demonstrated successful detection of the subpixel targets as well as close approximations to the geometric fractions in the retrieved fractions for the unmixing targets. These data, together with the ground truth, are planned to be made available to the community for evaluation and development of detection and unmixing algorithms.

8743-18, Session 4

SHARE 2012: analysis of illumination differences on targets in hyperspectral imagery

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This paper looks at a new data set that has been designed to analyze the various impacts of illumination change on targets. In addition, similar targets were placed on different backgrounds where spectral signatures were analyzed to determined impacts of background adjacency. Targets were also placed next to tree lines where they were fully illuminated but with the possible impact of tree shine. Hyperspectral, multispectral, and LiDAR modalities were used to image the targets in the above mentioned scenarios. Applications such as target detection are used to assess difficulties with finding such targets. The incorporation of LiDAR and physical models will aid in approximating the correct per-pixel signature to be used in the above mentioned target detection scheme. This technique can help mitigate issues related to varying illumination across a scene.

8743-19, Session 5

Detection and tracking of gas plumes in LWIR hyperspectral video sequence data

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The detection and segmentation of chemical plumes is difficult due to the natural diffusion process of a gas. As the gas disperses the boundary is highly dynamic, the edges become less defined, and the concentration becomes optically thin. We develop algorithms for automated detection of a gas plume in Long Wave Infrared (LWIR) hyperspectral video sequences collected at the Dugway Proving Ground using a standoff detection technique. Our approach uses a combination of dimension reduction and histogram equalization to prepare the hyperspectral videos for segmentation. First, Principal Components Analysis (PCA) is used to reduce the dimension of the entire video sequence. Next, a Midway method for histogram equalization is used. These methods redistribute the intensity values in order to reduce flicker between frames. PCA and Midway are used as

pre-processing steps to prepare the data for more sophisticated segmentation algorithms. Spectral clustering of this dataset yields important information in the spatial structure of the eigenfunctions. These can be used for a new fast classification algorithm that incorporates spatial patterning in the data, yields promising results. This algorithm is based on a modified MBO scheme that minimizes the Ginzberg-Landau functional. The output of this algorithm achieves superior results compared to more conventional methods such as K-means clustering and an adaptive matched subspace detector.

8743-20, Session 5

Geometrical interpretation of the adaptive coherence estimator for hyperspectral target detection

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A hyperspectral cube consists of a set of images taken at numerous wavelengths. Hyperspectral image data analysis uses each material's distinctive patterns of reflection, absorption and emission of electromagnetic energy at specific wavelengths for classification or detection tasks. Because of the size of the hyperspectral cube, data reduction is definitely advantageous; when doing this, one wishes to maintain high performances with the least number of bands. Obviously in such a case, the choice of the bands will be critical.

In this paper, we will consider one particular algorithm, the adaptive coherence estimator (ACE), for the detection of hyperspectral point targets. We give a quantitative interpretation of the dependence of the algorithm on the number and identity of the bands that have been chosen. Results on simulated data will be presented.

8743-21, Session 5

A novel automated object identification approach using key spectral components

Bart Kahler, Todd Noble, SAIC (United States)

Spectral remote sensing provides solutions to a wide range of commercial, civil, agricultural, atmospheric, security, and defense problems. Technological advances have expanded multispectral (MSI) and hyperspectral (HSI) sensing capabilities from air and space borne sensors. The greater spectral and spatial sensitivity have vastly increased the available content for analysis. The size of the data cubes obtained from today's sensors enable material identification via complex processing techniques. With sufficient sensor resolution, multiple pixels on target are obtained and by exploiting the key spectral features of a material signature among a group of target pixels and associating the features with neighboring pixels, object identification is possible. The authors propose a novel automated approach to object classification with HSI data by focusing on the key components of an HSI signature and the relevant areas of the spectrum (bands) of surrounding pixels to identify an object. The proposed technique may be applied to spectral data from any region of the spectrum to provide object identification. The effort will focus on HSI data from the visible, near-infrared and short-wave infrared to prove the algorithm concept.

8743-22, Session 5

Target detection using the background model from the topological anomaly detection algorithm

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The Topological Anomaly Detection (TAD) algorithm has been used as anomaly detector in hyperspectral and multispectral images. TAD is an algorithm based on graph theory that constructs a topological model of the background in a scene, and computes an "anomalousness" ranking for all of the pixels in the image with respect to the background, in order to identify pixels with uncommon or strange spectral signatures. The pixels that are modeled as background are clustered into groups or connected components, which could be representative spectral signatures of materials present in the background. Therefore, the idea of using the background components given by TAD in target detection is explored in this paper. In this way, these connected components are used as basis vectors of the background in a sub-pixel detector such as Orthogonal Subspace Projection (OSP), which removes the background effects and enhances the target signature by projecting the pixels onto a subspace orthogonal to the background. In addition, another metric to improve the detection is included in our methodology. This metric is the Structured Infeasibility Projector (SIP), which attempts to reject false alarms by projecting the pixels onto the subspace orthogonal to the target pixel. Experiments using different target pixels with varied complexity of detection are performed, in order to have a wide frame of study and assessment of the proposed methodology.

8743-23, Session 5

Low-rank decomposition-based anomaly detection

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With high spectral resolution hyperspectral imaging is capable of uncovering many subtle signal sources which cannot be known a priori or visually inspected. Such signal sources generally appear as anomalies in the data. Due to high correlation among spectral bands and sparsity of anomalies, a hyperspectral image can be decomposed into two subspaces: a background subspace specified by a matrix with low rank dimensionality and an anomaly subspace specified by a sparse matrix with high rank dimensionality. This paper develops an approach to finding such low-high rank decomposition to identify anomaly subspace. Its idea is to formulate a convex constrained optimization problem that minimizes the nuclear norm of the background subspace and little l1 norm of the anomaly subspace subject to a decomposition of data space into background and anomaly subspaces. By virtue of such a background-anomaly decomposition the commonly used RX detector can be implemented in the sense that anomalies can be separated in the

anomaly subspace specified by a sparse matrix. Experimental results demonstrate that the background-anomaly subspace decomposition can actually improve and enhance RXD performance.

8743-24, Session 5

Improved target recognition with live atmospheric correction

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Hyperspectral airborne sensing systems frequently employ spectral signature databases to detect materials. To achieve high detection and low false alarm rates, it is critical to retrieve accurate reflectance values from the camera's digital number (dn) output. A one-time camera calibration converts dn values to reflectance. However, changes in solar angle and atmospheric conditions distort the reflected energy, reducing detection performance of the system.

Changes in solar angle and atmospheric conditions introduce both additive (offset) and multiplicative (gain) effects independently for each waveband. A gain and offset correction can mitigate these effects. Correction methods based on radiative transfer models require equipment to measure solar angle and atmospheric conditions. Other methods use known reference materials in the scene to calculate the correction, but require an operator to identify the location of these materials. Our unmanned airborne vehicles application can use no additional equipment or require operator intervention. Applicable automated correction approaches typically analyze gross scene statistics to find the gain and offset values. Airborne hyperspectral systems have high ground resolution, so individual scenes do not include all the variation necessary to accurately calculate global statistics.

In the present work we present our novel approach to the automatic estimation of atmospheric and solar effects from the hyperspectral data. On approach is based on Hough transform matching of background spectral signatures with materials extracted from the scene. Scene materials are identified with low complexity agglomerative clustering. Detection results with data gathered from recent field tests are shown.

8743-25, Session 6

Multimodal detection of man-made objects

Richard L. Tutwiler, Matthew S. Baran, Donald J. Natale, The Pennsylvania State Univ. (United States)

This research presents an approach to multi-modal detection of man-made objects from aerial imagery. Detections are made in polarization imagery, hyperspectral imagery, and LIDAR point clouds then fused into a single confidence map. The detections are based on reflective, spectral, and geometric features of man-made objects in airborne images. The polarization imagery detector uses the Stokes parameters and the degree of linear polarization to find highly polarizing objects. The hyperspectral detector matches scene spectra to a library of man-made materials using a combination of the spectral gradient angle and the generalized likelihood ratio test. The LIDAR detector clusters 3D points into objects using principle component analysis and prunes the detections by size and shape. Once the three channels are mapped into detection images, the information can be fused without some of the problems of multi-modal fusion, such as edge reversal. The imagery used in this system was simulated with a first-principles ray tracing image generator known as DIRSIG.

8743-26, Session 6

A method to generate sub-pixel classification maps for use in DIRSIG three-dimensional models

Ryan Givens, Karl C. Walli, Air Force Institute of Technology (United States); Michael T. Eismann, Air Force Research Lab. (United States)

Developing a new remote sensing instrument is a costly and time consuming process. The Digital Imaging and Remote Sensing Image Generation (DIRSIG) model allows users to create synthetic images for a proposed sensor before building it. This enables algorithm testing and development, testing of image system designs, and the creation of data for training of image analysts allowing these processes to be in place prior to the sensor's first flight. However, to produce realistic synthetic images, DIRSIG requires facetized, three-dimensional models attributed with spectral and texture information which can also be costly and time consuming to produce. Recent work has shown that coincident LIDAR data and high-resolution imagery can be registered and used to automatically generate the geometry and texture information needed to build a DIRSIG scene, but user input is still required to attribute facets with either library or field measured spectral information. The proposed LIDAR/HSI Direct method fully automates the generation of a scene's geometry, texture, and spectral content when coincident LIDAR data, high-resolution imagery, and HyperSpectral Imagery (HSI) of a site are available. Furthermore, the fusion of these modalities potentially enables sub-pixel spectral unmixing resulting in a high-resolution classification map. When paired with the high-resolution imagery and spectra pulled directly from the HSI, the classification map can be used to accurately attribute spectral information to the three-dimensional model generated from the LIDAR data. As more datasets become available, this method provides a quick and accurate process for generating DIRSIG scenes using terrain and materials that were previously unavailable.

8743-27, Session 6

Snapshot spectral and polarimetric collection: video tracking and target identification

Brent D. Bartlett, Mikel D. Rodriguez, The MITRE Corp. (United States)

As the number of pixels continues to grow in consumer and scientific imaging devices, it has become feasible to collect the incident lightfield. In this paper, an imaging device developed around lightfield imaging is used to collect multi-spectral and polarimetric imagery in a snapshot fashion. The sensor is described and a video data set is shown highlighting the advantage of snapshot spectral and polarimetric imaging. Several computer vision approaches are applied to the video cubes to perform scene characterization and target identification. It is shown how the addition of spectral and polarimetric data to the video stream allows for multi-target identification and tracking not possible with traditional RGB video collection.

8743-28, Session 6

Detecting occluded and obscured targets in airborne hyperspectral imagery with co-registered lidar

Taylor Glenn, Paul D. Gader, Univ. of Florida (United States)

Hyperspectral image data provides a unique ability to detect targets at sub-pixel resolutions. This subpixel detection ability may not be sufficient however if the targets are obscured by shadow or occluded by tree cover. Lidar, with first and last return elevation measurements, allows for categorization of the scene into segments with knowledge of occlusion and obscuration properties. This segmentation information can potentially be beneficial to target detection. We analyze the performance of detection algorithms for obscured and occluded emplaced targets, and analyze methods of improving detection performance through the use of Lidar elevation information. We show results on a new dataset featuring high resolution (1m x 1m pixel size) VisNIR hyperspectral imagery with co-registered Lidar.

8743-29, Session 6

Blind analysis of multispectral and polarimetric data via canonical correlation analysis

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In blind scene analysis, the aim is to obtain information about background and targets without any prior information. Blind methods can be considered as pre-processing steps for scene understanding. By means of blind signal separation methodologies, anomalies can be detected and these anomalies can be exploited for target detection. There are many imaging sensor systems which uses different properties of the emittance or the reflectance characteristics of the scene components. Spectral reflectance properties are related to the material composition and these multispectral characteristics can be used for detection, identification and classification of the scene components. As the light scattered from the scene elements shows polarization , polarized measurements can be used as extra features. Multispectral and polarimetric images of a scene provide distinct information to some level and this information can be used to get deeper information on the scene and to make detection easier. In this study, spectral and polarimetric images of a scene is analyzed via Canonical Correlation Analysis (CCA) which is a powerful multivariate statistical methodology. Multispectral and polarimetric data (spectro-polarimetric data) are treated as two different sets. Canonical variants obtained by CCA give different scene components such as background elements and some man-made objects. The linear relationship of the polarimetric and multispectral data of the same scene is also obtained by CCA.

8743-30, Session 7

Lossless to lossy compression for hyperspectral imagery based on wavelet and integer KLT transforms with 3D binary EZW

Kai-jen Cheng, Jeffrey C. Dill, Ohio Univ. (United States)

It is paramount to have efficient compression algorithms to reduce the volume of hyperspectral imagery data. This paper studies a transform based lossless to lossy image compression for hyperspectral images, which includes integer Karhunen-Loeve transform (IKLT), discrete wavelet transform (IDWT) and binary embedded zerotree wavelet algorithm (EZW). The reversible IKLT is used for spectral decorrelation and energy compaction. The IDWT transforms the top n bands of IKLT transformed hyperspectral image to achieve multiresolution decomposition and energy compaction in the spatial domains. The sign and magnitude of wavelet coefficients are encoded separately. Lossy and lossless compressions of signs are implemented by conventional EZW algorithm and arithmetic coding respectively. The efficient binary EZW algorithm is applied to code magnitudes. The innovative quad-trees, which define the connections between coefficients in the top n principal bands, as well as the lower energy bands, not only improve the efficiency of the binary EZW but also optimize the performance of subsequent arithmetic coding.

The proposed compression was applied to 16 bit AVIRIS images. Comparing to JPEC2000, SPIHT, DPCM and CALIC, the binary EZW achieves lossless /lossy compression comparable to the best predictive algorithms with the computational efficiency of transform based algorithm.

8743-31, Session 7

Analytical and comparative analysis of lossy ultraspectral image compression

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AIRS (Atmospheric Infrared Sounder) images are a type of ultraspectral data cubes that are good candidates for compression as they include several thousand bands that account for well over 40MB of information per image. In this paper we describe and mathematically model an improved architecture to accomplish lossy compression of AIRS images by presenting a sequence of techniques executed under the context of preprocessing and compression stages. Specifically we describe both a preprocessing reversible stage that rearranges the AIRS data cube and a linear prediction based compression stage that improves the compression rate when compared to other state of the art ultraspectral data compression techniques. After defining a distortion measure as well as its effect on real applications (i.e. AIRS Level 2 products) we present a mathematical model to approximate the rate-distortion of the architecture and compare it against the experimental performance of the algorithm. The analysis relies on the vector quantization of the prediction error and assumes that the individual samples follow a Laplacian distribution that is the only source of distortion. In general under an open-loop encoding scheme, the distortion caused by the quantization of linear-prediction coefficients is masked by the distortion introduced by the prediction error itself. The effect of the preprocessing stage on the analytical model is accounted by different values of the Laplacian distribution such that the curve obtained by parametrically plotting rate against distortion is a close approximation of the experimental one.

8743-32, Session 7

Supervised method for optimum hyperspectral band selection

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Much effort has been devoted to development of methods to reduce hyperspectral image dimensionality by locating and retaining data relevant for image interpretation while discarding that which is irrelevant. Irrelevance can result from an absence of information that could contribute to the classification, or from the presence of information that could contribute to the classification but is redundant with other information already selected for inclusion in the classification process.

Early dimension reduction efforts focused on geometrically inspired models such as principal component analysis. More recently attention has turned to information theoretic approaches. For supervised classification, techniques using mutual information between class and data are showing promise in differentiating between data that is relevant to the classification of interest and data that is irrelevant.

We describe a new supervised method that uses mutual information to incrementally determine the most relevant combination of available bands and/or derived pseudo bands to differentiate a specified set of classes. We refer to this as relevance spectroscopy. The method identifies a specific optimum band combination and provides estimates of classification accuracy for data interpretation using a complementary, also information theoretic, classification procedure.

When modest numbers of classes are involved the number of relevant bands to achieve good classification accuracy is typically three or fewer. Time required to determine the optimum band combination is of the order of a minute on a personal computer. Automated interpretation of intermediate images derived from the optimum band set can often keep pace with data acquisition speeds.

8743-33, Session 7

Second order statistics target-specified virtual dimensionality

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Virtual dimensionality (VD) has received considerable interest with its use in specifying the number of spectral distinct signatures, denoted by p. So far all techniques are eigen-based approaches which use eigenvalues or eigenvectors to estimate the value of p. However, when eigenvalues are used to estimate VD such as Harsanyi-Farrand-Chang's method or hyperspectral signal subspace identification by minimum error (HySime), there will be no way to find what the spectrally distinct signatures are. On the other hand, if eigenvalues along with eigenvectors/singular vectors are used to estimate VD such as maximal orthogonal complement algorithm (MOCA), eigenvectors/singular vectors do not represent real signal sources. Most importantly, current available methods used to estimate VD run into two major issues. One is the value of VD being fixed at a constant. The other is failure in providing a means of finding signal sources of interest. As a matter of fact, the spectrally distinct signatures defined by VD should adapt its value to various target signal sources of interest. For example, the number of endmembers should be different from the number of anomalies. In order to resolve this dilemma this paper presents a new concept, referred to as target-specified VD (TSVD) whose value is determined by target signal sources of interest. The underlying idea of TSVD was derived from that used to develop high-order statistics (HOS) VD by Chang and Xiong who did not realize its applicability to second order statistics (2OS). In the past, two major types of 2OS-based target finding algorithms have been widely studied, unsupervised target detection algorithm, called automatic target generation process (ATGP) and anomaly detection-based algorithms, called Reed-Xiaoli detector (RXD)-like detection algorithms. These two types of 2OS-specified targets will be then used to determine the value of VD. Experiments are conducted in comparison with well-known and widely used eigen-based approaches.

8743-34, Session 7

Hyperspectral image unmixing via bi-linear generalized approximate message passing

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In hyperspectral unmixing, the objective is to decompose an electromagnetic reflectance dataset $bf{Y}inmathbb{R}^{Mtimes T}$, measured over M spectral bands and T pixels, into a set of N material spectra (or ``endmembers") ${bf{s}_n}_{n=1}^N$ with corresponding spatial abundances ${bf{a}_n}_{n=1}^N$, so that $bf{Y}=sum_{n=1}^N bf{s}_n bf{a}_n^textsf{T} + bf{W}$ with $bf{W}$ capturing noise effects. If the endmembers $bf{S}=[bf{s}_1,dots,bf{s}_N]$ were known apriori and sufficiently diverse (so that $bf{S}$ is full column rank), then the abundances $bf{A}=[bf{a}_1,dots,bf{a}_N]^textsf{T}$ could be inferred using, e.g., simple least-squares inversion $bf{A} approx bf{S}^+bf{Y}$. In practice, however, $bf{S}$ is unknown because it may not be known which materials are present in the scene, or--even if the materials present are known--their spectra can vary from reference values due to various factors such as sun angle, atmospheric absorption, etc. Moreover, classical approaches to endmember extraction such as VCA or N-FINDER rely on the availability of pure (i.e., single-material) pixels.

In this paper, we propose a novel approach to hyperspectral unmixing (i.e., joint estimation of endmembers and abundances) using the bilinear generalized approximate message passing algorithm (BiG-AMP), a recently proposed approach to matrix factorization based on loopy belief propagation. The BiG-AMP framework enables the exploitation of spectral coherence and non-negativity in $bf{S}$, as well as spatial coherence and simplex constraints in $bf{A}$. Moreover, an expectation-maximization technique can be used to automatically tune the prior statistics on $bf{S}$, $bf{A}$, and $bf{W}$ assumed by BiG-AMP. We establish numerically, though both synthetic and real-world examples, that BiG-AMP accomplishes nearly MMSE hyperspectral unmixing with runtimes that are orders-of-magnitude below the state-of-the-art Bayesian approaches.

8743-35, Session 7

Comparing quadtree region partitioning metrics for hyperspectral unmixing

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This paper presents an approach for unmixing using quadtree region partitioning. Images are partitioned in low spectral variability regions using quadtree region partitioning. Unmixing is performed in each individual region using the positive matrix factorization. The extracted endmembers are the clustered in endmembers classes which account for the variability of spectral endmembers across the scene. The proposed method lends itself to an unsupervised approach. In the paper, we will examine the effect of different metrics for spectral variability and the type of scene being analyzed. Hyperspectral imagery from different sources is used in the experiments.

8743-36, Session 8

Impact of specular reflection on bottom type retrieved from WorldView-2 images

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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. Recently the CWST was modified to process multi-spectral WorldView-2 imagery. Generally imagery processed through the CWST has been collected under optimal sun and viewing conditions so as to minimize surface effects such as specular reflection. As such, in our standard atmospheric correction process we do not include a specular reflection correction. In June 2010 a series of 7 WorldView-2 images was collected within 2 minutes over Moreton Bay, Australia. The images clearly contain varying amounts of surface specular reflection. Each of the 7 images was processed through the CWST using identical processing to evaluate the impact of ignoring specular reflection on coverage and consistency of bottom types retrieved.

8743-37, Session 8

Using multi-angle WorldView-2 imagery to determine bathymetry near Oahu, Hawaii

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Multispectral imaging (MSI) data collected at multiple angles over shallow water provide analysts with a unique perspective of bathymetry in coastal areas. Observations taken by DigitalGlobe's WorldView-2 (WV-2) sensor acquired at 39 different view angles on 30 July 2011 were used to determine the effect of acquisition angle on bathymetry derivation. The site used for this study was Kailua Bay (on the windward side of the island of Oahu). Satellite azimuth and elevation for these data ranged from 18.8 to 185.8 degrees and 24.9 (forward-looking) to 24.5 (backward-looking) degrees (respectively) with 90 degrees representing a nadir view. Bathymetry were derived directly from the WV-2 radiance data using a band ratio approach. Comparison of results to LiDAR-derived bathymetry showed that varying view angle impact the quality of the inferred bathymetry. Derived and reference bathymetry have a higher correlation as images are acquired closer to nadir. The band combination utilized for depth derivation also has an effect on derived bathymetry. Four band combinations were compared, and the Blue & Green combination provided the best results.

8743-38, Session 8

Automatic ship detection from commercial multispectral satellite imagery

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Commercial multispectral satellite sensors, in particular 8-band WorldView-2, spend much of their time over open-ocean. NRL has demonstrated an automatic processing system that finds ships in open water, and in the presence of clouds, in order to utilize the “ocean time” of orbiting assets for maritime domain awareness (MDA). A water/cloud clutter subspace is estimated, and a continuum fusion-derived anomaly detection scheme is applied. This produces a low false alarm rate system that maintains an acceptable detection probability.

8743-39, Session 8

A decade of measured greenhouse forcings from AIRS hyperspectral outgoing longwave spectra

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. Increased greenhouse gasses reduce the transmission of Outgoing Longwave Radiation (OLR) to space along spectral absorption lines causing the Earth’s temperature to rise in order to preserve energy equilibrium. This greenhouse forcing effect can be directly observed in the Outgoing Longwave Spectra (OLS) from hyperspectral space-borne infrared instruments with sufficiently high resolving power [R. Goody 1995, Harries 2001]. In 2001, Harries et. al observed significant increases in greenhouse forcings by direct inter-comparison of the IRIS spectra 1970 and the IMG spectra 1997 [Harries 2001]. We have extended this effort by measuring the annual rate of change of AIRS all-sky Outgoing Longwave Spectra (OLS) with respect to greenhouse forcings. Our calculations make use of a 20x20 degree monthly gridded brightness temperature product. Decadal trends for AIRS spectra from 2002-2012 indicate continued decrease of -0.06K/yr in the trend of Brightness Temperature of CO2 (14.15u and 4.3u), a decrease of -0.04K/yr BT in the O3 BT (9.8u), a decrease of -0.03K/yr in the CH4 BT (7.7u) and slightly positive increases of 0.03K/yr in the CFC11 and CFC12 BTs respectively of window channels at 8.7u and 11.1u, in accordance with results of the Montreal Protocol. Our 14.15u trends are consistent with the expected radiative forcings from 10 years of increased CO2 even though surface temperatures have not risen substantially over the last decade.

8743-40, Session 8

Initial validation of atmospheric compensation for a Landsat land surface temperature product

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The Landsat series of satellites is the longest set of continuously acquired moderate resolution multispectral satellite imagery collected on a single maintained family of instruments. The data are very attractive because the entire archive has been calibrated and characterized so that sensor reaching radiance values are well known. Because of the spatial and temporal coverage provided by Landsat, it is an intriguing candidate for a land surface temperature (LST) product, an important earth system data record for a number of fields including numerical weather prediction, climate research and a number of agricultural applications. Using Landsat’s long-wave infrared thermal band, LST can be derived with a well-characterized atmosphere and a known surface emissivity. This work integrates the North America Regional Reanalysis dataset (atmospheric profile data) with ASTER derived emissivity data to perform LST retrievals. This paper emphasizes progress toward atmospheric compensation at each Landsat pixel. Due to differences in temporal and spatial sampling, a number of interpolations are required to compute the radiance due to temperature at each pixel, introducing error into the process. Radiosonde data and water temperatures derived from buoys are used as ground truth data to explore the error in the final predicted temperature. Preliminary results show consistent errors of less than 1 K in clear atmospheres but higher errors in hotter and more humid atmospheres. Future work will analyze results to predict error in the final retrieved temperatures using atmospheric conditions. The final goal is to report both a predicted LST and a confidence in this value.

8743-75, Session P-TUE

Progressive constrained energy minimization for subpixel detection

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Constrained energy minimization (CEM) has been widely used for subpixel detection. It makes use of the sample correlation matrix R to suppress background so as to enhance detection of targets of interest. In many real world problems implementing target detection on a timely basis is crucial, specifically, moving targets. However, since the calculation of the sample correlation matrix R needs the entire data samples prior to its detection such requirement prevents CEM from being implemented as a real time processing algorithm. In order to resolve this dilemma, the sample correlation matrix R must be replaced with a causal sample correlation matrix formed by only those data samples that have been visited and up to the currently being processed data sample. This causality is a pre-requisite to real time processing. By virtue of such a causality designing and developing a real time processing version of CEM becomes feasible. This paper presents a progressive CEM (PCEM) where the causal sample correlation matrix can be updated sample by sample. Accordingly, PCEM allows the CEM to be implemented as a causal CEM (C-CEM) as well as real time (RT) CEM via a recursive update equation in real time.

8743-76, Session P-TUE

GPUs for parallel on-board hyperspectral image radiometric normalization

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The main challenge of the hyperspectral remote sensing is the enormous computational requirements needed to effectively process a collection of high dimensional data sets in large remote sensing data repositories. Fortunately, hyperspectral image processing algorithms exhibit inherent parallelism at multiple levels, and map nicely on high performance

systems such as graphics processing units (GPUs). Meanwhile, GPUs are easy to adapt to on-board data processing scenarios, in which low-weight and low-power integrated components are desirable to reduce mission payload. This paper proposed a GPU-based implementation of radiometric normalization algorithms, which is used as a representative case study of on-board data processing techniques for hyperspectral image. Radiometric normalization of hyperspectral image aims at reducing or eliminating the vertical strips and resuming the true radioactive information. Three algorithms of radiometric normalization based on the column average and standard deviation of raw image statistical characteristics, i.e. the adjacent column balanced normalization (ACBN), moment matching normalization (MMN) and the mean normalization (MN), were implemented and applied to real hyperspectral images for evaluating their performance. These algorithms need no other parameters and variables but image pixel digital values, so very easy to apply, especially for on-board data processing with efficient parallel methods. These algorithms have been implemented using the compute device unified architecture (CUDA), and tested on the NVidia Tesla C2075 architecture. The airborne Pushbroom Hyperspectral Imager (PHI) was flown to acquire the spectrally contiguous images in different regions as experimental datasets. Further more, the proposed implementations are quantitatively compared and assessed in terms of both radiometric normalization accuracy and parallel efficiency. Radiometric normalization accuracy has been assessed by the full field and adjacent field methods. The results show that MN worked best among the three methods and the speedups achieved by the GPU implementation over their CPU counterparts are outstanding. Considering that a series of satellites with hyperspectral sensors will be launched in the near future, this study provides a thoughtful perspective on the potentials of adapting these techniques to on-board as well as on-the-ground hyperspectral image processing.

8743-77, Session P-TUE

Impact of spatial complexity preprocessing on hyperspectral data unmixing

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For most of the success, HSI processing techniques have their origins in multidimensional signal processing with a special emphasis on optimization based on objective functions. Many of these techniques (ICA, PCA, NMF, OSP, etc.) have their basis on collections of single dimensional data and do not take in consideration any spatial based characteristics (such as the shape of objects in the scene). Recently, in an effort to improve the processing results, several approaches that characterize spatial complexity (based on the neighborhood information were introduced).

Our goal is to investigate how spatial complexity based approaches can be employed as preprocessing techniques for other previously established methods. First, we designed for each spatial complexity based technique a step that generates a hyperspectral cube scaled based on spatial information. Next we feed the new cubes to a group of processing techniques such as ICA and PCA. We compare the results between processing the original and the scaled data.

We compared rhe results on the scaled data with the results on the full data. We built upon these initial results by employing additional spatial complexity approaches. We also introduced new hybrid approaches that would embed the spatial complexity step into the main processing stage. Compared to previous research, our work provides a comprehensive analysis of spatial complexity approaches including identification of common traits.

8743-78, Session P-TUE

Code aperture design and performance comparison based on coded aperture spectral snapshot imager (CASSI) system

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A coded aperture spectral snapshot imager (CASSI) system provides an probable approach to capture both spectral information and 2D sparse spatial information with a single shot image, according to the code aperture and dispersion element. However, the reconstruction process dealing highly compressive measurements with a single shot image is seriously limited by the design of efficient coded aperture pattern. Considering the improvement of SNR and the flexibility in different observing object, An optimal design of coded aperture should help lower the pressure in reconstructing 3D spectral date cube with no loss of entrance pupil energy, meanwhile satisfy the demand in spatial/spectral resolution simultaneously.

In this paper, we research to find a proper mathematical method helping the design of code aperture. The new method, based on the theory of compressive sensing and the study of traditional spectral data, is strictly constrained by spatial/spectral restricted isometric property (RIP) and the irrelevant conditions in spectral dimension, and its realistic physical and technical problems were also discussed. We sort the code aperture's optimal forms of mathematics by testing the normal reconstruction algorithms under the same signal sparse ratio and CS measurements. We did many computational simulations and analysis to simulate the whole process. Based on the simulations, we reconstructed a series of 1280*1036*22 spectral image data cube by the CASSI system to confirm our theory.

8743-79, Session P-TUE

Concealed target detection using hyperspectral imagers based on intersection kernel of SVM

Min-Sheob Shim, Sungho Kim, Yeungnam Univ. (Korea, Republic of)

This paper presents a concealed object detection based on the intersection kernel Support Vector Machine (SVM). Hyperspectral imagers are widely used in the field of target detection and material analysis. In military applications, it can be used to border protection, concealed target detection, reconnaissance and surveillance. If you do not detect disguised enemies in advance, the damage of allies will be catastrophic by unexpected attack. For example, tanks disguise themselves using similar bush pattern in terrain. Concealed object detection using radar and terahertz method is widely used. However, these active techniques are easily exposed to the enemy. Electronic Optical Counter Counter Measures (EOCCM) using hyperspectral imagers can be a feasible solution. We use the feature of spectral profile directly and the intersection kernel based SVM. Since we use the same experiment set up absolute spectral information can be useful. Different materials show different spectrums although they look similar in CCD camera. In this experiment, we chose objects with similar colors and similar forms such as wig and hair, plant and military uniform, etc. According to the experimental results, the proposed method can detect concealed targets correctly.

8743-80, Session P-TUE

Fusion and quality analysis for satellite images using contourlet transform

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Recent developments in satellite sensor technologies have provided satellite images with high spatial and spectral resolutions. However, multispectral images have low spatial resolution and panchromatic images have low spectral resolution. Therefore, image fusion techniques are necessary to improve the spatial resolution of spectral images by injecting spatial details of high-resolution panchromatic images. The objective of image fusion is to provide useful information by improving the spatial resolution and the spectral information of the original images. The fusion results can be utilized in various applications, such as military, medical imaging, and remote sensing. This paper addresses two issues in image fusion: i) image fusion method and ii) quality analysis of fusion results. First, a new contourlet-based image fusion method is presented, which is an improvement over the wavelet-based fusion. This fusion method is then applied to a case study to demonstrate its fusion performance. Fusion frameworks and algorithms for both contourlet-based and wavelet-based methods are discussed in detail. Second, quality analysis for the fusion results is discussed. The main purpose of the quality analysis is to quantitatively analyze the performance of the fusion methods. Therefore, we employed various quality metrics including: i) average gradient and standard deviation for spatial quality analysis, and ii) correlation coefficient and Qavg index for spectral quality analysis. Our results indicate that the proposed contourlet-based fusion method performs better than the conventional wavelet-based fusion methods. Furthermore, the proposed contourlet-based fusion method has advantage in improving the spatial resolution while preserving the original spectral information.

8743-81, Session P-TUE

Improving performance of hyperspectral image classification via adaptive principle subspace detection

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In this paper, we propose a novel algorithm called the Adaptive Principle Subspace Detection (APSD) to preprocess hyperspectral images before performing the classification. The principle subspace is defined as the subspace that the center pixel of a neighborhood belongs to. For a given neighborhood centered on a test pixel, the APSD generates a set of weights using the nonnegative low rank approximation of the neighborhood pixels. We will show that such weights can be extracted from the sparse coefficients matrix of the nonnegative low rank approximation of the neighborhood pixels. APSD then computes the weighted sum of all pixels in the neighborhood to produce a synthesized pixel for the center pixel. Classification is then performed on the synthesized center pixels instead of the original pixels. APSD introduces two advantages for classification. First, if there exists more than one class within the neighborhood, which is represented by different subspaces, then all but the principle subspace is suppressed by the weights when generating the center pixel. Furthermore, comparing with the original center pixel, the APSD enforces the synthesized pixel to lay closer to the center of the principle subspace. Therefore, the synthesized pixel lies away from the boundary of the principle subspace which will benefit the performance of classification since the synthesized pixel is more discriminative than the original one. The algorithm is tested on several hyperspectral images and experiments show that our algorithm outperforms the classification methods without APSD preprocessing.

8743-82, Session P-TUE

Target detection in hyperspectral images: a comparative study of ICA and other algorithms

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Hyperspectral data acquired over hundreds of narrow contiguous wavelength bands is extremely suitable for target detection but requires spectral modeling using a priori available target spectra, a condition difficult to meet in practice. It therefore necessitates algorithms which do not depend upon target spectra for target detection. Independent component analysis (ICA), an evolving new technique that aims at finding out components which are statistically independent or as independent as possible, can be extended for target detection as it does not have any requirement of a priori availability of target spectra. A comparative assessment of target detection for hyperspectral images using ICA versus various other target detection algorithms therefore assumes significant interest. The aim of this paper is to compare ICA based algorithm with four spectral matching algorithms namely, Orthogonal Subspace Projection (OSP), Constrained Energy Minimisation (CEM), Spectral Angle Mapper (SAM) and Spectral Correlation Mapper (SCM), and four anomaly detection algorithms namely, OSP anomaly detector (OSPAD), Reed-Xiaoli anomaly detector (RXD), Uniform Target Detector (UTD) and a combination of Reed-Xiaoli anomaly detector and Uniform Target Detector (RXD-UTD) for target detection. A set of synthetic and AVIRIS hyperspectral data containing aircrafts as targets were used for the experiments. A comparison of true positive and false positive rates of target detections obtained from ICA and other algorithms plotted on a receiver operating curves (ROC) space indicates superior performance of ICA over other algorithms.

8743-83, Session P-TUE

Interferometric imaging spectropolarimeter using polazation modulation

Xin Meng, Jianxin Li, Rihong Zhu, Nanjing Univ. of Science and Technology (China)

We introduce a novel imaging spectropolarimeter. One image plane interferometric Fourier transform imaging spectrometer without slit is combination with a simple polarization modulation component consisting of four sets of polarization devices, each consist of one retarder and one linear polarizer.The four retarders are made of the same material and have a union thickness, so as the four polarizers. The fast axis of the retarders and the transmission axis of the polarizers are oriented at (0°, 0°), (0°, 90°), (45°, 45°), (0°, 45°) relative to the x axis We can get four polarization states of each inteferometric image by rotating the polarization modulation component, form where all the stokes polarization parameters can be got. The most significant advantage of the method is that there is no aliasing among different fringes with different polarization information.So it can be used to measure narrow-band sepctrum, so as the broad-band sepctrum.Additionally, the advantages of the Fourier transform spectrometer are reserved, such as high radiative throughput.

8743-84, Session P-TUE

High Etedue interferometric imaging spectrometer

Jianxin Li, Xin Meng, Rihong Zhu, Nanjing Univ. of Science and Technology (China)

The technology of image plane interferometric hyperspectral imaging is mainly applied in remote sensing imaging field. In order to realize the spectral imaging of targets at different distances, a method of image plane interferometric hyperspectral imaging is presented. A re-imaging interferometic system is set up by inserting front-end imaging lens, relay collimating lens and transverse shear beam splitter in infinite imaging system. A separated front-end imaging lens method with choice of zoom lens or fixed focus lens is adopted to achieve spectral imaging of targets at long and short distances. The imaging system, resolution of spectrum and push broom mode are analyzed. Experimental device is set up to detect the targets of near field indoor and far field outdoor. A microscopic spectral imaging test of biological tissue is also carried out with the device. The experimental results show that the proposed imaging method is effectively applied in hyperspectral imaging of targets at different distances.

8743-86, Session P-TUE

Water mapping through universal pattern decomposition method in comparison to modified normalized difference water index (MNDWI)

Muhammad Hasan Ali Baig, Lifu Zhang, Liu Kai, Tong Shuai, Institute of Remote Sensing and Digital Earth (China); Ji Lei, U.S. Geological Survey (United States)

Water Mapping has been an important research issue both in optical and microwave remote sensing for proper assessment of agriculture, flood losses, military targets and ecology. The existing indices are sensor-dependent like NDVI, NDWI, and MNDWI etc. In this study vegetation index based on the Universal Pattern Decomposition Method has been analyzed in detail and some modifications are suggested to use it for proper water mapping. MODIS and Landsat data have been used whil Otsu method is used for developing thresholds to delineate water from non-water features. This index gave very good results and accuracy assessment led to the significance of this index for both multispectral and hyperspectral data.

8743-41, Session 9

Detection of unknown gas-phase chemical plumes in hyperspectral imagery

James Theiler, Brendt E. Wohlberg, Los Alamos National Lab. (United States)

Gas-phase chemical plumes exhibit, particularly in the infrared, distinctive emission signatures as a function of wavelength. Hyperspectral imagery can exploit this distinctiveness to detect specific chemicals, even at low concentrations, using matched filters that are tailored both the the specific structure of the chemical signature and to the statistics of the background clutter. But what if the chemical species is unknown? One can apply matched filters to a long list of candidate chemicals (or chemical mixtures), or one can treat the problem as one of anomaly detection. In this case, however, the anomalous signals of interest are not completely unknown. Gas spectra are generically sparse (absorbing or emitting at only a few wavelengths), and this property can be exploited to enhance the sensitivity of anomaly detection algorithms. This paper will investigate the utility of sparse signal anomaly detection for the problem of finding plumes of gas with unknown chemistry in hyperspectral imagery.

8743-42, Session 9

Hyperspectral chemical plume quantification via background radiance estimation

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The quantification of chemical plumes by remote hyperspectral sensing is a challenging problem due to the sensitive non-linear dependence of the at-sensor radiance on the details of the gas signature and environmental variables. Existing algorithms assume that the off-plume radiance of a pixel containing the plume signal is unobservable. However, when the problem is limited to a single gas, the complete off-plume radiance may be estimated from the bands in which the gas absorption is nearly zero. It is then possible to compute the difference between the on- and off-plume radiances and solve for the plume strength from Beer's Law. The major advantage of the proposed method is that the gas strength can be resolved from the radiance difference so that the estimation error remains small for thick plumes. The resulting estimate may be input to an optimization algorithm for further performance improvement. The key factor that determines the ultimate estimation performance is whether there are enough signal-free spectral bands so the off-plume radiance can be approximated accurately. Gases with narrow-band features, such as SF6, are ideal for this mechanism. The problem is more challenging for gases with broader features, such as TEP. However, our experiments have shown that good results are possible for these cases as well.

8743-43, Session 9

Detection and tracking of gas clouds in an urban area by imaging infrared spectroscopy

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The release of toxic industrial compounds in urban areas is a threat for the population and the environment. In particular in cities with harbor areas, large amounts of toxic industrial chemicals are loaded, transported, and unloaded close to populated areas. In order to supply emergency response forces with information about the released compounds after accidents or terrorist attacks, monitoring systems such as the scanning imaging spectrometer SIGIS 2 or the hyperspectral imager HI 90 were developed and presented in previous works.
Both systems are based on the method of infrared Fourier-transform spectroscopy. They provide real-time information about the presence of hazardous gases in the atmosphere and images of the cloud. The systems were deployed to monitor gas clouds released in the harbor area of Hamburg. The gas clouds were identified, visualized and quantified from a distance in real time. Both systems delivered images of the gas clouds which made it possible to track the dispersion of the clouds. Using data of two systems it was possible to identify contaminated areas and to determine the source location.

8743-44, Session 9

Spectral target detection using a physical model and a manifold learning technique

James A. Albano, David W. Messinger, Rochester Institute of Technology (United States)

Identification of materials from calibrated radiance data collected by an airborne imaging spectrometer depends strongly on the atmospheric and illumination conditions at the time of collection. This, along with distributional and/or linear assumptions about the data in the hyperspace, limits the performance of current target detection methodologies in complex radiometric environments and highly cluttered scenes. This paper presents a methodology for identifying material spectra with the assumption that each unique material class forms a lower-dimensional manifold (surface) in the higher-dimensional spectral radiance space and that all in-scene spectra reside on, or near, these theoretic manifolds. Using a physical model, a manifold characteristic of the target material spectrum exposed to varying illumination and atmospheric conditions is formed. A graph-based model is then applied to the radiance data to capture the intricate structure of each material manifold followed by the application of the commute time distance (CTD) transformation to separate the target manifold from the background. This nonlinear transformation is based on a Markov-chain model of a random walk on a graph and is derived from an eigendecomposition of the graph Laplacian matrix. This paper discusses the properties of the CTD transformation, the atmospheric and illumination parameters varied in the physical model and the target manifold's influence on the direction of the CTD axes. A comparison between target detection algorithms applied in the spectral radiance, reflectance, and CTD spaces will be given and quantified using receiver operating characteristic (ROC) curves and other visual techniques.

8743-45, Session 9

Target detection performed on manifold approximations recovered from hyperspectral data

Amanda K. Ziemann, David W. Messinger, James A. Albano, Rochester Institute of Technology (United States)

In high dimensional data, manifold learning seeks to identify the embedded lower-dimensional, non-linear manifold upon which the data lie. This is particularly useful in hyperspectral imagery where inherently m-dimensional data is often sparsely distributed throughout the n-dimensional spectral space, with m<< n. By recovering the manifold, inherent structures and relationships within the data -- which are not typically apparent otherwise -- may be identified and exploited. The sparsity of data within the spectral space can prove challenging for many types of analysis, and in particular with target detection. In this paper, we propose that manifold recovery be used as a preprocessing step for target detection algorithms. A graph structure is first built upon the data and the transformation into the manifold space is based upon that graph structure. Then, standard target detection algorithms are applied. We present an analysis of target detection performance in the manifold space for both in-scene targets and spectral library targets.

8743-46, Session 9

Hyperspectral target detection by Gaussian/ non-Gaussian subspace division and nonparametric density estimation

Gil A. Tidhar, Stanley R. Rotman, Ben-Gurion Univ. of the Negev (Israel)

Hyperspectral imaging data may exhibit non Gaussian distributions that significantly deteriorate the performance of target detection algorithms based on multivariate Gaussian distributed data assumption. We present a new solution to this existing problem by dividing the data into two separate subspaces - one which is essentially multivariate Gaussian distribution and the other which is essentially non-Gaussian. The non Gaussian subspace whose dimension is much smaller than that of the Gaussian subspace is modeled by a non-parametric joint probability density estimator which is also used to develop an LRT test for target detection. The Gaussian subspace data is modeled using established models for such data then used with established target detection algorithms most suitable for Gaussian background data. The fusion of the two detection algorithms results in an improved target detection method. We develop the new method for data analysis and target detection and demonstrate its power against existing benchmark techniques.

8743-47, Session 10

NASA Goddard's lidar, hyperspectral, and thermal airborne imager (G-LiHT)

Lawrence A. Corp, NASA Goddard Space Flight Ctr. (United States) and Sigma Space Corp. (United States); Bruce D. Cook, Elizabeth M. Middleton, NASA Goddard Space Flight Ctr. (United States)

Two years ago, scientists in the Biospheric Sciences Laboratory at NASA's Goddard Space Flight Center began an effort to integrate commercial off the shelf LiDAR, hyperspectral, and thermal components to produce a compact, lightweight and portable system that can be used on a wide range of airborne platforms to support a number of NASA Earth Science research projects and space-based missions. The result of this instrument fusion effort was G-LiHT, a unique system that permits simultaneous measurements of vegetation structure, foliar spectra and surface temperatures. The complementary nature lidar, optical, and thermal data provide an analytical framework for the development of new algorithms for mapping plant species composition, plant functional types, biodiversity, biomass and carbon stocks, and plant growth. This will enhance our ability to design new missions and produce data products related to biodiversity and climate change. G-LiHT is designed to give scientists access to the data that is needed to understand the relationship between ecosystem form and function and stimulate the advancement of synergistic algorithms. G-LiHT has been used to collect more than 300 hours of data for NASA sponsored studies, including NASA's Carbon Monitoring System (CMS) and American ICESat/GLAS Assessment of Carbon (AMIGA-Carb). These acquisitions target a broad diversity of forest communities and ecoregions across the CONUS and Mexico. Here we will discuss the components of G-LiHT, their calibration and performance characteristics, operational implementation, data processing workflows; we will also provide examples of higher level data products that are currently under development.

8743-48, Session 10

On super-resolved coded aperture spectral imaging

Hoover F. Rueda, Univ. of Delaware (United States); Henry Arguello, Univ. of Delaware (United States) and Univ. Industrial de Santander (Colombia); Gonzalo R. Arce, Univ. of Delaware (United States)

Coded aperture-based optical imaging systems are at the forefront of optical imaging modeling since they allow to capture three-dimensional scenes of spectral information in a single two-dimensional focal plane array (FPA) snapshot. Coded Aperture Snapshot Spectral Imager (CASSI) is a remarkable architecture in this field whose snapshot measurements are random modulated and dispersed versions of the underlying hyper-spectral scene, which are considered analogous to the so-called random projections in compressive sensing (CS) theory. In CASSI, the spatial and spectral resolution of the reconstructed scene highly depends on the ratio between the coded aperture and the FPA pixels pitches. However, the increasing cost of small-pitch FPAs meanly in the infrared wavelength domain limits the broad use of CASSI. This work focuses on the sensing and reconstruction of high-resolution hyper-spectral scenes from low-resolution FPA detectors. Precisely, we present a multiple-shot extension of CASSI where spectral super-resolution can be attained by using high-resolution coded apertures. In the proposed system, a second high-resolution coded aperture is introduced into CASSI architecture to encode both spatial and spectral dimensions of the data cube. This approach allows the reconstruction of super-resolved hyper-spectral data cubes, where the number of spectral bands is significantly increased. Simulation results show an improvement of up to 6 dB in PSNR image reconstruction, at the time that a four-fold increase in spectral resolution is achieved.

8743-49, Session 10

A prototype panoramic compact shortwave infrared hyperspectral sensor for maritime sensing: performance and applications

K. Peter Judd, Jonathan M. Nichols, James R. Waterman, U.S. Naval Research Lab. (United States); Colin C. Olson, Sotera Defense Solutions, Inc. (United States); Dan Guerin, Brandywine Photonics LLC (United States); Gordon Scriven, Opto Knowledge Systems, Inc. (United States)

There is current interest in upgrading Navy capabilities for wide area situational awareness, detection, and identification in “blue water” wide areas, littoral and port environments, and from land-based surveillance posts. This presentation reviews the design and operation of a panoramic passive short-wave infrared hyperspectral imager to explore these applications. The system is designed around a commercial 640 x 512

InGaAs detector sensitive to radiation in the 0.9-1.7 micron waveband, with a compact optical design consisting of a Dyson spectrometer and a commercial color corrected 50 mm F/1.4 telescope. The spatial data are aligned with the 640 pixel direction and the system has an IFOV of 0.5 mrad. The spectral resolution is ~8.7 nm with 111 bands illuminated. The sensor package is mounted to a variable speed pan/tilt unit that provides the scanning to generate the hyperspectral cube. To examine the imaging quality, characteristics, and capabilities of the system, data were acquired of ship traffic into and out of the port of San Diego. For baseline and comparison purposes, image data from a broadband short-wave infrared sensor and two narrow field of view hyperspectral sensors systems are presented. In addition, spectral discrimination of maritime features and traffic is discussed in light of a kernel principal component analysis detection algorithm and receiver operating characteristic curve performance is described. Finally, methods for introducing locally measured meteorological parameters into the data conditioning component of the analysis chain is demonstrated and potential improvements to the detection capabilities are discussed.

8743-50, Session 10

Modeling, development, and testing of a shortwave infrared supercontinuum laser source for use in active hyperspectral imaging

Joseph Meola, Air Force Research Lab. (United States)

Hyperspectral imaging (HSI) systems are currently used for numerous intelligence, surveillance, and reconnaissance (ISR) applications. These passive imaging systems rely on naturally reflected/emitted radiation as the source of the signal. Thermal infrared systems measure radiation emitted from objects in the scene. As such, they can operate at both day and night. However, visible (VIS) through shortwave infrared (SWIR) systems measure solar illumination reflected from objects. As a result, their use is limited to daytime applications. The University of Michigan/ Omni Sciences have produced high powered broadband SWIR super-continuum laser (SSCL) illuminators. A 25-watt breadboard system was recently characterized in a laboratory setting at UM. Additionally, a 5-watt unit was recently packaged and tested at Wright-Patterson Air Force Base (WPAFB) to gauge beam quality and to serve as a proof-of-concept for potential active HSI use at longer ranges. The SSCL was placed in a tower and directed along a 1.6km slant path to various target materials draped over a tilted plywood stand on the ground. The results of this testing along with modeling of an operational system are discussed here.

8743-51, Session 10

Low-complexity image processing for a high-throughput, low-latency snapshot multispectral imager with integrated tiled filters

Bert Geelen, Carolina Blanch, Klaas Tack, Andy Lambrechts, IMEC (Belgium)

Traditional spectral imaging cameras typically operate as pushbroom cameras by scanning a scene. This approach makes such cameras well-suited for high spatial and spectral resolution scanning applications, such as remote sensing and machine vision, but ill-suited for 2D scenes with free movement. This limitation can be overcome by single frame, multispectral (here called snapshot) acquisition, where an entire three-dimensional multispectral data cube is sensed at one discrete point in time and multiplexed on a 2D sensor.

Our snapshot multispectral imager is based on optical filters monolithically integrated on CMOS image sensors with large layout flexibility. Using this flexibility, the filters are positioned on the sensor in a tiled layout, allowing trade-offs between spatial and spectral resolution. At system-level, the filter layout is complemented by an optical sub-system which duplicates the scene onto each filter tile. This optical sub-system and the tiled filter layout lead to a simple mapping of 3D spectral cube data on the sensor, facilitating simple cube assembly. Therefore, the required image processing consists of simple and highly parallelizable algorithms for reflectance and cube assembly, enabling real-time acquisition of dynamic 2D scenes at low latencies. Moreover, through the use of monolithically integrated optical filters the multispectral imager achieves the qualities of compactness, low cost and high acquisition speed, further differentiating it from other snapshot spectral cameras. Our prototype camera can acquire multispectral image cubes of 256x256 pixels over 32 bands in the spectral range of 600-1000nm at 340 cubes per second for normal illumination levels.

8743-52, Session 11

Interactive mapping and quantification tools for remote sensing imagery

Reid B. Porter, Los Alamos National Lab. (United States)

The task of turning raw imagery into semantically meaningful maps and overlays is a key area of remote sensing activity. Image analysts, in communities ranging from environmental monitoring to intelligence, use imagery to generate and update maps of terrain classifications, crop types, road networks, buildings, and so on. Often this problem is cast as a pixel labeling problem, and a large number of solution methods have been developed. Although the performance of these automated methods is improving, they are still error prone and often not tailored to the problem at hand, which means analysts spend large amounts of time in post-processing: editing results and fixing errors.

In this paper we describe an approach to reduce analyst time in post-processing by learning from user edits and corrections. The idea is to identify repetitive, often tedious, corrections made by the analyst, and then predict (automate) additional corrections in the larger image or image archive. We first describe the space of post-processing interactions, and then argue that we must move beyond standard "label learning" in order to automate this process. We then describe the additional pixel grouping and ungrouping interactions that we believe are key to accelerating post-processing, and present solution methods for learning these interactions.

We demonstrate the effectiveness of our approach (in terms of analyst productivity) for a number of mapping applications using commercial satellite imagery, including road networks, canopy mapping and crop quantification.

8743-53, Session 11

Enhancement of hyperspectral imagery using spectrally weighted tensor anisotropic nonlinear diffusion for classification

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Tensor Anisotropic Nonlinear Diffusion (TAND) is a divergence PDE-based diffusion technique that "guided" by an edge descriptor, such as the structure tensor, to stir the diffusion. The structure tensor for vector valued images such as HSI is most often defined as the average of the scalar structure tensors for each band. The problem with this definition is the assumption that all bands provide the same amount of edge information giving them the same weights. As a result non-edge pixels can be reinforced and edges can be weakened resulting in a poor performance by processes that depend on the structure tensor. Iterative processes such as TAND, in particular, are vulnerable to this phenomenon. Recently a weighted structure tensor based on the heat operator has been proposed. The weights are based on the heat operator. This tensor takes advantage of the fact that, in HSI, neighboring spectral bands are highly correlated, as are the bands of its gradient. By taking advantage of local spectral information, the proposed scheme

gives higher weighting to local spectral features that could be related to edge information allowing the diffusion process to better enhance edges while smoothing out uniform regions facilitating the process of classification. This article present how classification results are affected by of using the TAND based on the heat weighted structure tensor as an image enhancement step in a classification system.

8743-54, Session 11

Pan-sharpening of spectral image with anisotropic diffusion for fine feature extraction using GPU

Weihua Sun, Bin Chen, David W. Messinger, Rochester Institute of Technology (United States)

Feature extraction from satellite image is a challenging topic. Commercial satellite data sets, such as WorldView 2 images, are often delivered with a high spatial resolution panchromatic image (PAN) as well as a corresponding multispectral spectral image(MSI). Certain fine features are only visible on the PAN but hard to discern on the MSI. To fully utilize the high spatial resolution of the PAN and the rich spectral information from the MSI, a pan sharpening process can be carried out. In this paper, we propose a novel and fast pan sharpening process with the aim to aid feature extraction that enhances salient spatial features. The process starts with an initial estimation by either simply upscaling the spectrum image using nearest neighbor interpolation or pan-sharpening using Price's approach (1987); then the upscaled image is optimized through anisotropic diffusion. Digital count difference from the PAN and spectral angle difference in the MSI provide gradient priors for the diffusion process. Our approach is capable of preserving salient edges in both PAN and MSI as well as eliminating spatial noise. In addition, the process is highly parallel with intensive neighbor operations and can be accelerated on a general purpose GPU card with NVidia CUDA architecture. We hope this algorithm can facilitate fine feature extraction from satellite images.

8743-55, Session 11

An analysis of the probability distribution of spectral angle and Euclidean distance in hyperspectral remote sensing using microspectroscopy

Ronald G. Resmini, Christopher J. Deloye, The MITRE Corp. (United States); David W. Allen, National Institute of Standards and Technology (United States)

Determining the probability distribution of hyperspectral imagery (HSI) data and, more importantly, the distribution of the results of algorithms applied to those data, is critical to understanding algorithm performance and the closely related activity of establishing performance metrics such as probability of detection, false alarm rate, and minimum detectable and identifiable quantities. The results of analyses of visible/near-infrared (VNIR; 0.4 micrometer to 0.9 micrometer) HSI microscopy data of small fragments (~1.25 cm in size) of minerals are presented. HSI microscopy, also known as microspectroscopy, is the acquisition of HSI data cubes of fields of view ranging from centimeters to millimeters in size. It is imaging spectrometry but at a small spatial scale. With HSI microspectroscopy, several thousand spectral signatures may be easily acquired of individual target materials—samples of which may be quite small. With such data, probability distributions may be very precisely determined. For faceted/irregularly shaped samples and mixtures (checkerboard, intimate, or microscopic), HSI microscopy data readily facilitate a detailed assessment of the contribution of the materials, their morphology, spectral mixing interactions, radiative transfer processes, view/illumination geometry contributions, etc., to the observed probability distribution(s) of the HSI data and of algorithm output. Here, spectral angle, the individual components of spectral angle (e.g., the inner product or numerator of the spectral angle equation), Euclidean distance, and L1 norm values are calculated. Regions of interest (ROI) on the fragments are easily defined that contain thousands of spectra far from the fragments' edges though translucency sometimes remains a factor impacting spectral signatures. The aforementioned metrics are derived for the spectra in an ROI of individual mineral fragments; across ROIs of different minerals; and with an ROI of an inert background. The resulting probability distributions of the various populations of the metrics are decidedly non-Gaussian though the precise probability distribution is difficult to determine. The HSI microscopy method is described as are the results of the analyses applied to the data of the mineral fragments. The interpretation of the microspectroscopy data is framed within the ongoing investigation into determining how the spectral variability on the ~10 micrometer spatial scale relates to the spectral variability on larger scales such as those acquired by airborne remote sensing systems.

8743-56, Session 11

Advanced spectral signature discrimination algorithm

Sumit Chakravarty, New York Institute of Technology (United States)

This paper presents a novel approach to the task of hyperspectral signature analysis. Hyperspectral signature analysis has been studied a lot in literature and there has been a lot of different algorithms developed which endeavors to discriminate between hyperspectral signatures. There are many approaches for performing the task of hyperspectral signature analysis. Binary coding approaches like SPAM and SFBC use basic statistical thresholding operations to binarize a signature which are then compared using Hamming distance. This framework has been extended to techniques like SDFC wherein a set of primate structures are used to characterize local variations in a signature together with the overall statistical measures like mean. As we see such structures harness only local variations and do not exploit any co-variation of spectrally distinct parts of the signature. The approach of this research is to harvest such information by the use of a technique similar to circular convolution. In the approach we consider the signature as cyclic by appending the two ends of it. We then create a copy of the spectral signature. These two signatures can be placed next to each other like the rotating discs of a combination lock. We then find local structures at different circular shifts between the two cyclic spectral signatures. Texture features like in SDFC can be used to study the local structural variation for each circular shift. We can then create different measure by: 1) calculating average amount of variations at a shift and thereby generating a vector (where each element is the average value for a shift); 2) by creating histogram from the shifts. Experiments are performed to compare the results of the new algorithm with the current spectral signature discriminations processes.

8743-57, Session 11

Blind source separation of the HyMap hyperspectral data via canonical correlation analysis

Ozgur Polat, ASELSAN Inc. (Turkey); Yakup Özkazanç, Hacettepe Univ. (Turkey)

In hyperspectral data analysis, blind separation of the target and background can be considered as a pre-processing step in the target detection process. Blind Source Separation (BSS) techniques can be used when there is no prior information on the scene for image understanding. Previously, Principal Component Analysis and Independent Component Analysis methods are used as blind techniques for the analysis of hyperspectral data. In this study, we propose a blind analysis methodology based on Canonical Correlation Analysis (CCA) for the analysis of hyperspectral data. CCA is a multivariate method of analysis for the exploration of the data structures which extremize the

correlations between two data sets. The hyperspectral data analyzed in this study is the HyMap sensor data which is available in the Target Detection Blind Test website. We produce two data sets out of the HyMap data cube which are later subjected to CCA. In the creation of these data sets, two different approaches are used. In first case, the HyMap data cube is simply divided into two sub-cubes by simple spectral separation. As another approach, the second data cube is derived from the HyMap data by a spatial filtering. In both cases, two data sets are analyzed via CCA and canonical variates of these data sets are obtained. The scene components are obtained from images expressed by the canonical variates obtained via CCA. The CCA methodology and its use as a blind analysis tools is presented on the HyMap data.

8743-58, Session 12

Intensity offset and correction of solid samples measured behind quartz cover glass

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Accurate and calibrated hemispherical/diffuse reflectance spectra libraries of solids are becoming more important for both hyperspectral and multispectral remote sensing exploitation. Many solids are in the form of powders or granules and in order to measure their diffuse reflectance spectra in the laboratory it is necessary to place the samples behind a transparent medium such as glass or quartz for the UV, visible or near-infrared spectral regions; the glass prevents the sample's unwanted dispersal into the instrument or laboratory environment. Using both experimental and theoretical methods we have found that for the case of an integrating sphere-coupled detector using fused quartz to contain the samples leads to an offset or skewing in the reflectance values. Although expected dispersive effects were observed for the fused quartz window in the UV, no wavelength effects were observed due to the quartz, only intensity shifts. The measured reflectance values are predominantly skewed by the reflectance from the air-quartz and sample-quartz interfaces with intensity-dependent distortions leading to measured values up to nearly ca. 6% too high for a 2% reflectance surface, ca. 3.8% too high for 10% reflecting materials, approximately correct (to within experimental error) for 40% to 50% diffuse reflecting surfaces, and nearly 2% too low for 99% reflecting Spectralon surfaces. The deviations arise from the added reflections from the quartz surfaces as verified by theory, modeling and experiment. Empirical correction factors were implemented into post-processing software to redress the artifact for hemispherical and diffuse reflectance data across the 300 to 2300 nm range.

8743-59, Session 12

Estimation of measurement uncertainties for a hyperspectral imager operating at the sub-millimeter spatial scale

David W. Allen, National Institute of Standards and Technology (United States); Christopher J. Deloye, Ronald G. Resmini, The MITRE Corp. (United States)

Assessing the ability of a hyperspectral imaging system to detect the presence of a substance or to quantify the abundance requires an end-to-end analysis of all of the measurement parameters. One part of the end-to-end analysis is the estimation of the uncertainties related to the reflectance spectra measured by the hyperspectral imager. Currently, there is no one single approach to this issue. In this work, estimated uncertainties were derived from the characterization of the sensor parameters including wavelength, straylight, and signal-to-noise for a visible/near-infrared (VNIR; 400 nm to 900 nm) hyperspectral imager. The combined estimated uncertainty was then compared to known optical reflectance standards, traceable to NIST, in order to gauge the level of agreement between the estimated uncertainties and the known values of the standards. In a simulation exercise, a petri dish of real world materials, as might be encountered in an Earth remote sensing scene, was imaged using the hyperspectral imager. The materials and the abundance of each were accounted for independently. This provided a datacube with points distributed in n-dimensional space with comparable complexity to realistic scenes. The classification of the components in the scene was determined by selecting representative reference spectra from regions-of-interest (ROI) within the scene and matching the remaining pixels in the scene to the selected spectra. The reference spectra were then adulterated to different degrees to represent different degrees of measurement uncertainty. The scene was then reclassified with the altered reference spectra. The differences in classification were quantified as products of an error matrix.

8743-60, Session 12

An automated method for locating spectral features for signature analysis and library optimization

William Basener, Rochester Institute of Technology (United States) and Exelis Visual Information Solutions (United States); Robert McEwen, National Ground Intelligence Ctr. (United States)

Library analysis and optimization has become an important component of robust hyperspectral target detection and identification algorithms. A key component of detection and identification library development is determining confusers, those materials whose signature is spectrally similar to desired targets. An Automatic Feature Finder has been developed to analyze VNIR/SWIR ground-truth signatures and automatically determine the locations and various statistics of absorption features subject to analyst review and adjustment. The locations and statistics are then combined with signature metadata and used for library analysis, including a feature-focused signature comparison algorithm, a library categorization algorithm, and a feature query algorithm

8743-61, Session 12

Spectral variability constraints on multispectral and hyperspectral mapping performance

Fred A. Kruse, Kenneth G. Fairbarn Jr., Naval Postgraduate School (United States)

Common approaches to multispectral imagery (MSI) and hyperspectral imagery (HSI) data analysis often utilize key image endmember spectra as proxies for ground measurements to classify imagery based on their spectral signatures. Most of these, however, take an average spectral signature approach and do not consider spectral variability. Multiple spectral measurements, whether from imagery data or utilizing a field spectrometer, demonstrate high variability linked not only to inherent material variability, but to acquisition parameters such as spatial and spectral resolution (spectral mixing). This research explores causes and characteristics of spectral variability in remotely sensed data and its effect on spectral classification and mapping. A ground-truth map supplemented by field spectral measurements was prepared and used for accuracy assessment. WorldView-2 and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data at similar spatial resolution were corrected to reflectance using a model-based approach supplemented by field spectral measurements. These data were then analyzed using ground and image spectral endmember spectra. Endmember spectra were assessed in terms of their spectral variability, and statistical and spectral-feature-based classification approaches were tested and compared to the ground truth map. Results illustrate that improved mapping can be achieved when spectral variability of individual endmembers is taken into account in the classification.

8743-62, Session 12

Multispectral and hyperspectral advanced characterization of soldier's camouflage equipment

Philippe Lagueux, Telops (Canada); Mariusz Kastek, Tadeusz Piatkowski, Rafal Dulski, Military Univ. of Technology (Poland); Vincent Farley, Martin Chamberland, Telops (Canada)

The requirements for soldier camouflage in the context of modern warfare are becoming more complex and challenging given the emergence of novel infrared sensors. There is a pressing need for the development of adapted fabrics and soldier camouflage devices to provide efficient camouflage in both the visible and infrared spectral ranges.

The Military University of Technology has conducted an intensive project to develop new materials and fabrics to further improve the camouflage efficiency of soldiers. The developed materials shall feature visible and infrared properties that make these unique and adapted to various military context needs.

This paper presents the details of an advanced measurement campaign of those unique materials where the correlation between multispectral and hyperspectral infrared measurements is performed.

8743-63, Session 13

Spectral image destriping using a low-dimensional model

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Striping effects, i.e., artifacts that vary with the image column or row, may arise in hyperspectral or multispectral imagery from a variety of sources. One potential source of striping is a physical effect inherent in the measurement, such as a variation in viewing geometry or illumination across the image. More common sources are instrumental artifacts, such as a variation in spectral resolution, wavelength calibration or radiometric calibration, which can result from imperfect corrections for spectral "smile" or detector array nonuniformity. This paper describes a general method of suppressing striping effects in spectral imagery by referencing the image to a spectrally low-dimensional model. The destriping transform for a given column or row is taken to be linear, i.e., specified by a gain and offset. The image cube model is derived from a subset of spectral bands or principal components thereof. The general approach is effective for all types of striping, including broad or narrow, sharp or graduated, and is applicable to radiance data at all optical wavelengths and to reflectance data in the solar (visible through short-wave infrared) wavelength region. Some specific implementations are described, including a method for suppressing effects of viewing angle variation in long slant path imagery.

8743-64, Session 13

New algorithms for destriping and registration correction for Hyperion imagery

Shawn D. Hunt, John Lunzer, Univ. de Puerto Rico Mayagüez (United States)

This work presents new algorithms for correcting data from the Hyperion Imager. Several issues with the data are well known, including data striping, missing columns, the spectral smile, and registration differences between the visible and SWIR bands. This work includes correction for all the above issues and also includes filtering to improve the noisy bands that are typically discarded. One of the major goals of the algorithms was to preserve information while at the same time improving the image for classification and unmixing algorithms. As a result, the new destriping algorithm does a very good job of protecting non-striped data, with a second layer of processing to fill in zero mean column stripes with adjacent column data, and fix columns affected by outlying offsets. The algorithms include parameters that can be selected by the user, with suggested values given. A comparison has been done between unprocessed and processed data comparing classifying and unmixing using hyperion images over south west Puerto Rico. These show the algorithms not only improve the data for visual inspection, but also classification and unmixing.

8743-65, Session 13

Accurate accommodation of scan-mirror distortion in the registration of hyperspectral data cubes

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To improve the spatial sampling of scanning hyperspectral cameras, it is often necessary to capture numerous overlapping image cubes and later mosaic them to form the overall image cube. For hyperspectral camera systems having broad-area coverage, whisk-broom scanning using an external mirror is often employed. Creating the final image cube mosaic requires sub-pixel correction of the scan-mirror distortion, as well as alignment of the individual image cubes. For systems lacking geo-positional information, relating sensor to scene, alignment of the image scans is non-trivial. Here we present a novel algorithm that removes scan distortion and aligns hyperspectral image cubes based on correlation of the cubes' image content with a reference image.

The algorithm is able to provide robust results by recognizing that the cubes' image content will not always match identically with that of the reference image. For example, in cultural heritage applications, the reference color image of the finished painting need not match the under-painting seen in the SWIR. Our approach is to identify a corresponding set of points between the cubes and the reference image, using a subset of wavelet scales, and then filtering out matches that are inconsistent with a map of the distortion. The filtering is performed by removing points iteratively according to their proximity to a function fit to their disparity (distance between the matched points). Our method will be demonstrated and our results validated using hyperspectral image cubes (960-1670, 1000-2400 nm) and visible reference images from the fields of remote sensing and cultural heritage preservation.

8743-66, Session 13

Automated geo/ortho registered aerial imagery product generation using the mapping system interface card (MSIC)

Paul E. Lewis, National Geospatial-Intelligence Agency (United States)

This paper describes the final assembly, testing, and commercial availability of the Mapping System Interface Card (MSIC). The 2.3kg MSIC is a self-contained, compact, variable configuration, low cost, real-time precision metadata annotator with embedded INS/GPS designed specifically for use in small aircraft. The MSIC was specifically designed to convert commercial-off-the-shelf (COTS) digital cameras and imaging/non-imaging spectrometers with Camera Link standard data streams into mapping systems for airborne emergency response and scientific remote sensing applications. COTS digital cameras and imaging/non-imaging spectrometers covering the ultraviolet through long-wave infrared wavelengths are important tools now readily available and affordable for use by emergency responders and scientists. The MSIC will significantly

enhance the capability of emergency responders and scientists by providing a direct transformation of these important COTS sensor tools into low-cost real-time aerial mapping systems.

8743-67, Session 13

An uncertainty estimate for the georeference of high resolution hyperspectral images of an urban scenario

Thomas O. Opsahl, Trym V. Haavardsholm, Norwegian Defence Research Establishment (Norway)

Images from an airborne hyperspectral pushbroom camera can be georeferenced based on navigation data and a 3D-model of the scene. This geospatial information makes it possible to rectify the image and to position any points of interest. For some applications, e.g. change detection, it can be beneficial to know the uncertainty in the positioning of individual pixels. Although rough estimates easily can be made, it is non-trivial to compute these uncertainties directly. In this paper we investigate how simple Monte Carlo simulations can be used in a direct georeferencing scheme to estimate the uncertainty in the geospatial positioning of individual pixels. Based on uncertainties in the navigation, the line of sight for every pixel can be represented by a bundle of rays. By intersecting these with the surface model we can estimate the pixel's position and the uncertainty of this estimate. When considering a high resolution image combined with a high resolution surface model this approach gets computationally very intensive, so a GPU is used to solve the intersection problem. We present results from an urban scene and discuss possible applications. The images are captured by the HySpex VNIR-1600 camera in FFI's demonstrator system for airborne hyperspectral target detection.

8743-68, Session 13

Evaluation of the CASSI-DD hyperspectral compressive sensing imaging system

Maria Busuioceanu, David W. Messinger, Rochester Institute of Technology (United States); John B. Greer, Justin C. Flake, National Geospatial-Intelligence Agency (United States)

Compressive Sensing (CS) systems aim to capture data with fewer measurements than traditional sensors under the assumption that hyperspectral imagery is redundant and thus compressible in the spatial and spectral dimensions. We utilize the Coded Aperture Snapshot Spectral Imager-Dual Disperser (CASSI-DD) CS model to simulate compressive sensing hyperspectral measurements and apply a novel image reconstruction algorithm using Bregman iterations to create high resolution hyperspectral imagery. We examine the effect of two parameters in the sensor model, the number of physical measurements and the spectral smoothing parameter, on the spatial and spectral fidelity of simulated data. The impacts of the CS sensor model and reconstruction process on the data cloud are quantified using various metrics. The utility of the CASSI-DD sensor model for various hyperspectral applications are described. The results help identify the strengths and limitations of CS and determine which applications under which circumstances are better suited for CS systems.

8743-69, Session 13

Modeling satellite imaging sensors over optically complex bodies of water

Robert Nevins, St. Olaf College (United States); Aaron Gerace, Rochester Institute of Technology (United States)

Several operational remote sensing satellites are effective for monitoring open ocean Case 1 waters where the optical properties are dominated by a single constituent, phytoplankton, and its associated material. However, few instruments have the appropriate spatial and radiometric resolution for monitoring optically complex Case 2 waters, as they contain significant levels of suspended material and color-dissolved organic material, in addition to chlorophyll. Landsat's new Operational Land Imager (OLI), which is scheduled for launch in February 2013, exhibits the radiometric resolution required to monitor Case 2 waters, and is particularly attractive for resolving the nearshore environment because of its spatial fidelity. The purpose of this study is to compare the retrieval potential of OLI over Case 2 waters with existing sensors: ETM+, MERIS, and AVIRIS.

To evaluate each sensor's constituent retrieval potential, sensor models were developed based on three key sensor characteristics that impact the in-water constituent retrieval process: signal-to-noise ratios (SNR), spectral coverage, and quantization. SNR was calculated from image data for the operational satellites and from system specifications for the OLI instrument. Spectral response functions and bit depths were obtained from the literature for each of the satellites. The resulting sensor models were then used to sample output radiance spectra from multiple Hydrolight simulations, which were generated based on user-specified levels of Case 2 constituents. A constituent retrieval algorithm was applied to the simulated image data and an error found with respect to the known levels for each spectral curve. Results of this simulated case study indicate that OLI outperforms its predecessor ETM+ and may potentially achieve retrieval errors that are in-line with AVIRIS and MERIS.

8743-70, Session 14

Spectral dependence of texture features integrated with hyperspectral data for area target classification improvement

Corey Bangs, Marine Corps Intelligence Activity (United States); Fred A. Kruse, Richard C. Olsen, Naval Postgraduate School (United States)

Hyperspectral data were assessed to determine the effect of integrating spectral data and extracted texture feature data on classification accuracy. Four separate spectral ranges (hundreds of spectral bands total) were used from the VNIR-SWIR portion of the electromagnetic spectrum. Haralick texture features (contrast, entropy, and correlation) were extracted from the average grey-level image for each of the four spectral ranges studied. A maximum likelihood classifier was trained using a set of ground truth regions of interest (ROIs) and applied separately to the spectral data, texture data, and a fused dataset containing both. Classification accuracy was measured by comparison of results to a separate verification set of test ROIs. Analysis indicates that the spectral range (source of the grey-level image) used to extract the texture feature data has a significant effect on the classification accuracy. This result applies to texture-only classifications as well as the classification of integrated spectral data and texture feature data sets. Overall classification improvement for the integrated data sets was near 1%. Individual improvement for an "Urban" class alone showed approximately 9% accuracy increase from spectral-only classification to integrated spectral and texture classification. Texture-only classification accuracy was highest for a "Dirt Path" class at approximately 92% for the spectral range from 947 to 1343nm. This research demonstrates the effectiveness of texture feature data for more accurate analysis of hyperspectral data and the importance of selecting the correct spectral range to be used for the grey-level source to extract these features.

8743-72, Session 14

A semi-supervised classification algorithm using the TAD-derived background as training data

Lei Fan, David W. Messinger, Brittany Ambeau, Rochester Institute of Technology (United States)

In general, spectral image classification algorithms fall into one of two categories: supervised and unsupervised. In unsupervised approaches, the algorithm automatically identifies clusters in the data without a priori information about those clusters (except perhaps the expected number of them). Supervised approaches require an analyst to identify training data to "learn" the characteristics of the clusters such that they can then classify all other pixels into one of the pre-defined groups. The classification algorithm presented here is a semi-supervised approach based on the Topological Anomaly Detection (TAD) algorithm. The TAD algorithm defines background components based on a mutual k-Nearest Neighbor graph model of the data, along with a spectral connected components analysis. Here, the largest components produced by TAD are used as regions of interest (ROI's), or training data for a supervised classification scheme. By combining those ROI's with a Gaussian Maximum Likelihood (GML) or a Minimum Distance to the Mean (MDM) algorithm, we are able to achieve a semi-supervised classification method. We test this classification algorithm against data collected by the HyMAP sensor over the Cooke City, MT area, as well as other datasets such as the Indian Pines scene and the University of Pavia scene.

8743-73, Session 14

Scale profile as feature for quick satellite image object-based classification

David Dubois, Richard Lepage, Ecole de Technologie Supérieure (Canada)

With the increasing precision of recent spaceborne sensors, remotely sensed images have become exceedingly large and detailed. These images are being used more and more often in the preparation of emergency maps when a disaster occurs. Visual interpretation of very high resolution satellite images is quite long and automatic pixel-based methods require a lot of memory, processing power and time. When a disaster occurs, every second counts for the emergency teams and preparing relevant maps from remotely sensed images requires hours of work for multiple photo-interpreters teams. A fast and efficient mean of detecting relevant objects and evaluating damages is required. Buildings are frequently extracted from pre- and post- event images to evaluate damaged regions where rescue efforts should be concentrated. Existing pixel-based approaches are not appropriate for this task. In this paper, we propose to use a fast level-set image transformation in order to obtain a hierarchical representation of image objects. A scale mapping algorithm is adapted to extract relevant shapes and discriminant features such as the scale profile. The scale profile is the contrast difference between interesting levels in the hierarchical representation of a shape. Our studies indicate that the scale profile can help discriminate between land cover classes such as building, road, vegetation and shadow. Shape, scale and intensity features are prepared to train a SVM (Support Vector Machine) classifier with RBF (Radial Basis Function) kernel and the classifier's parameters are optimized by cross-validation. Relevant results are obtained from multiple test sets on similar and dissimilar images. The detected buildings can then be used for automated damage assessment.

8743-74, Session 14

Multiscale vector tunnel classification algorithm for hyperspectral images

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Hyperspectral image classification is one of the most popular information extraction methods. These methods consist of a variety of algorithms involving supervised or unsupervised. In supervised classification, some reference data are used. Training data are not used in unsupervised classification methods. The type of a classification algorithm depends on the nature of the input and reference data.

Despite the fact that various supervised classification algorithms may be used to decide the class of unknown pixels, spectral matching and statistical based methods are the most widely known classification algorithms for hyperspectral imaging. Spectral matching algorithms try to identify the similarity of the unknown spectral signature of test pixels with the expected signature. However, most spectra in real applications are random and their variability can be described by using statistical models. The amount of training data required for nonparametric classifier increases with respect to the dimensionality. Since the size of training samples is limited in most cases, it is necessary to develop new analytic methods using spectral signatures to enhance the performance and avoid increasing the computational time.

In this study, an efficient spectral similarity method employing multi-scale vector tunnel for supervised classification of the materials in hyperspectral imagery is introduced. With the proposed algorithm, a simple spectral similarity based decision rule using reference data or spectral signature is formed and compared with the Euclidian Distance (ED) and the Spectral Angle Map (SAM) classifiers. The prediction of multi-level upper and lower spectral boundaries of spectral signatures for all classes across spectral bands constitutes the basic principle of the proposed algorithm. The proposed distance measure has the ability of not only tracing the total changes of illumination level, but also detecting the shape of the spectral signature.

The proposed method may be summarized as in the following:

Step 1: If a priori class information does not exist, the reference spectral signatures from some hyperspectral data or spectral signature libraries are acquired for the initialization step.

Step 2: Vector tunnel parameters are defined according to shape of the spectral signatures.

Step 3: By using tunnel parameters, n-dimensional vector tunnels around the reference spectra are formed.

Step 4: The n-dimensional vector tunnels are separated into multiple layers using scaling parameters.

Step 5: Whole pixels in the image are tested whether they lie in one of the tunnel. If a pixel lies in a unique tunnel, it is labeled as belonging to corresponding class.

Step 6: If the spectral signature of the test pixel belongs to none of the vector tunnel or multiple vector tunnels, the vector tunnel weighting parameters are calculated for all classes.

Step 7: According to maximum value of the weighting parameters, test pixel is labeled to corresponding class.

Step 8: If a priori class information exists, training data are used to produce mean vectors and standard deviation vectors for all classes.

Step 9: By using the mean vectors as reference spectra and the standard deviation vectors as tunnel parameters, the vector tunnels are formed around the mean vectors.

Step 10: Steps 4-7 are repeated to complete the classification process.

The proposed method is tested on AVIRIS Indiana's Pine and HYDICE Urban data. Although multi-scale vector tunnel classifier does not need intensive mathematical calculation, it provides improved classification results compared to ED and SAM classifiers. Quantitative classification results for AVIRIS data and visual classification results of HYDISE data will be given in the full paper.

8744-1, Session 1

Generalized linear correlation filters

Andres F. Rodriguez, Air Force Research Lab. (United States) and Carnegie Mellon Univ. (United States); B. V. K. Vijaya Kumar, Carnegie Mellon Univ. (United States)

We present two generalized linear correlation filters (CFs) that encompass most of the state-of-the-art linear CFs. The common criteria that are used in linear CF design are the mean squared error (MSE), output noise variance (ONV), and average similarity measure (ASM). We present a simple formulation that uses an optimal tradeoff among these criteria both constraining and not constraining the correlation peak value, and refer to them as generalized Constrained Correlation Filter (CCF) and Unconstrained Correlation Filter (UCF). We show that most state-of-the-art linear CFs are subsets of these filters. We also present the modified CCF (mCCF) that chooses a unique correlation peak value for each training image, and show that mCCF usually outperforms both UCF and CCF.

8744-2, Session 1

An ATR architecture for algorithm development and testing

Gøril M. Breivik, Kristin H. Løkken, Alvin Brattli, Hans C. Palm, Trym V. Haavardsholm, Norwegian Defence Research Establishment (Norway)

A test system with four cameras in the infrared and visible spectra will be mounted on a high speed jet aircraft. The system is under development at FFI and will be used for image acquisition and for development and test of automatic target recognition (ATR) algorithms. The sensors on board produce large amounts of data, the algorithms can be computationally heavy and the data processing is complex. This puts great demands on the system architecture; it has to run in real-time and at the same time be suitable for algorithm development.

In this paper we present an architecture for ATR systems that is designed to be flexible, generic and efficient. The architecture is based on modules, which enables simple exchange of specific algorithms without affecting the rest of the system. The modules are generic and can be used in various configurations depending on the application, e.g. a complete ATR application for the test system or a simpler application for ATR algorithm development. A software framework in C++ that handles large data flows in non-linear pipelines is used for implementation to ensure efficient processing.

As an example, a system for segmentation algorithm development has been implemented according to the proposed architecture. The segmentation module is similar to one that can be used in the complete ATR test system, although the module configuration is different. Two additional modules are implemented to read data and to visualize the result. The system is used to try out two different segmentation algorithms on infrared images from sea trial recordings.

8744-3, Session 1

Implementation of a cascaded HOG-based pedestrian detector

Christopher Reale, Prudhvi Gurram, Shuowen Hu, Alex L. Chan, U.S. Army Research Lab. (United States)

Pedestrian detection in images and videos is a heavily researched topic with several applications including surveillance, tracking, and robotics. Many existing pedestrian detection algorithms in some way build on the seminal work by Dalal and Triggs. Dalal and Triggs's method trains a Support Vector Machine (SVM) with Histogram of Oriented Gradient (HOG) features to distinguish between human and non-human samples. In order to decrease the computation time required to process a test image while still maintaining the performance at approximately the same level, most of the pedestrian detection algorithms are implemented as a cascade of classifiers. Certain cascaded versions of Dalal and Triggs HOG-based pedestrian detector already exist in the literature. Each step of the cascade consists of an ensemble of weak classifiers to obtain a certain detection and false alarm rate. Normally the meta-algorithm used to combine the weak classifiers is the AdaBoost technique. However, a detailed explanation of this implementation is currently lacking in the literature. The usual implementation of AdaBoost technique has led to a slow convergence of the ensemble and hence, large number of weak classifiers at each step of the cascade. In this paper, a detailed step-by-step explanation of the previous implementation is provided along with a detailed discussion of the convergence issues. A novel implementation of a cascaded HOG-based pedestrian detector is also presented. This approach uses Asymmetric Boosting, a more general version of AdaBoost that can handle unequal penalties for Type 1 and Type 2 classification errors. The new detector is tested on a widely used database like the CalTech Pedestrian Dataset and its performance is analyzed in terms of both computation time and accuracy.

8744-4, Session 1

No-reference image quality measurement for low-resolution images

Josh Sanderson, Wright State Univ. (United States); Yu Liang, Shane Fernandes, Michael Henderson, Central State Univ. (United States); Darrell Barker, Air Force Research Lab. (United States)

Quantitative measurement for image quality plays an important role in image processing and analysis. This paper mainly investigates three no-reference measurement schemes, which are based on the standard deviation, the maximum, and the mean of the magnitude of the intensity gradient of images respectively. Each measurement scheme is critically accessed using low resolution gray-scale images acquired by unmanned aerial vehicles cruising over the city. These images aim to disclose the movement of varies of vehicles such as a semi -truck, light colored cars, and dark colored cars, etc. The experimental results demonstrate that, compared to alternative schemes, the standard deviation based scheme provides a more accurate measurement about the quality of images. In addition, standard deviation based scheme demonstrates superior correlation with alternative schemes to measure the quality of images.

8744-5, Session 1

Unsupervised pedestrian detection using support vector data description

Prudhvi Gurram, Shuowen Hu, Christopher Reale, Alex L. Chan, U.S. Army Research Lab. (United States)

Pedestrian detection is an important research area in machine vision due to its impact on wide ranging applications like robotics, surveillance, and vehicular technology for the military, the law-enforcement community, and the commercial sectors. However, all the existing state-of-the-art techniques for pedestrian detection using ground based imagery are supervised algorithms. The general framework of such algorithms consists of extracting low level features like Histogram of Oriented Gradient (HOG) features in the first step, collecting these features according to a template (full human or parts of human) to form data samples. The data samples are extracted from positive (human present) and negative (human not present) images, which are then used to train a binary classifier. There have been numerous efforts to improve the performance of the pedestrian detectors in terms of speed by using cascade of classifiers framework, and in terms of accuracy, by using

additional features. The supervised pedestrian detectors suffer from the disadvantage that the test data distributions should look very similar to the training data distributions, and will fail if there is dramatic change in the scene or scale of the pedestrians.

In this paper, in order to deal with the disadvantages of supervised techniques, an unsupervised pedestrian detection algorithm is proposed. An image is first divided into detection windows and HOG features are collected over the window using overlapping blocks of different sizes. Each window provides a data sample. The data samples extracted from the whole image are then modeled as a normalcy class using Support Vector Data Description (SVDD). The benefit of using the state-of-the-art SVDD technique to model the normalcy class is that it can be controlled by setting an upper limit on the outliers allowed during the modeling process. Thus, the outliers that are detected during the modeling of the normalcy class are hypothesized as detection windows that contain pedestrians in them. The premise of this algorithm is that the HOG features in a detection window will be similar over all the non-human regions in the image and will differ from that of the human regions. The system is tested on existing pedestrian detection datasets and its performance analyzed for accuracy and detection rate.

8744-7, Session 2

Improved real-time photogrammetric stitching

Jason P. de Villiers, Jaco Cronje, Council for Scientific and Industrial Research (South Africa)

Photogrammetric stitching is a means to generate panoramas from multiple images without requiring computationally expensive image processing in the form of searching for and then matching image features and creating a homography between the images. Rather, both the system and the cameras are pre-calibrated and use is made of these parameters to efficiently perform the stitching. The authors previously presented an overview of this procedure in 2009[1].

This paper provides several enhancements to that earlier work on real-time stitching. Specifically this paper provides three main additions to the stitching algorithm without compromising its real time performance.

Firstly, the blending is extended from one to two dimensions, so that multiple rows of cameras can be used. The implementation of this blending has been optimised to improve the execution speed of the algorithm.

Secondly, stabilisation inputs have been incorporated so that the stitching algorithm can output data already stabilised for platform motion with out the need for further processing. The determination of these stabilisation inputs is not part of the scope of this paper, and could be from inertial systems or subsequent processing of prior stitched images.

The third contribution made by this paper is to decrease the sensitivity to depth for extremely large baseline systems by considering multiple stitch geometries simultaneously. This allows for modular and distributed designs of implemented systems.

Timing tests - on high and low power Graphics Processor Units - are performed on the various algorithms and their corresponding stitches are presented and discussed.

[1] J de Villiers, “Real time photogrammetric stitching of high resolution video on COTS hardware” in Proceedings of the International Symposium on Optomechatronic technologies, Istanbul, Turkey, 2009.

8744-8, Session 2

Multi-camera rigid body pose estimation using higher-order dynamic models

Alec E. Forsman, David A. Schug, Naval Air Warfare Ctr. Aircraft Div. (United States); Anton Haug, Johns Hopkins Univ. Applied Physics Lab. (United States)

We describe a Bayesian filtering process that estimates the pose (3-D position and orientation) of a moving rigid body using multiple cameras. The estimator also produces an arbitrary number of pose derivatives. We first discuss various ways to represent 3-D orientation. Unfortunately all 3 parameter representations have areas of instability. Higher dimensional representations are stable but require unwieldy constraints. Our combination of an axis-angle vector with a unit quaternion represents orientation minimally while remaining stable under realistic circumstances. Our dynamic model of rigid body motion can include an arbitrary number of derivatives, and we explicitly develop it up to the third order. Our observation model takes a predicted pose and produces the 2-D locations in each camera’s image plane of the visible features on the body’s surface. We provide noise terms for both the dynamic and observation models. We describe how our models are used in extended and unscented Kalman filters, and also in a particle filter. As a baseline we also describe a non-linear least squares method that uses just our observation model. We construct a synthetic testing scenario, and use root-mean-square error analysis to grade the relative performance of each model/filter combination. We derive the Cramer-Rao lower bound that gives the best achievable performance for our particular scenario. Our results show that adding derivatives to the state vector significantly improves the accuracy of pose estimates, and we also show which type of Bayesian filter is best suited to the task.

8744-9, Session 2

Score-based gating control method in the presence of stop-move maneuvering motorboat’s wake

Fatih Pektas, ASELSAN Inc. (Turkey)

A motorboat’s wakes can cause difficulties as they appear in a track’s gate. While a motorboat is idle for long enough, the gate size reduces to its minimum. Immediately after, if motorboat makes a stop-move maneuver with maximum acceleration, true radar measurement can appear off the gate. In this case, the tracker can continue to update the track with target’s wake measurements falling in gate and this can mislead the tracker.

In order not to miss the true measurement belonging to a track, a secondary gate should be created with larger size than that of the primary gate at the same gate center. However, this gate should only be created when an anomaly is detected at the tracker. This paper investigates when such secondary gates should be created.

In this paper, a score-based method is presented to control gating in the presence of wake left behind a suddenly accelerated boat. This method is based on scoring the probability distributions characterising the number radar measurements. The number of detections coming from clutter is K-distributed and the number of detections belonging to true target is Poisson distributed across the surveillance region. The method treats the motorboat’s wake as target originated measurement rather than clutter. Therefore, a probability distribution similar to true target’s with a different parameter is used to score the wake separately. Based on the scores, security gating decision is made.

The real data experiments show that track continuity is maintained successfully with the use of score-based gating control method.

8744-10, Session 3

An empirical evaluation of infrared clutter for point target detection algorithms

Mark McKenzie, Sebastien Wong, DSTO (Australia); Danny Gibbins, The Univ. of Adelaide (Australia)

Developing a robust understanding of the statistics of clutter is an important step in the development any automatic target detection, tracking and recognition system. This paper describes an empirical study into the impact of local environmental conditions for the detection

of point targets using wide field of view infrared sensors on airborne platforms. The main hypothesis posed is that there exist one or more quantitative statistical measures of an IR image, which can be correlated to the ability of algorithms to detect point sources. A number of statistical metrics for measuring scene complexity were investigated including: global variance, local variance, probability of edge metric, Der metric, root mean square (RMS) clutter metric, temporal RMS metric and relative clutter metric. These were correlated with common point target detection algorithms including: spatial Constant False Alarm Rate Detector (CFAR), the Marr-Hildreth Detector, Spatial Matched Filter Detector, the Least Squares Power Model Detector, Partial Differential Equation Detector, Adaptive Spatial Hypothesis Detection, a Hidden Markov Spatiotemporal Detector, Bayesian Spatiotemporal Detector and the Elementary Motion Detector. The quantitative evaluation was performed using 20 hours of infrared imagery collected over a three month period from helicopter flights in a variety of clutter environments, which was painstakingly tagged in five second increments with meta-data regarding the local environmental conditions. The research method, samples of the IR data sets, and results of the correlation between scene complexity metrics and point target detection algorithms are presented.

8744-11, Session 3

Hyperspectral remote sensing and illegal oil bunkering in the Niger Delta of Nigeria

Henry O. Odunsi, Earth Info Services (Nigeria)

Hyperspectral remote sensing is a modern technology for earth observation monitoring. The technique requires high-resolution imaging capacity for detecting and revealing significant information of the environment. This method of remote sensing is satellite based and is designed for natural resource monitoring and management. The Niger Delta is the Oil and Gas capital of Nigeria. This region contains most of the country's oil reserves and oil production. The Niger Delta is a sedimentary basin of global ecological significance. It is home to about 17 million people and rank as the third largest wetlands in the world. Crude oil production in this region is about 2.7 million barrels per day and generates over 90% of Nigeria's total export earnings. Illegal oil bunkering activities is one of the major challenges in the Niger Delta. This is mainly attributed to corruption and high level of youth unemployment. Some other challenges in this region have been conflict for space due to acute shortage of infrastructural development and marginalization. There is a major threat to the environment due to the activities of oil and gas exploration and production. Illegal oil bunkering and oil production activities have resulted in oil pollution, damage to marine flora and fauna, mangrove deforestation and loss of biodiversity. The role of government in setting up and implementing regulations is the key to minimizing the potential environmental impact. With over 500 oil drilling sites in the Niger Delta, a valuable tool in monitoring these activities is therefore essential. The importance of hyperspectral imaging is crucial as a result of the urgent need for sustainable development in Nigeria. Because of the huge loss in revenue due to the illegal oil theft in the country, it is imperative to explore the services of the National Space agency in providing a management option for these illegal activities.

8744-12, Session 3

Position-independent ATR using hierarchical Hidden Markov Model as the identification algorithm *(Invited Paper)*

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

A recursive hierarchical algorithm based on hidden Markov models is used to build a model of the identification target. The end result of the recursive matching is an optimal scene-to-model transformation, along with a recognition degree of suitability value between the scene and the model.

8744-13, Session 4

Noise cancellation in IR video based on empirical mode decomposition

José P. Ave, Manuel Blanco-Velasco, Fernando Cruz Roldán, Univ. de Alcalá (Spain); Antonio Artés Rodríguez, Univ. Carlos III de Madrid (Spain)

Currently there is a huge demand for simple low cost IR cameras for both civil and military applications, among which one of the most common is the surveillance of restricted access zones. In the design of low cost IR cameras, it is necessary to avoid the use of several elements present in more sophisticated cameras, such as the refrigeration systems and the temperature control of the detectors, so as to prevent the use of a mechanical modulator of the incident radiation (chopper). Consequently, the detection algorithms must reliably separate the target signal from high noise and drift caused by temporal variations of the background image of the scene and the additional drift due to thermal instability detectors. A very important step towards this goal is the design of a preprocessing stage to eliminate noise. Thus, in this work we propose using the Empirical Mode Decomposition (EMD) method to attain this objective. In order to evaluate the quality of the reconstructed clean signal, we compute the mean square error between the original signal and the reconstructed signal using synthetic signals. Moreover, the Average to Peak Ratio is assessed to evaluate the effectiveness in reconstructing the waveform of the signal from the target. We compare the EMD method with other classical method of noise cancellation based on the Discrete Wavelet Transform (DWT). The results reported by simulations show that the proposed scheme based on EMD performs better than traditional ones.

8744-14, Session 4

Robust coastal region detection method using image segmentation and sensor LOS information for infrared search and track

Sungho Kim, Yeungnam Univ. (Korea, Republic of); Sun-Gu Sun, Agency for Defense Development (Korea, Republic of); Soon Kwon, Daegu Gyeongbuk Institute of Science and Technology (Korea, Republic of); Kyung-Tae Kim, POSTECH (Korea, Republic of)

This paper presents a novel coastal region detection method for infrared search and track. The coastal region detection is critical to home land security and ship defense. We can detect coastal regions robustly by combining the infrared image segmentation and sensor line-of-sight (LOS) information. The K-means-based image segmentation can provide initial region information and the sensor LOS information can predict the approximate horizon location in images. The evidence of coastal region is confirmed by contour extraction results. The experimental results on remote coasts and near coasts validate the robustness of the proposed coastal region detector.

8744-15, Session 4

Person detection in LWIR imagery using image retrieval

Thomas Müller, Daniel Manger, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

This paper addresses the detection and localization of persons in LWIR imagery which is useful especially in visual surveillance tasks such as intruder detection in military camps or for gaining situational awareness. A robust and fast image retrieval function is adapted to detect and localize persons in LWIR using a suitable, extensive image data base that covers a variety of different shapes and appearances of persons in LWIR.

The basic idea behind this approach is, in contrast to the visual optical band (VIS), that persons in thermal infrared exhibit somehow similar, weakly individualized signatures which can be matched to a sufficient degree to images in the data base and, thus, can be distinguished from background structures and other objects. Dedicated pre and post processing routines optimize the results and compensate for a possibly occuring lack of image features needed by the image retrieval function.

The achieved results document the practical benefit and the robustness of the presented aproach. The computation times are low and independent from the size of the data base that can be chosen large to cover a wide range of situations.

8744-16, Session 4

Hot spot detection and classification in LWIR videos for person recognition

Michael Teutsch, Thomas Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Person recognition is a key issue in visual surveillance. It is needed in many security applications such as intruder detection in military camps but also for gaining situational awareness in a variety of different applications. In this paper, a solution for LWIR imagery is presented that is based on hot spot classification to distinguish persons from background clutter and other objects. We focus on objects in higher distance with small appearance in the image, where popular approaches such as SIFT with implicit shape models don't work reliably. Different algorithms are compared and temporal context is utilized to achieve optimal results. Hot spots are detected, localized, and tracked along the LWIR image sequence. Various kinds of image features are extracted from the spots and evaluated for their separability potential. Different methods for features space reduction are implemented and tested. Finally, classifiers such as Support Vector Machine (SVM), Bayes, and k-Nearest-Neighbor (k-NN) classifier are compared to each other and extended to benefit from the temporal information of the tracked spots. In some experiments, we demonstrate that slight changes of spot appearance during tracking due to motion of camera platform or spot will result in more robust classification performance. Furthermore, the algorithms run in real-time.

8744-17, Session 4

Image restoration and superresolution for on-demand satellite imagery

Riad I. Hammoud, Luis Galup, Diane G. Mills, BAE Systems (United States)

A confluence of advances in overhead systems and imaging sensors, communications, image processing science and mobile computing has unleashed unprecedented capabilities for enabling on-demand overhead imagery in a timely and persistent manner for pre-mission planning. Using COTS low-cost overhead imaging sensors and limited bandwidth, the on-demand transmitted images to the handheld device are oftentimes low-quality and low-resolution.

This paper will review first various classes of methods for image restoration, multiple-frame super resolution, and deblurring techniques. Then it will investigate and propose a variant of the centralized sparse-coding representation model for low-resolution blurred satellite image restoration.

8744-18, Session 4

Multilayer robust and adaptive dismounts detection approach for WAPS

Riad I. Hammoud, BAE Systems (United States); Matthew Antone, Massachusetts Institute of Technology (United States)

This paper describes a novel multi-layer robust and adaptive dismounts (humans) detection framework in a wide-area persistent aerial surveillance system. The problem is very challenging due to clutter presence, low pixel-density of dismounts (2-30 pixels in size), high SNR, low contrast-difference between dismounts and background, weak thermal signature, moving platform (UAV), parallax, occlusions and illumination changes.

In the proposed framework, the images are geo-registered first. Then, each image is automatically classified as bright sunny day, dim (or cast shadow) or night time imagery based on the analysis of the gray-scale distribution of the entire image (or a sub-image). This allows the framework to dynamically determine the optimal parameters of the subsequent modules such as segmentation thresholds, contrast enhancement and thermal range, and subsequently make our system more tolerant to lighting changes. An initial set of potential dismounts is generated from multiple segmentations of a smoothed and contrast-enhanced version of the input image. Then an area filter is applied to eliminate candidates outside a desired size range ([6-30 pixels] in our experiment). Further, seven complementary filters are applied to each potential dismount. These filters compute the contrast and thermal signatures, clutter percentage, dynamic signature, global motion signature, forward motion history, and shape characteristics. Motion artifacts due to parallax and miss-registration are filtered out with various motion filters. The shape-based filter reduces the confusion between light-poles and true dismounts. These evidences produced by these filters are fused together and a probability is assigned to the potential candidate that determines its likelihood of being a true dismount or not.

Our experiments on day and night time videos shown that the proposed framework yielded higher true detection rate and much lower false alarms than the standard GMM-based background modeling technique.

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8744-19, Session 5

Boosting target tracking using particle filter with flow control

Nima Moshtagh, Moses W. Chan, Lockheed Martin Space Systems Co. (United States)

Missile detection and tracking with passive infrared (IR) sensors can be challenging due to significant degradation and corruption of target signature by atmospheric transmission and clutter effects. This paper summarizes our efforts in phenomenology modeling of boosting targets with overhead IR sensors, and developing algorithms for tracking targets in the presence of background clutter. On the phenomenology modeling side, the clutter images are generated using a high fidelity end-to-end simulation testbed. It models atmospheric transmission, structured clutter and solar reflections to create realistic background images. The dynamics and intensity of a boosting target are modeled and injected onto the background scene. Pixel level images are then generated with respect to the sensor characteristics. On the tracking analysis side, a particle filter for tracking dim targets in a sequence of clutter images is developed. The particle filter is augmented with a mechanism to control particle flow. Specifically, velocity feedback is used to constrain and control the particles. The performance of the developed "adaptive" particle filter is verified with tracking of a boosting target in the presence of clutter and occlusion.

8744-20, Session 5

Dynamic data driven applications systems (DDDAS) modeling for ATR

Erik P. Blasch, Gunasekaran Seetharaman, Air Force Research Lab. (United States); Jianbo Gao, Wright State Univ. (United States); Frederica Darema, Kitt C. Reinhardt, Air Force Office of Scientific Research (United States)

The DDDAS concept uses applications modeling, mathematical algorithms, and measurement systems to work with dynamic systems. Automatic Target Recognition (ATR) can be a dynamic task as sensors, targets, and the environment are constantly changing. We use the DDDAS concept to develop an ATR methodology for multiscale-multimodal analysis that seeks to integrated sensing, processing, and exploitation. In the analysis, we use image fusion techniques to explore the capabilities and analogies that DDDAS has with information fusion. The key attribute of coordination is the use of sensor management as a data driven technique to improve performance. In addition, DDDAS supports the need for modeling from which uncertainty and variations are used within the dynamic models for advanced performance.

8744-21, Session 5

The rigid non-cooperative target recognition in practice based on the sparse representation

Bo Sun, Xuewen Wu, Jun He, Xiaoming Zhu, Beijing Normal Univ. (China)

In recent years, more and more researchers' attention has been drawn to the sparse representation-based classification (SRC) method and its application in pattern recognition, due to its high recognition rate, robustness to corruption and occlusion, and little dependence on the feature etc. However, sufficient training samples are always required by the sparse representation method for the effective recognition. In practical applications, it is generally difficult to obtain the sufficient training samples of test targets, especially non-cooperative targets. The experiential results show the performance of sparse representation method will significantly degrade when the training samples are not enough. So the key issues in the target recognition based on the sparse representation are to obtain sufficient training samples in different scales, angles, and different illumination conditions, and to construct the over-complete dictionary with discriminative ability. In this paper, a new sparse representation-based framework is proposed for the rigid non-cooperative target recognition in the practical applications and given as follows:

(1) To make the uniformly scaled model of rigid target, e.g. vehicles, ships etc.;

(2) To design an four-axis linkage platform to collect the images in different scales, 3D angles and different illumination as the training samples;

(3) To train the large-scale samples and get an efficient sparse representation-based recognition dictionary containing the scale, angle and illumination information, with the proposed online dictionary learning algorithm;

(4) To recognize the rigid non-cooperative target with the smallest total variation (TV) algorithm.

The experimental results show that the proposed solution is effective for the rigid non-cooperative target recognition in the practical application, especially, where the desired features of the sparse representation method are kept.

8744-22, Session 6

Pre- and post-processing correlation filter data

Andres F. Rodriguez, Air Force Research Lab. (United States) and Carnegie Mellon Univ. (United States); B. V. K. Vijaya Kumar, Carnegie Mellon Univ. (United States)

Correlation filters have been shown to perform well for localization and classification tasks. In this paper, we investigate different techniques used to pre- and post-process the data to improve the correlation filter performance. In addition, we present an efficient method to use zero-mean, unit-norm test chips in a large test image. We compare the localization, classification, and recognition performance when we apply one or more of these methods.

8744-23, Session 6

Automatic target recognition solution space factorization

Charles F. Hester, Kelly K. D. Risko, U.S. Army Research, Development and Engineering Command (United States)

Solution paces for Automatic Target Recognition (ATR) can be defined in a union of subspaces model of the problem space. The descriptive model solution set forms a space of solutions that affords an abundance of solutions. Indeed the power set of the solution set are all the solutions which contain many invariance descriptions which are generalization of the solutions. To explore this space we will define invariance descriptions and this will allow the factorization of the solution space. Using these factorizations specific generalizations of the data in the ATR problem space will be created. We will provide examples and a demonstrated use of these generalizations.

8744-24, Session 6

Dealing with circular correlation effects

Andres F. Rodriguez, Air Force Research Lab. (United States) and Carnegie Mellon Univ. (United States); B. V. K. Vijaya Kumar, Carnegie Mellon Univ. (United States)

Discrete Fourier transforms (DFTs) are typically used to compute correlations and implementing correlation filters (CFs). Because of the properties of DFT, resulting correlations are actually circular (also known as periodic) correlations. The result is that it is generally not possible to design a CF that produces the desired linear correlation output. While there is no exact solution to this problem, there are several techniques that may be used to improve results. In this paper, we describe these techniques and provide some experimental results that compare these techniques.

8744-25, Session 6

Multi-kernel aggregation of local and global features in long-wave infrared for detection of SWAT teams in challenging environments

Ankit Arya, Derek T. Anderson, Cindy Bethel, Daniel Carruth, Mississippi State Univ. (United States)

A vision system was designed for people detection to provide support to SWAT team members operating in challenging environments such as low-to-no light, smoke, etc. When the vision system is mounted on a mobile robot platform: it will enable the robot to function as an effective member of the SWAT team; to provide surveillance information; to make

first contact with suspects; and provide safe entry for team members. The vision task is challenging because SWAT team members are typically concealed, carry various equipment such as shields, and perform tactical and stealthy maneuvers. Occlusion is a particular challenge because team members operate in close proximity to one another. An uncooled long wave infrared (LWIR) imager, 7.5 to 13.5 ?m, was used. A unique thermal dataset was collected of SWAT team members from multiple teams performing tactical maneuvers during monthly training exercises. Our approach consisted of two stages, a weakly trained object detector to find candidate windows (i.e., people), and a secondary feature extraction, multi-kernel (MK) aggregation and classification step to distinguish between SWAT team members and civilians. Two types of thermal features, local and global, are presented based on maximally stable extremal region (MSER) blob detection. Two support vector machine (SVM) classifiers were trained using only LWIR data or a combination of LWIR and RGB data, achieving ?84.5% cross validation accuracy.

8744-26, Session 6

From Shape to Threat: Exploiting the Convergence Between Visual and Conceptual Organization for Weapon Identification and Threat Assessment *(Invited Paper)*

Abdullah N. Arslan, Christian F. Hempelmann, Carlo Di Ferrante, Salvatore Attardo, Nikolay M. Sirakov, Texas A&M Univ.-Commerce (United States)

The present work is a part of a larger project whose goal is to develop a system capable of threat assessment in public places using video. The system consists of: data storage (weapon ontology), input, and search. The ontology extension and search optimization are subjects of the present study. With respect to the input data a sequence of video frames will be exploited, but a single image is in use right now..

To assess the threat the system recognizes the weapon, if any, carried by a suspect. For this purpose image segmentation and matching approaches are developed. Every ontology node is labeled by shape or convex hull (CH) sequences (visual information), and contains conceptual (high level) information about the corresponding weapon. We are building the ontology on the base of the conceptual knowledge and hierarchical relations between the weapons. Geometric - visual information is utilized to perform the ontology search, which imposes the need for visual organization. The new paper will study the convergence, fusion and correlation between the conceptual and the visual organizations of the ontology in order to optimize the search, nodes labeling approaches and algorithms.

The CH sequences are located at conceptually higher nodes, and identify a particular category such as “pistol”, “rifle”, “machine gun”. The shape sequences label nodes containing single weapon and its meta information. As such, the CH is a joint point between the conceptual and the visual organizations of the ontology.

The paper will also present the automatic querying the Web for data collection to fill up the ontology. Further the paper will exploit the correlations between visual and conceptual information like, long barrel implies a long range, for the purpose of threat assessment.

8744-27, Session 6

Improved sample covariance matrix estimation for real-time target detection in hyperspectral imagery

Wei Yang, Ctr. for Earth Observation and Digital Earth (China) and Chinese Academy of Sciences (China); Bing Zhang, Lianru Gao, Yuanfeng Wu, Ctr. for Earth Observation and Digital Earth (China); Li Ni, Ctr. for Earth Observation and Digital Earth (China) and Chinese Academy of Sciences (China)

Real-time target detection in hyperspectral imagery is more and more applied in surveillance and reconnaissance. However, the executing time in target detection is always limited by the covariance matrix computing. This paper investigates the methods of covariance matrix computation for real-time processing. Meanwhile, an effective sample covariance matrix estimation method is provided in this paper. This method utilizes the spatial correlation in hyperspectral imagery, and effectively reduces the amount of computation. Spectral vector projection and spectral vector rearrangement are applied to select the sample pixels. Compared with iterative computations of covariance matrix, sample covariance estimation weakens the relationship of adjacent pixels in timing sequence, so it is suitable for parallel computing. Based on the improved covariance matrix computing, a new real-time target detection approach is provided.

The hyperspectral data in whiten space has little correlation and is suitable for analyzing the difference among spectral vectors. Whiten vector projection utilizes the projection length to discriminate spectral feature of target. This approach reduces the amount of computation by preserving the major component of conventional target detection algorithm. The real-time and automated target detection method in hyperspectral imagery has been evaluated by some experiments on a digital signal processor (DSP) platform. Target detection results on an actual hyperspectral data set demonstrate that the speedup provided by improved the sample covariance matrix estimation is significant.

8744-28, Session 7

Chipping and segmentation of target of interest from low-resolution electro-optical data

Shane Fernandes, Yu Liang, Michael Henderson, Central State Univ. (United States); Josh Sanderson, Wright State Univ. (United States); Darrell Barker, Air Force Research Lab. (United States)

This paper mainly discusses the chipping and segmentation of target-of-interest (TOI) from low-resolution gray-scale electro-optical (EO) data, which is acquired by unmanned aerial vehicle (UAV) hovering above the city. As the pre-processing for automatic target recognition, chipping and segmentation of TOI consist of the following two steps: regional chipping and target segmentation. Regional chipping is dedicated to obtaining the minimal region surrounding the TOI so that it can be accurately and efficiently recognized. Target segmentation is dedicated to isolating a TOI from the background and is implemented using the diffusion algorithm. The whole work is accomplished in MATLAB and is critically assessed using the given EO data.

8744-29, Session 7

Robust static and moving object detection via multi-scale attentional mechanisms

Alexander L. Honda, Yang Chen, Deepak Khosla, HRL Labs., LLC (United States)

Real-time detection of objects in video sequences captured from moving platforms is a key task for UAV surveillance applications. It is common to require expensive frame to frame registration as preprocessing to object detection in this type of video sequence. We explore the spectral residual algorithm, a fast linearithmic run time saliency model which requires no training and has no temporal dependencies, which is capable of detecting proto-objects in static scenes. In this article we describe methods for enhancing the spectral residual saliency algorithm to generate tight bounding boxes around object candidates from video sequences captured from moving platforms. These object candidates can then be passed to classification for identification at a later stage. We describe methods which make the spectral residual algorithm more robust to color images and objects of varying size via a pyramidal approach. Furthermore we describe a technique for processing the resulting saliency map into a set of tight bounding boxes suitable for extracting images for classification. Finally we give a simple method for reducing false positives using knowledge about scene pose and plausible object dimensions. The overall system is a fast, robust, and efficient detection system designed for reliable performance on UAV surveillance platforms.

8744-30, Session 7

AKITA: Application Knowledge Interface To Algorithmsinterface to algorithmic selection

Paul Barros, Allison Mathis, Kevin Newman, Steve M. Wilder, Lockheed Martin Corp. (United States)

Abstract-We propose a methodology for utilizing sensor meta-data and limited preprocessing in order to determine which of a large suite of algorithms is most appropriate to a given data set. Rather than applying several general purpose algorithms or requiring a human operator to oversee the analysis of the data set, our method allows the most effective algorithm to be chosen conserving both computational and human resources.

For example, the amount of video data being produced daily is far greater than can ever be analyzed. Computer vision algorithms can help to sift through for the relevant data, but not every algorithm is suited to every data type nor is it efficient to run them all. For example a full body detector won't work well when the camera is zoomed in or when it is raining and all the people are occluded by foul weather gear. However, leveraging metadata knowledge of the camera settings and the conditions under which the data was collected (generated by automatic preprocessing), face or umbrella detectors could be applied instead, increasing the likelihood of a correct reading.

Further refinements allow for operator input when desired. Data collected in theatre often has a limited period of utility. If an operator was able to specify that the dissemination time could not exceed ten minutes the system would take that into account while making its decision. Conversely, given all night, the system may choose other sets of relevant algorithms to generate useful knowledge to the edge.

To this end, we present the AKITA system, a modular knowledge layer which takes utilities knowledge of the system and environment to determine how to most efficiently and usefully process whatever data it is given.

8744-31, Session 7

Automatic laser beam alignment using blob detection for an environment monitoring spectroscopy

Jarjees A. Khidir, Youhua Chen, Gary T. Anderson, Univ. of Arkansas at Little Rock (United States)

This paper describes a fully automated system to align an infra-red laser beam with a small retro-reflector over a wide range of distances. The component development and test were especially used for an open-path spectrometer gas detection system. Using blob detection under OpenCV library, an automatic alignment algorithm was designed to achieve fast and accurate target detection in a complex background environment. Test results are presented to show that the proposed algorithm has been successfully applied to various target distances and environment conditions.

8744-32, Session 7

Target localization and function estimation in sparse sensor networks *(Invited Paper)*

Natalia A. Schmid, West Virginia Univ. (United States)

The problem of distributed estimation of a parametric function in space is stated as a maximum likelihood estimation problem. The function can represent a parametric physical field generated by an object or be a deterministic function that parameterizes an inhomogeneous spatial random process.

In our formulation, a sparse network of homogeneous sensors takes noisy measurements of the function. Prior to data transmission, each sensor quantizes its observation to M levels. The quantized data are then communicated over parallel noisy channels to a fusion center for a joint estimation.

The numerical examples are provided for the cases of (1) a Gaussian-shaped field that approximates the distribution of pollutions or fumes produced by an object; (2) a magnetic field generated by a ferromagnetic object, and (3) a radioactive field due to a spatial counting process with the intensity function decaying according to the inverse square law. The dependence of the integrated mean-square error on the number of quantization levels, the number of sensors in the network and the SNR in observation and transmission channels is analyzed. The performance of the developed estimators is compared to unbiased Cramer-Rao Lower Bound.

8744-41, Session 7

A method for constructing orthonormal basis finsctions with good time-frequecy localization

Izidor Gertner, The City College of New York (United States)

No Abstract Available.

8744-33, Session 8

SAR imaging in the presence of spectrum notches via fast missing data IAA *(Invited Paper)*

William T. Rowe, Univ. of Florida (United States); Johan Karlsson, KTH Royal Institute of Technology, Department of Mathematics (Sweden); Luzhou Xu, Integrated Adaptive Applications, Inc. (United States) and Univ. of Florida (United States); George-Othon Glentis, Univ. of Peloponnese (Greece); Jian Li, Univ. of Florida (United States)

A synthetic aperture radar (SAR) system operating in congested frequency bands (such as UHF or VHF) suffers from radio frequency interference (RFI) from narrowband sources. When RFI interference is suppressed by frequency notching, gaps are introduced into the fast time phase history. This results in a missing data spectral estimation problem, where the missing data increase sidelobe energy and degrade image quality.

The adaptive spectral estimation method Iterative Adaptive Approach (IAA) has been shown to provide higher resolution and lower sidelobes than comparable methods, but at the cost of higher computationally complexity. Current fast IAA algorithms reduce the computational complexity using Toeplitz/Vandermonde structures, but are not applicable for missing data cases because these structures are lost. When the number of missing data samples is small, which often is the case in SAR with RFI, we use a low rank completion to restore the Toeplitz/Vandermonde structures. We show that the computational complexity of the proposed algorithm is considerable lower than the state-of-the-

art and demonstrate the utility on a simulated frequency notched SAR imaging problem.

8744-34, Session 8

HALOS: compact, high-speed adaptive optics

Geoff P. Andersen, Fassil Ghebremichael, HUA Inc. (United States); Ravi Gaddipati, Phani Gaddipati, Centum Engineering (United States); Paul Gelsinger-Austin, Ken R MacDonald, HUA Inc. (United States)

We have constructed a closed-loop adaptive optics system that operates at 100kHz without the need for a computer. The system uses a multiplexed hologram which is essentially pre-programmed with the response functions of each actuator in a given deformable mirror. An input beam incident on this hologram reconstructs a pair of focused beams - one for each actuator. The power ratio of each pair is directly related to the absolute phase of the wavefront for a particular actuator, so a simple feedback circuit between a fast photodetector array and the deformable mirror can provide fast, computer-free closed-loop correction.

We present results from a working holographic adaptive laser optics system (HALOS) incorporating a 32-actuator MEMS-based deformable mirror and an off-the-shelf, photon counting avalanche photodiode array. A simple digital circuit has been constructed to provide autonomous control and the entire system fits in the palm of your hand. Our results demonstrate that this device is largely insensitive to obscuration and in principle can run as fast with one actuator as with one million. We will further show how HALOS can be used in image correction, laser beam projection as well as phased-array beam combination.

8744-35, Session 8

Performance metric development for a group state estimator in airborne UHF GMTI applications

Ryan A. Elwell, U.S. Army Communications-Electronics Research Development and Engineering Command (United States)

This paper describes the development and implementation of evaluation metrics for group state estimator (i.e. group tracker) algorithms. Key differences between group tracker metrics and single-target tracker metrics are the method used for track-to-truth association and the characterization of group raid size. Another significant contribution of this work is the incorporation of measured radar performance in assessing tracker performance. The result of this work is a set of measures of performance derived from canonical individual target tracker metrics, extended to characterize the additional information provided by a group tracker. The paper discusses additional considerations in group tracker evaluation, including the definition of a group and group-to-group confusion. Metrics are computed on real field data to provide examples of real-world analysis, demonstrating an approach which provides characterization of group tracker performance as it relates to sensor performance.

8744-36, Session 8

A simulation study of target detection using hyperspectral data analysis

Ershad Sharifahmadian, Yoonsuk Choi, Shahram Latifi, Univ. of Nevada, Las Vegas (United States)

Target detection is difficult when the target is concealed or placed under ground or water. To detect and identify concealed objects from a distance, simultaneous analysis of the HyperSpectral Imaging (HSI) and Wideband (WB) data is studied. While the HSI analysis may render surface information about objects, the WB data can reveal information about inner layers of the object and its content.

Two of the challenging issues with object identification using HSI are (i) computational complexity of the analysis and (ii) signature mismatch. Here, combination of an enhanced version of the robust matched filter and the morphological endmember extraction algorithm is utilized. In addition, the wideband technology is utilized to provide more information about concealed target, and to support spectral processing for object uncovering more effectively.

During simulation, electromagnetic waves and propagation area (free space, different objects in scene) are modeled. In fact, an object is modeled as different layers with different thicknesses.

At the beginning of simulation, target locations are estimated. To do this, the interactions of electromagnetic signals with target will be studied. The existence of the target is estimated by the detection of spectral signature relating to material used in the target. In other words, the simultaneous presence of a spectral signature corresponding to the main materials of the specific target in the hyperspectral data helps detect the target.

In fact, the reflected higher frequency signals provide information about exterior layers of both the target object and the background; in addition, the reflected lower frequency signals provide information about interior layers of the target object. Matlab simulation is performed using HSI, and WB technology at different frequencies (KHz-GHz) and powers to identify different objects.

8744-37, Session 8

Sonar signal feature extraction for target recognition in range-dependent environments

Patrick J. Loughlin, Vikram T. Gomatam, Univ. of Pittsburgh (United States)

Identifying underwater objects from their sonar backscatter is an important task in active sonar operations, the success of which can depend on environmental factors as well as the object characteristics. For example, in shallow water, sound can undergo significant dispersion, such that the backscatter from an object can change with propagation, and hence the ``target signature” differs depending on the location of the target and receiver. We have previously derived features for automatic target recognition that are invariant to dispersion in range-independent as well as weakly range-dependent channels. These approaches were based on the normal and adiabatic modal solutions, respectively, of the Helmholtz equation. In this paper we develop a feature extraction process for more complicated range-dependent propagation as described by the parabolic propagation model, which is better suited to handling environmental variabilities and inconsistent boundary conditions. We develop an invariant feature extraction algorithm that negates the effects of dispersion and absorption introduced by the channel, and draw parallels between these new features and our previous features.

8744-38, Session 8

New electro-optic laser scanner desing for continuous coverage over a 120 x 120 degree field of regard

Scott R. Davis, Scott D. Rommel, Seth T. Johnson, Neil A. Rebolledo, Stephanie M. McMahon, Michael H. Anderson, Vescent Photonics Inc. (United States); Jason M. Auxier, U.S. Naval Research Lab. (United States)

We will present a design and data for new EO scanners that will provide: 120o x 120o field of regard (FOR), point-to-point transit time < 1 ms, full FOR raster (e.g., 1000x1000 points) < 1 sec, and complete FOR coverage with no “blind spots”. These scanners are achievable via the combination: electro-evanescent optical refractors for continuous

scanning over 60o?20o and cycloidal diffractive waveplates (also called polarization gratings) for discrete scanning to boost the total scan angle to 120o?120o. The polarization gratings provide significant size and cost advantages over prior birefringent prism approaches. The electro-evanescent optical refractors used to fill in the gaps between the discrete angles (>90% of FOR not addressed) provide speed and lack-of-blind-spots advantages over past optical phased array approaches. For example, a sweep over 1000 spots may be realized in <1 ms, rather than the 1000 x 5 ms relaxation times with past approaches. In this paper we will present progress on the manufacturing and performance of the optical refractors including beam quality, throughput, and aperture size. A full theoretical design and data supporting the viability of a full coverage 120 x 120 degree EO scanner will be presented.

8744-40, Session 8

Propagation effects in channels

Leon Cohen, Hunter College (United States)

No Abstract Available.

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8745-1, Session 1

Estimability of Thrusting Trajectories in 3D from a Single Passive Sensor

Ting Yuan, Yaakov Bar-Shalom, Peter Willett, Univ. of Connecticut (United States); R. Ben-Dov, S. Pollak, Univ of Connecticut (United States)

The problem of estimating the state of thrusting/ballistic endoatmospheric projectiles moving in 3-dimensional (3-D) space using 2-dimensional (2-D) measurements from a single passive sensor is investigated. The estimability is analyzed based on the Fisher Information Matrix (FIM) of the target parameter vector, comprising the initial launch (azimuth and elevation) angles, drag coefficient and thrust, which determine its trajectory according to a nonlinear motion equation. The initial position is assumed to be obtained from the first measurement line of sight (LoS) intersected with the ground plane. The full rank of the FIM ensures that this is an estimable system. The corresponding Cramer-Rao lower bound (CRLB) quantifies the estimation performance of the estimator that is statistically efficient and can be used for impact point prediction (IPP). Due to the inherent nonlinearity of the problem, the maximum likelihood estimate (MLE) of the target parameters is found by using the iterated least squares (ILS) numerical approach. A drag coefficient-thrust grid-based ILS search over the launch angles space is proposed. The grid-ILS approach is shown to converge to the global maximum and its reliable estimation performance further verifies the estimability.

8745-2, Session 1

Comparing truth-to-track assignment methods for situation correctness

John R. Maskasky, Mark E. Silbert, Naval Air Warfare Ctr. Aircraft Div. (United States)

Evaluating the performance of a target tracking system requires first determining which tracks should be assigned to which targets. This is the truth-to-track assignment (TTA) problem. Unfortunately, determining the truth-to-track assignments can be problematic when the targets are closely spaced since the measurements can be ambiguous as to which target was observed. As a result, which target is being tracked could be ambiguous as well. This ambiguity in the target tracks makes the TTA problem more difficult. There are three common methods to find the TTAs: nearest neighbors, global cost minimization, and Report Identity Based (RIB). Nearest neighbors and global cost minimization are similar since both use a distance or cost function to establish the corresponding target. RIB, on the other hand, determines the identities of the measurements that the track used and selects the target based on majority-rule. This study compares these three assignment methods, taking differing amounts of track history into account when computing the assignments. The methods are compared using various simulated scenarios to determine how the three TTAs along with differing amounts of track history affect common performance metrics such as track accuracy and track purity. The study shows that all methods perform well when there is little ambiguity but RIB performs more agreeably as the scenarios become more complex. In addition, RIB provides a richer set of assignments that allows for more objective performance metrics. The results of this study are applicable where it is critical to evaluate tracking performance objectively such as quantifying the performance of automated detect-and-avoid systems.

8745-3, Session 1

Advances in displaying uncertain estimates of multiple targets

David F. Crouse, U.S. Naval Research Lab. (United States)

In practical tracking systems, there is no inherent “order” to the states of targets present. Moreover, the number of targets present is not known a priori and is always an uncertain quantity. Because of the orderless nature of the multitarget tracking problem, extensive work has been performed in the past deriving finite set statistics (FISST) along with the set integral to form a rigorous mathematical basis for tracking. In this framework, it has been shown that traditional estimators, such as the expected value, produce undesirable or meaningless results for target state estimation due both to the orderless nature of the target states as well as the unknown number of targets present.

Minimum mean optimal subpattern assignment (MMOSPA) estimation has been shown to provide meaningful estimates in instances of target identity uncertainty when the number of targets present is known. This paper demonstrates that accurate, approximate MMOSPA estimates for tracking can be calculated in miliseconds to microseconds without extensive optimization, using off-the-shelf hardware. This makes MMOSPA estimation a practicable alternative to more traditional estimators.

However, this does not address the question of how to summarize information in a true random finite set probability density function under FISST, where the number of targets present is unknown and the traditional definition of the expected value is meaningless. To address this, a minimum mean Wasserstein distance estimator is defined analogously to how MMOSPA estimates were defined for known target numbers. This estimator provides a collection of target state estimates with probabilities of target existence.

8745-4, Session 1

Tracklets classification for target signature detection

Sowmya Ramakrishnan, Riad I. Hammoud, Nathan Shnidman, BAE Systems (United States)

This paper describes a robust classification approach of short-tracks (tracklets) of moving targets in wide aerial surveillance imagery into three categories: vehicles, dismounts and clutter. Such a classification enables stitching of short duration tracklets into longer high confidence target tracks, enhances target purity through occlusions, and offers potential for automatic events detection.

Using a robust statistical background model in conjunction with multi-scale filtering, moving targets are automatically localized, nominated and tracked auto-regressively through probabilistic fusion of kinematics and appearance, to produce tracklets of short duration. We then utilize the imagery and motion masks to compute a rich feature space over the tracklets, which is derived from spatiotemporal, geometric, kinematic and spectral attributes of the extracted target image and mask. In particular, higher order statistical moments used for shape description, kinematic features and a set of regional statistics are computed over the target mask. Feature vectors ascribe the tracklets with a compact yet rich representation in the signature feature space that allows applying machine learning paradigms to classify the target signature labels. An extensive training database of tracked targets was assembled to cover wide range of scenarios and operational conditions and high quality ground truth annotations were created through rigorous manual labeling of signature types. Using this training data, we trained a number of standard statistical classifiers for supervised learning such as Naïve Bayes and Support Vector Machines and used them to classify unseen test sets. We were able to achieve 85% overall signature accuracy with a 90% true positive rate for clutter over a large test set.

8745-5, Session 1

Overview of Dempster-Shafer methods in target tracking

Erik P. Blasch, Air Force Research Lab. (United States); Jean C. Dezert, Benjamin Pannetier, ONERA (France)

Over the years, there have been many proposed methods in set-based tracking. One example of set-based methods is the use of Dempster-Shafer techniques to support belief-based tracking. In this paper, we overview the issues and concepts that motivated Dempster-Shafer (DS) methods for simultaneous tracking and classification/identification. DS methods have some attributes, if applied correctly; but there are some pitfalls that need to be carefully avoided. Such comparisons and applications are found in DSmT methods from which the PCR5 rule supports a more comprehensive approach if researchers are interested in applying evidential techniques to target tracking. In the paper, we overview the issues to report on two decades of research in the area.

8745-6, Session 2

Decentralized closed-loop collaborative surveillance and tracking performance sensitivity to communications connectivity

Jonathan T. DeSena, Sean R. Martin, Jesse C. Clarke, Daniel A. Dutrow, Brian C. Kohan, Andrew J. Newman, Johns Hopkins Univ. Applied Physics Lab. (United States)

As the number and diversity of sensing assets available for intelligence, surveillance and reconnaissance (ISR) operations continues to expand, the limited ability of human operators to effectively manage, control and exploit the ISR ensemble is exceeded, leading to reduced operational effectiveness. Our approach is to apply the principles of feedback control to ISR operations, “closing the loop” from the sensor collections through automated processing to ISR asset control. Previous work by the authors demonstrating closed-loop control, involving both platform routing and sensor pointing, of a multi-sensor, multi-platform ISR ensemble tasked with providing situational awareness and performing search, track and classification of multiple targets. The multi-asset control used a joint optimization of routes and schedules in a centralized architecture, requiring a fully-connected communications network. This paper presents an extension of the previous work to a decentralized architecture that relaxes the communications requirements. The decentralized approach achieves a solution equivalent to the centralized system when the network allows full communications and gracefully degrades ISR performance as communications links degrade. The decentralized closed-loop ISR system has been exercised via a simulation test bed against a scenario in the Afghanistan theater under a variety of network conditions, from full to poor connectivity. Simulation experiment results are presented.

8745-7, Session 2

GMTI radar resource management and partially observed Markov decision processes

Bhashyam Balaji, Defence Research and Development Canada, Ottawa (Canada)

Consider an electronically scanning ground moving target indication (GMTI) radar that is tracking several several ground moving targets. The problem is to schedule the beam in order to minimize some cost that is a function of GMTI tracker outputs.

The radar resource management scheme used in this paper divides the problem into two subproblems with different time scales. Specifically, the proposed radar control architecture consists of two parts: a macromanager and a micromanager. The macromanager allocates priority weights to the targets. For instance, it could be the track variances, or persumed threat level, such as from the output of a syntactic tracker. The micromanager is initiated based on the target priority vector provided by the macromanager and allocates the radar beams accordingly.

In this paper, the focus is on the micro-manager, i.e., we consider the following problem: Given the target priority vector, how long should the micro-manager track the targets before returning control to the macromanager (that in turn furnishes a new priority vector)?

The micromanager problem can be viewed as a sequential detection problem that consists of the following two actions—stop and return control to the macromanager, or continue. Recent work (by Krishnamurthy et al) has shown that the optimal decision for certain costs is characterized by a monotone policy on the a partial ordering defined on a set of positive-definite covariance matrices. As a result, it is possible to design and estimate and implement monotone parametrized decision policies in real time. This requires the specification of the costs for these actions. There are several possibilities for the stopping costs (that lead to monotone decision policies), and the choice of the cost depends on the application.

Several simulations are carries out using typical practical algorithms and system parameters. Specifically, the kinematic model for the (assumed nonmaneuvering) target is taken to be the discrete-time constant velocity model. The filtering algorithm is taken to be extended Kalman filter (EKF). The performance of the optimal decision policy is compared to the simple periodic policy. It is found that the optimal decision policy provides a lower envelope of the deterministic periodic policies.

8745-8, Session 2

Sensor selection for target localization in a network of proximity sensors and bearing sensors

Qiang Le, Hampton Univ. (United States); Lance Kaplan, U.S. Army Research Lab. (United States)

This work considers the sensor selection and the fusion method using a network of proximity sensors that provide binary measurements, and bearing sensors that provide bearing measurements.

In previous work, we have developed a novel form of a probability hypothesis density (PHD) filter to track multiple targets in a network of proximity sensors. The PHD filter originally proposed by Mahler assumes that the measurements are independent and associated to one target.

To fuse the data from the hybrid network, in the paper we consider two fusion strategies to update the weights of PHD particles: one is iteration-based fusion where the weights could be first updated by proximity sensors, then are updated by bearing sensors, or vice versa. The other is association-based fusion where the weights are products of individual weights updated by bearing sensors and proximity sensors. Note the first fusion methods is the traditional iterative method originally proposed by Mahler. As a result, the order of fusing sensors makes differences in the localization performance. The second method treats the types of sensors equally. But it requires the data association of the bearing measurements and the targets.

To select the type of sensors, we consider two selection methods based upon Renyi divergence. One is based upon the single target particle level. The other is based upon the multitarget particle level. While the single target Renyi divergence does not require the association for the bearing measurements and the targets, the multitarget Renyi divergence requires the association. The paper will compare the localization performances for different fusion strategies and selection methods.

8745-9, Session 2

Evaluating detection and estimation capabilities of magnetometer based vehicle sensors

David Slater, Garry M. Jacyna, The MITRE Corp. (United States)

The focus of this work is on two Measures of Performance (MOPs) for Unattended Ground Sensors (UGS). UGS are placed near roads to detect passing vehicles and estimate properties of the vehicle's trajectory such as bearing and speed. The first MOP considered is the probability of detection. We derive probabilities of detection for a network of sensors over an arbitrary number of observation periods and explore how the probability of detection changes when multiple sensors are employed. The performance of UGS is also evaluated based on the level of variance in the estimation of trajectory parameters. We derive the Cramer-Rao bounds for the variances of the estimated parameters for two cases: when no a priori information is known and when the parameters are assumed to be Gaussian with known variances. Sample results show that UGS perform significantly better in the latter case.

8745-10, Session 2

Tracking and predicting of multiple interacting deformable objects from flash lidar range image data

Ryan J. Poore, Richard L. Tutwiler, Matthew S. Baran, Donald J. Natale, The Pennsylvania State Univ. (United States)

This work focuses on three main components of the proposed object tracking and predicting system: first, its ability to maintain an object's identification while all the objects interact: second, its ability to accurately predict and adapt its motion filters for the tracked object: third, to detect correlation between the high level patterns of group activity to a simulated database of group activity.

The tracking algorithm models each object to be tracked with an implicit contour. Each object's contour is evolved according to the minimization of a custom energy function that is comprised of a region-based term, an edge-based term, and a motion-based term. The evolution of the contour is guarded from merging objects with separate identification numbers through topological constraints. The system maintains an object's identification by comparing the feature vectors calculated from the segmented object contours. The feature vectors utilized are the centroid position, predicted centroid position, objects motion, along with the shape and range statistics. The prediction of the object's position and motion are performed using an interacting multiple model (IMM) algorithm that operates multiple Kalman filters in parallel, each of which is matched to a unique motion model: random walk, constant velocity, and constant acceleration. A basic comparison method of relative position and motion to a simulated database is implemented to indicate if a group pattern of behavior is observed.

8745-11, Session 3

Urban multitarget tracking via gas-kinetic dynamics models

Ronald P. S. Mahler, Lockheed Martin Corp. (United States)

Multitarget tracking in urban environments presents a major theoretical and practical challenge. Challenges include: complex interactions between vehicles and between vehicles and intersections; limited sensor capabilities; and limited feature information. A recently suggested approach: modeling traffic dynamics using the fluid-kinetic methods of traffic-flow theory. I propose a more general, gas-kinetic (GK) approach. GK models have been described as "bridging the gap between microscopic behavior of individual drivers and the macroscopic dynamics of traffic flow." They are theoretically consistent with familiar macroscopic, mesoscopic, and microscopic traffic-flow models. In GK, one models traffic flow as a 1D or 2D constrained gas. The foundational concept in GK is the "phase-space density"—a.k.a. the probability hypothesis density (PHD)—and the best-possible solution to traffic-flow tracking turns out to be an exact PHD filter. The GK model (and its macro, meso, or micro approximations) is the time-update step of this exact PHD filter. The CPHD filter is its measurement-update step.

8745-12, Session 3

Background agnostic CPHD tracking of dim targets in heavy clutter

Adel I. El-Fallah, Aleksandar Zatezalo, Scientific Systems Co., Inc. (United States); Ronald P. S. Mahler, Lockheed Martin Corp. (United States); Raman K. Mehra, Scientific Systems Co., Inc. (United States); Wellesley E. Pereira, Air Force Research Lab. (United States)

Detection and tracking of dim targets in heavy clutter environments is a daunting theoretical and practical problem.

Application of the recently developed Background Agnostic Cardinalized Probability Hypothesis Density (BA-CPHD) filter provides a very promising approach that adequately addresses all the complexities and the nonlinear nature of this problem.

In this paper, we present analysis, derivation, development, and application of a BA-CPHD implementation for tracking dim ballistic targets in environments with a range of unknown clutter rates, unknown clutter distribution, and unknown target probability of detection.

The effectiveness and accuracy of the implemented algorithms are assessed and evaluated. Results that evaluate and also demonstrate the specific merits of the proposed approach will be presented.

8745-13, Session 3

Tracking, identification and classification with random finite sets

Ba Tuong Vo, Ba-Ngu B. Vo, Curtin Univ. (Australia)

In multi-target tracking, identification and classification, the states, identities and class of an unknown and time number of targets is to be estimated, given a sequence of measurements in the presence of noise, missed detections, false alarms, and data association uncertainty. This paper presents a novel approach to multi-target tracking, identification and classification based on random finite sets or finite set statistics. Our approach is encapsulates a dynamic Bayesian estimation paradigm combined with random finite sets or finite set statistics modelling for the multi-target state and measurement. Based on the class of Generalized Labeled Multi-Bernoulli densities, a closed form recursive filter is derived which propagates the full multi-target posterior. The recursion is closed under both the time prediction and data update steps, and hence is a conjugate result, which jointly propagates information on the target states, cardinalities, identities, and class. Formal statistical estimators and their properties including optimality are further discussed which enable final stage estimation or extraction of the state, identity and class estimates from the posterior. Implementation and tractability issues are also briefly discussed.

8745-15, Session 3

PHD filtering with localised target number variance

Emmanuel D. Delande, Jeremie Houssineau, Daniel E. Clark, Heriot-Watt Univ. (United Kingdom)

Mahler's Probability Hypothesis Density (PHD filter), proposed in 2000, addresses the challenges of the multiple-target detection and tracking problem by propagating a mean density of the targets in any region of the state space. However, when retrieving some local evidence on the target presence becomes a critical component of a larger process – i.e. for sensor management purposes – the local target number is insufficient unless some confidence on the estimation of the number of targets can be provided as well. In this paper, we propose a first implementation of a PHD filter that also includes an estimation of localised variance in the target number following each update step; we then illustrate the advantage of the PHD filter+variance on simulated data from multiple-target scenarios.

8745-16, Session 3

Divergence detectors for multitarget tracking algorithms

Ronald P. S. Mahler, Lockheed Martin Corp. (United States)

Single-target tracking filters will typically diverge when their internal measurement or motion models deviate too much from the actual models. In recent papers, Niu, Varshney et al. have introduced a metric that recursively measures the degree of nonlinearity in a single-target tracking problem, by detecting filter divergence: the normalized innovation squared (NIS). In this paper, we begin by showing that NIS is actually a special case of a generalized NIS (GNIS) metric, defined in terms of the data-updated Bayes normalization factor. Given this, we show how to both heuristically and rigorously generalize the GNIS metric to a multisensor-multitarget GNIS (MGNIS) metric. We also show how to derive closed-form formulas for the MGNIS metric when it is used to measure the divergence/convergence of PHD and CPHD filters. To illustrate the behavior of these MGNIS metrics, we derive formulas for a number of special cases.

8745-17, Session 3

A Gaussian mixture ensemble transform filter for vector observations

Santosh Nannuru, Mark Coates, McGill Univ. (Canada); Arnaud Doucet, Univ. of Oxford (United Kingdom)

The ensemble Kalman filter (EnKF) provides an attractive compromise between the Kalman filter and the particle filter, both of which can struggle to perform adequately when they are applied in a high-dimensional state space. Like the particle filter, the EnKF is a Monte Carlo approximation to the Bayesian filtering problem, but during the update stage it applies the Kalman update equations to migrate the particles to new locations in the state space. The particle weights remain constant over time. One of the limitations of the EnKF is that it relies on the Gaussian approximation being a reasonably accurate representation of the filtering distribution. Reich recently introduced a Gaussian mixture ensemble transform filter [1]. This filter is capable of addressing scenarios where the prior cannot be adequately represented using a single Gaussian, but can be reasonably accurately modeled using a Gaussian mixture. Reich's derivation is only suitable for a scalar-valued measurement or when there is a vector of uncorrelated measurements. In this work, we extend the derivation to the more general case of vector observations with arbitrary correlations. However, we illustrate through numerical simulation experiments that the practical implementation of this filter is challenging. Even with scalar measurements, the filter is prone to instability, but this is exacerbated by correlated vectors of observations. We briefly discuss implementation strategies that can mitigate some of the stability difficulties.

[1] S. Reich, "A Gaussian mixture ensemble transform filter," arXiv:1102.3089, July 2011.

8745-18, Session 3

Fusion of imaging data and auxiliary signal for target classification

Aleksandar Zatezalo, Ssu-Hsin Yu, Scientific Systems Co., Inc. (United States)

Fusion of imaging data with auxiliary signal such as EW data for multitarget classification poses daunting theoretical and practical challenges. We use prior probabilities assigned to image and signal feature elements to handle the problem of data synchronization, feature quality and object occlusion in a unified manner. In our approach, current state and class probability distributions estimated from previous instances are fused with new outputs from individual classifiers immediate after the outputs become available to establish updated state and class probability distributions in a Bayesian framework. Results are presented that demonstrate joint segmentation and tracking, target classification using imaging data, and fusion of imaging data with noisy auxiliary EW information under realistic simulation scenarios.

8745-19, Session 3

Missile tracking using a multiple model particle filter

Aleksandar Zatezalo, Adel I. El-Fallah, Scientific Systems Co., Inc. (United States); Ronald P. S. Mahler, Lockheed Martin Corp. (United States); Raman K. Mehra, Scientific Systems Co., Inc. (United States); Charles E. Lewis, Missile Defense Agency (United States)

Accurate tracking of a missile in its ascending phase is a challenging problem due to variety of encountered uncertainties in the boost phase accelerations, in the booster transition times, and in the booster separation forces. In addition, different types of geographically dispersed sensors need to be utilized in a seamlessly integrated fashion in order to ensure adequate track maintenance for both the missile and its generated debris.

A multiple model particle filter is developed, implemented, and tested to address this challenging problem. The filtering algorithm is derived using nonlinear filter methodology and the theory of finite-state time-nonhomogeneous Markov processes. Preliminary results obtained using a one-stage simulation testbed are presented and discussed.

8745-20, Session 3

Tracking multiple missiles using a network of sensors

Adel I. El-Fallah, Aleksandar Zatezalo, Scientific Systems Co., Inc. (United States); Ronald P. S. Mahler, Lockheed Martin Corp. (United States); Raman K. Mehra, Scientific Systems Co., Inc. (United States); Rene Silva-Viego, Missile Defense Agency (United States)

Accurate and robust tracking of multiple missile trajectories using a network of dispersed and disparate sensors that include radars and EO/IR, is a challenging problem. Missile trajectory uncertainties, multisensor detection constraints, and measurement stochasticity has to be modeled and tested for robust performance. For centralized multisensor multitarget tracking, we apply the multisensor multitarget Posterior Expected Number of Targets of Interest (PENTI) sensor management objective function to dynamically estimate the optimal dwelling of sensors on targets. Each sensor can be tasked either individually or jointly, that is we either perform an un-coordinated or a coordinated sensor management. The un-coordinated sensor management allows for the estimation and tasking of each sensor at its location, whereas the coordinated sensor management estimates sensor parameters (e.g.

where to direct the field of view of each sensor) at a central location and distributes or communicates the corresponding tasks to each sensor at its own location. Both sensor management approaches are implemented and tested using the PENTI objective function and multitarget densities.

The performance of the two resulting algorithms are compared and tested against different multisensor multitarget scenarios.

8745-21, Session 4

Accelerating the OODA loop with multisensor systems

Greg Gottschalk, Kevin Andryc, Timothy Eagleson, Pete Kuzdeba, Michael Rose, Jesse D. Chamberlain, Daniel LaValley, Brent Kowal, Nick Beluzo , Brian Rusiecki, L-3 KEO (United States)

Ambush tactics rely on surprise as a force multiplier. Analyzed in terms of the Observe, Orient, Decide and Act (OODA) loop, the ambushing forces seek to start the OODA loop one cycle ahead of their opposition. In this paper we propose an integrated systems approach to collapsing this window of advantage, mitigating the effectiveness of enemy direct fire weapon systems prior to and during ambushes. Response time is compressed via a multisensor system including an Optical Shot Detection System and a Remote Weapon Station equipped with 360° imaging. The rapid application of precise and overwhelming return fire also has the effect of slowing the OODA loop of the ambushing forces, further reducing advantage conferred by surprise.

Prior to and during an ambush the 360° imaging system keeps the Soldier aware of surroundings. Once the first shot has been fired, signal processing algorithms in the Optical Shot Detection System provide target identification and classification. In addition the Optical Shot Detection System can provide precise bearing and elevation coordinates, enabling the CROWS Remote Weapon Station to slew to the source of hostile fire without human intervention. Simultaneously, the coordinates can also be fed to the staring 360° imaging system, slewing the electronic zoom faster than motors allow and helping to orient the operator. Keeping the Soldier in the loop for all lethal weapons mitigates the potential for collateral damage. Data from other sensors can be fused into the 360° display, providing an easily understandable Machine-Human Interface to the Soldier.

8745-22, Session 4

High level information fusion (HLIF) with nested fusion loops

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With the vast increases in accumulated data, information fusion has become even more challenging. Through the years, some common frameworks have emerged for dealing with information fusion—perhaps the most ubiquitous being the JDL Data Fusion Group and their initial 4-level data fusion model. Since these initial developments, numerous models of information fusion have emerged, hoping to better capture the human-centric process of data analyses within a machine-centric framework. 21st Century Systems, Inc. introduces Fusion with Uncertainty Reasoning using Nested Assessment Characterizer Elements (FURNACE) to handle bias, ambiguity, and uncertainty (BAU) for Situation Modeling, Threat Modeling, and Threat Prediction. It combines JDL fusion levels with nested fusion loops and state-of-the-art data reasoning. Initial research has shown that FURNACE is able to reduce BAU and improve the fusion process by allowing high level information fusion (HLIF) to affect lower levels without the double counting of information or other biasing issues. The initial FURNACE project was focused on the underlying algorithms to produce a fusion system able to handle BAU and repurposed data in a cohesive manner. FURNACE supports the analyst's efforts to develop situation models, threat models, and threat predictions to increase situational awareness of the battlespace. FURNACE will not only revolutionize the military intelligence realm, but also benefit the larger homeland defense, law enforcement, and business intelligence markets. FURNACE, through its information fusion capabilities, will provide deception detection and identification services to a number of government and business entities.

8745-23, Session 5

A robust technique for semanic annotation of group activities based on recognition of extracted features in video streams

Amir Shirkhodaie, Vinayak Elangovan, Tennessee State Univ. (United States)

Recognition and understanding of group activities can significantly improve situational awareness in Surveillance Systems. To maximize reliability and effectiveness of Persistent Surveillance Systems, annotations of sequential images gathered from video streams (i.e. imagery and acoustic features) must be fused together to generate semantic messages describing the group activity. To facilitate efficient fusion of extracted features from any physical sensors a common structure will suffice to ease integration of processed data into new comprehension. In this paper, we detail a framework for extraction and management of pertinent features/attributes vital for annotation of group activities reliably. A robust technique is proposed for facilitation of fusion of generated features from video streams which pertains to a modified Transducer Markup Language (TML) data format. By aggregation of multi-attribute TML messages, we have demonstrated that salient group activities can be discovered. This, in turn, facilitates generation of semantic messages describing the group activities. This paper presents experimental results of different group activities taken under different context and demonstrates the efficiency and effectiveness of the proposed modified TML data structure facilitating fusion of extracted information from video streams.

8745-24, Session 5

Feynman path integral discretization and its applications to nonlinear filtering

Bhashyam Balaji, Defence Research and Development Canada, Ottawa (Canada)

The continuous-discrete and continuous-continuous nonlinear filtering problems have been investigated for the past several decades using various methods. The investigation of such problems leads one to consider certain parabolic second-order partial differential equations (PDEs). Specifically, for the continuous-discrete filtering problem the relevant PDE is the Fokker-Planck-Kolmogorov forward equation. Similarly, a relevant PDE for the continous-continuous nonlinear filtering problem is the Yau-Yau equation proposed by Shing-Tung Yau and Stephen Yau.

The PDEs of interest can be reformulated as integral equations. As a result, in order to solve the filtering problem it is , in principle, sufficient to obtain the fundamental solution of the PDEs. There are several formal solutions, including one based on Feynman path integrals (FPIs). It is noted that FPIs have been widely investigated for finite (quantum particle mechanics) and finite-dimensional spaces (quantum field theory) for the past several decades. There also exist several formulations of the FPIs with varying levels of rigor. In this paper, the discretization approach is studied where the FPI is defined as a limit of finite-dimensional integrals. Unlike the formal functional methods (widely and successfully) used in modern quantum field theory, the discretization approach has the advantage of providing a rigorous mathematical foundation.

The discretization approach is then applied to a well-known filtering problem specified by a Benes drift. The paper concludes with some remarks on the advantages and disadvantages of the various approaches.

8745-25, Session 5

Particle flow inspired by Knothe-Rosenblatt transport for nonlinear filters

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We compare the Monge-Kantorovich optimal transport (MKT) problem with particle flow for nonlinear filters. These two problems are closely related, and there are opportunities to exploit algorithms & theorems developed in one field for the other application. However, there are several key differences between MKT and particle flow. In particular, MKT requires the solution of a nonlinear PDE (the Monge-Ampere PDE), whereas particle flow only requires the solution of a linear PDE with constant coefficients, resulting in much less real time computational complexity than MKT. Also, particle flow uses a log-homotopy, whereas MKT uses a homotopy. MKT is a rich source of mathematical theorems for existence & uniqueness of particle flow. Particle flow has derived several algorithms that are extremely fast for certain special cases (e.g. Gaussian prior and Gaussian likelihood; incompressible flow; irrotational flow; Fourier flow; small curvature flow; zero curvature flow, etc.), whereas MKT has not. Moreover, particle flow is fast & accurate for problems with high dimensional state vectors, whereas MKT applications have been limited to rather low dimensions (2 or 3).

8745-26, Session 5

Particle flow with non-zero diffusion for nonlinear filters

Frederick E. Daum, Raytheon Co. (United States); Jim Huang, Raytheon (United States) and Raytheon Co (United States)

We derive a new algorithm for particle flow corresponding to Bayes' rule by assuming that the flow has fixed finite dimension. This results in a dramatic reduction in real time computational complexity, because we only need to solve ODEs rather than PDEs. This idea is a natural generalization of our zero curvature flow, which is a specialization of our small curvature flow algorithm. Moreover, this new theory is related to exact finite dimensional filters based on the assumption of conditional probability densities from the exponential family (Daum 1986). One can exploit this relationship to derive fast & accurate algorithms for particle flow corresponding to Bayes' rule. In this context, the issue of zero process noise for the flow vs. non-zero process noise becomes crucial, whereas it was not apparently important in our previous work. In particular, for plants with zero process noise, one can prove that the only non-trivial fixed finite dimensional filters are for estimation problems that can be embedded in the Kalman filter problem (i.e., linear & Gaussian problems), whereas this no-go theorem does not hold with non-zero process noise.

8745-27, Session 5

Zero curvature particle flow for nonlinear filters

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We derive a new algorithm for particle flow by assuming zero curvature. This results in a quadratic algebraic equation for the flow rather than a PDE, and hence the computational complexity is reduced dramatically. Obviously zero curvature flows exist for state spaces that are Euclidean, but such flows might not exist for non-Euclidean state spaces with disconnected components or holes or other obstructions to the flow of particles for Bayes' rule. But, to quote Lingji Chen: "engineers do not give up", and hence we consider piecewise zero curvature flows or enlarging the dimension of the state space to facilitate particle flow (somewhat analogous to travelling through higher dimensional tunnels in space time in science fiction and modern physics). One can also just code the algorithm in MATLAB and see what happens, ignoring theoretical obstructions. This is analogous to our numerical experiments with incomporessible flow, which does not generally exist in state spaces with dimension lower than 2 or 3, but which works extremely well in our numerical experiments anyway. In particular, the particles just flow around obstructions in spaces of dimension higher than one. Schnirelman has proved several theorems on incompressible flow induced by homotopies in dimensions higher than two that help to explain why our algorithms work so well.

8745-28, Session 5

Fourier transform particle flow for nonlinear filters

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We derive four new algorithms to design particle flow for nonlinear filters using the Fourier transform of the PDE that determines the flow of particles corresponding to Bayes' rule: div(pf)=. This exploits the fact that our PDE is linear with constant coefficients. We avoid computing the inverse Fourier transform by using the generalized inverse of a large linear operator in k-space along with Monte Carlo approximation of the multidimensional Fourier integral. We also use a variance reduction method as well as a stabilization method to enhance robustness. We show numerical experiments comparing our performance with several other filters (EKF, bootstrap PF, EKF PF, UKF PF, auxiliary PF, MALA MCMC PF). Our filter beats the EKF by several orders of magnitude in accuracy for difficult nonlinear problems, and it is roughly ten orders of magnitude faster than the bootstrap PF for the same accuracy for high dimensional problems.

This theory can be applied to essentially any estimation or decision problem, including: tracking, guidance and navigation, control, robotics, Bayesian decisions, predicting the weather and the stock market. We show many numerical results for various nonlinearities, with both stable and unstable plants, varying process noise, measurement noise, initial uncertainty of the state vector, and dimension of the state vector from d = 1 to 30. Our theory uses particle flow (like physics) to compute Bayes' rule, rather than a pointwise multiply. We do not use resampling of particles or proposal densities or importance sampling or any Markov chain Monte Carlo method. But rather, we design the particle flow with the solution of a linear first order highly underdetermined PDE, like the Gauss divergence law in electromagnetics. The talk explains what a particle filter is, and why engineers like particle filters, but we also explain the curse of dimensionality. We explain particle degeneracy and how we solve it with a simple cartoon. This talk is for normal engineers who do not have nonlinear filters for breakfast.

8745-30, Session 6

Sequential testing over multiple stages and performance analysis of data fusion

Gaurav S. Thakur, The MITRE Corp. (United States)

We describe a methodology for studying the performance of decision-level data fusion between different sensor configurations. We first discuss a static framework based on a Bayesian network formulation of classical probabilistic data fusion, which allows elementary fusion structures to be stacked and analyzed efficiently. We then present an extension of the Wald sequential test for combining the outputs of the static framework over time. This variant of the sequential test involves multiple, distinct stages of operation, where the evidence accumulated from each stage is carried over into the next one. We view such a test as a heterogeneous random walk and discuss a simple deterministic algorithm to efficiently compute the performance and decision time distributions of the test for given, time-dependent input statistics. This approach is motivated by modeling a bank of anomaly sensors that observe a target moving closer over time, reach an initial static fused decision, and if justified, activate additional, interrogator sensors that continue to collect static fused evidence over time until a final decision is made about the target. The multiple-stage configuration allows sensors that have a high cost of

operation to remain inactive unless specifically called upon. We finally discuss some examples illustrating the different types of behavior that appear in the distributions of the stage transition and decision times, based on the target's movements.

8745-32, Session 6

Multisource information fusion for enhanced simultaneous tracking and recognition

Bart Kahler, SAIC (United States)

A layered sensing approach helps to mitigate sensor, target, and environmental operating conditions affecting target tracking and recognition performance. Radar sensors provide standoff sensing capabilities over a range of weather conditions; however, operating conditions such as obscuration can hinder radar target tracking. By using other sensing modalities such as electro-optical (EO) building cameras or eye witness reports, continuous target tracking and recognition may be achieved when radar data is unavailable. Information fusion is necessary to associate independent multisource data to ensure accurate target track and identification is maintained. Exploiting the unique information obtained from multiple sensor modalities with non-sensor sources will enhance vehicle track and recognition performance and increase confidence in the reported results by providing confirmation of target tracks when multiple sources have overlapping coverage of the vehicle of interest. The author uses a fusion performance model in conjunction with a tracking and recognition performance model to assess which combination of information sources produce the greatest gains for both urban and rural environments for a typical sized ground vehicle.

8745-33, Session 6

Dempster-Shafer theory and connections to information theory *(Invited Paper)*

Joseph S. Peri, Johns Hopkins Univ. Applied Physics Lab. (United States)

The Dempster-Shafer theory is founded on probability theory. The entire machinery of probability theory, and that of measure theory, is at one's disposal for the understanding and the extension of the Dempster-Shafer theory. It is well known that information theory is also founded on probability theory. Claude Shannon developed, in the 1940's, the basic concepts of the theory and demonstrated their utility in communications and coding. Shannonian information theory is not, however, the only type of information theory. In the 1960's and 1970's, further developments in this field were made by French and Italian mathematicians. They developed information theory axiomatically, and discovered not only the Wiener-Shannon composition law, but also the hyperbolic law and the Inf-law. The objective of this paper is to demonstrate the mathematical connections between the Dempster Shafer theory and the various types of information theory. A simple engineering example will be used to demonstrate the utility of the concepts.

8745-66, Session PSTue

Infrared small target detection technology based on OpenCV

Lei Liu, Jilu Chen, Nanjing Univ. of Science and Technology (China)

Small target tracking in infrared (IR) image sequences has been an important part in many military or civil fields such as video supervision, precision guidance and human-computer interfaces. Nowadays, different algorithms have been proposed for infrared target tracking. However, under complex backgrounds, such as clutter, varying illumination, and occlusion, the traditional tracking method often loses the real infrared small target. To cope with these problems, in this paper we have researched on the traditional infrared small target tracking methods, summarized the advantages and disadvantages of these algorithms. On the basis of the analysis of these methods, according to the characteristics of the small target in infrared images, we propose an improved tracking algorithm to enhance the tracking performance. The experimental results show that, compared with the traditional algorithm, the presented method greatly improves the accuracy and effectiveness of infrared target tracking under complex scenes, and the results are satisfactory.

8745-67, Session PSTue

Simultaneous optimization by simulation of iterative deconvolution and noise removal for non-negative data

Abolfazl M. Amini, Southern Univ. and A&M College (United States); George E. Ioup, Juliette W. Ioup, Univ. of New Orleans (United States)

This paper introduces a method by which one can find the optimum iteration numbers for noise removal and deconvolution of sampled data. The method employs the mean squared error, which is the pointwise square of the difference between the deconvolution result and the input for optimization. As an example of the iterative methods of noise removal and deconvolution, the always convergent method of Ioup is used for the simultaneous optimization by simulation research presented in this paper. This method is used to achieve optimization for two Gaussian impulse response functions, one narrow (rapidly converging) and the other wide (slowly converging). The input function used consists of three narrow peaks selected to give some overlap after convolution with the Gaussian impulse response function. Normally distributed noise is added to the convolution of the input with the impulse response function. A range of signal-to-noise ratios is used in the optimization of the always convergent iterations for both of these Gaussians. For the narrow Gaussian 15 signal-to-noise ratio cases are used while for the wide Gaussian 11 signal-to-noise ratios cases are used. To achieve statistically reliable results 50 noisy data sets are generated for each signal-to-noise ratio case. For a given signal-to-noise ratio case the average mean squared error, the average optimum deconvolution, and the average noise removal iteration numbers are found and tabulated. The tabulated results are plotted versus the average SNR. Once these optimum numbers are found they can be used in an equivalent window in the Fourier transform domain.

8745-68, Session PSTue

Simultaneous optimization by simulation of iterative deconvolution and noise removal to improve the resolution of impulsive inputs

Abolfazl M. Amini, Southern Univ. and A&M College (United States); George E. Ioup, Juliette W. Ioup, Univ. of New Orleans (United States)

This paper introduces a method by which one can find the optimum iteration numbers for noise removal and deconvolution of sampled data. The method employs the mean squared error, which is the pointwise square of the difference between the deconvolution result and the input for optimization. The always convergent iterative deconvolution and noise removal methods of Ioup are used for the simultaneous optimization by simulation research presented in this paper. This method is used to achieve optimization for a wavelet impulse response functions. The optimized always convergent results are compared to that of least square inverse filtering and the reblurring procedure of Kawata and Ichioka. The input data used is a spike train of various separations to give a calibrated measure of resolution. A range of signal-to-noise ratios (SNR's) is used in the optimization procedure. No noise removal is used prior to unfolding

for the reblurring procedure and the least squares inverse filtering methods. To achieve statistically reliable results 50 noisy data sets are generated for each SNR case for the always convergent method and 10 noisy cases for the reblurring procedure and the least squares inverse filtering techniques. For a given SNR case the average mean squared error, the average optimum deconvolution, and the average noise removal iteration numbers are found and tabulated. The tabulated results are plotted versus the average SNR. Once these optimum numbers are found they can be used in an equivalent window in the Fourier transform domain.

8745-69, Session PSTue

Self-adaptive characteristics segmentation optimized algorithm of weld defects based on flooding

Changying Dang, Jianmin Gao, Wang Zhao, Fumin Chen, Xi'an Jiaotong Univ. (China)

In order to improve the accuracy and efficiency of weld defect segmentation in automatic radiographic nondestructive testing and evaluation (NDT&E), an effective weld defect segmentation algorithm based on flooding has been developed, which has self-adaptive characteristics. Contraposing the sparse distribution characteristic of the defects in the radiographic testing films, an idea of point-feature extraction has been proposed to detect the defect-seed points. Only the regions that have defect-seed points are implemented the segmentation so as to reduce the calculation amount of segmentation algorithm. In addition, aiming at the canyon characteristics of the 3D topographic map of defect regions, we have used for reference the idea of the water flooding in nature to submerge the defect-seed points. Because of gravity, water flows to low-lying areas and overflows if it is full. Once the defect-seed points are submerged by water flooding, the threshold values of defects segmentation are determined through the flooded area and ascending velocity of water level. Then, the defect regions are segmented from radiographic films.

The segmentation algorithm is made up of defects point-feature extraction, defect-seed point detection and flooding segmentation. The purpose of defect point-feature extraction is to provide the seed points or domains for the detection of defect seeds. The detection of defect-seed points is to detect the presence of the defects in the radiographic image. If the defects exist, the defect-seed points will be marked and positioned to prepare for the flooding. And the purpose of flooding segmentation is to implement the defect segmentation in the defect regions.

Based on the actual weld defects of the porosity, slag inclusion, lack of penetration, lack of fusion, crack and so on, which often appear in the automatic radiographic NDT&E, the comparative experiments are carried out to compare the proposed algorithm with the watershed and background subtraction segmentation algorithm. And the experiment results confirm that the proposed algorithm obviously improves the accuracy and efficiency of weld defect segmentation.

8745-71, Session PSTue

Intrusion detection on oil pipeline right of way (ROW) using monogenic signal representation

Binu M. Nair, Varun Santhaseelan, Univ. of Dayton (United States); Chen Cui, University of Dayton Vision Lab (United States); Vijayan K. Asari, Univ. of Dayton (United States)

We present an object detection algorithm to automatically detect and identify possible intrusions such as construction vehicles and equipment on the regions designated as the pipeline right-of-way (ROW) from high resolution aerial imagery. The pipeline industry has buried millions of miles of oil pipelines throughout the country and these regions are under constant threat of unauthorized construction activities. The heavy weight of these vehicles and equipment can cause a tremendous strain which may cause cracks and oil leakages and so requires the need for automatic threat detection. The proposed detection algorithm makes use of the monogenic signal representation to extract the local phase information. Computing the monogenic signal from a two dimensional object region enables us to separate out the local phase information (structural details) from the local energy (contrast) thereby achieving illumination invariance. In this paper, we use a pyramidal template based matching technique computed from the local phase information of a single high resolution training image to classify a construction vehicle with each level corresponding to a certain scale. In order to account for different orientations, a pyramidal template matching is applied for every five degree rotation of the search region at a particular scan and the corresponding detections are compared using mutual information to obtain the final detection. A nearest neighbor classifier is used as the matching criterion along with a threshold for minimum distance to filter out the false detections. The algorithm is successfully tested on the aerial imagery containing seven different classes of construction equipment.

8745-72, Session PSTue

Optimising the use of hyperspectral and multispectral data for regional crop classification

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Field surveys of crop species are difficult, time consuming and expensive to execute for large areas. Optical remote sensing has emerged as the most useful data source for quantitatively classifying the land-cover types and even crop species at the landscape scale. Especially hyperspectral imaging data contain a lot of information about the spectral properties of the earth surface, which definitely is useful for distinguishing subtle material differences just as different species of crops. But hyperspectral remotely sensed data usually have narrow spatial coverage because of their limited detector array size. Multispectral data may not realize unique identification of crop endmembers because of coarse spectral resolution, especially for the crop with the similar biochemical features. To fully make use of the virtues from both hyperspectral and multispectral data, this paper proposed a method of multisensor analysis to improve multispectral classification with the modeled multispectral signatures from hyperspectral signatures. Both the hyperspectral and multispectral data were atmospherically corrected and spatially nested. The noise removed hyperspectral data were used to extract the endmembers. The crop types of endmembers were determined according to the in situ survey on the ground. Consequently, the hyperspectral signatures of endmembers were gotten. The multispectral signatures of endmembers were determined through the convolution of the hyperspectral signatures with the multispectral response function. The classification results with the modeled multispectral and real hyperspectral signatures from selected endmembers showed the classification distributions are similar for both multispectral and hyperspectral data in overlap regions. Full-scene mapping using the modeled multispectral signatures allows subsequent mapping of extended areas within the multispectral data. The accuracies assessment from the independent field surveys showed the proposed classification method is promising and classification results have already achieved the desired accuracies.

8745-73, Session PSTue

Close-loop fusion system structure: information fusion and resource management

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Abstract: Information fusion systems developed from JDL model and its revisions have been applied in many areas, such as battlefield awareness, natural and man-made disasters monitor, and robot navigation. The different levels of information, which may be from sensors, human reports, and data from the Internet, can be combined to achieve a better inference about some entities or their relationships that cannot be obtained from a single sensor or source. The structure of fusion system has an important effect on the fusion performance. A close-loop fusion system structure, which includes both information fusion (IF) and resource management (RM) modules, is proposed. The relationship between IF and RM is explained in detail. An example of tracking a maneuvering target is given to validate the system structure presented in this paper.

8745-74, Session PSTue

Breast tumor classification via single-frequency microwave imaging

Cuong M. Do, Rajeev Bansal, Univ. of Connecticut (United States)

We propose a novel method for the classification of breast tumors (malignant versus benign) based on principal component analysis (PCA) following single-frequency microwave imaging. For initial evaluation, a simplified model of the biological tissue was developed in a frequency-domain finite-element framework. The model incorporated various combinations of dielectric constant and conductivity. A double-level classification scheme allows classifying a tumor with high accuracy.

8745-75, Session PSTue

Safety threat object detection by fusion of RGD-D data and hyperspectral imaging

Jangwoo Lee, Soon Kwon, Daegu Gyeongbuk Institute of Science & Technology (Korea, Republic of); Sungho Kim, Yeungnam Univ. (Korea, Republic of)

This paper presents a method for detecting public satety threats by fusion of RGB-D data and hyperspectral image. Object detection performed by the RGB-D data obtained from Kinect. Each spin image contains 3D object center information. 3D hough voting and K-means clustering can produce initial matching pairs of 3D points. Through RANSAC and absolute orientation quaternion, 3D objects are detected with accurate 3D pose information. Hyperspectral image is used for detected object's properties and material analysis. Hyperspectral analysis is used to identify safety threat materials such as guns and knifes, and powder. In this paper, Hyperspectral image acquisition method is introduced using SPECIM hyperspectral camera (VNIR). These techniques include Hyperspectral image acquisition system, hyperspectral imaging calibration, PCA, linear combination of hyperspectral features, etc. The fusion of RGB-D data and hyperspectral image analysis provides more accurate and concrete safety threats detection.

8745-76, Session PSTue

Stabilizing bidirectional associative memory with principles in independent component analysis and null space

Yuriy Luzanov, Air Force Research Lab. (United States); James P. LaRue, Jadco Signals (United States)

Our results show that by managing the principal components, modeled in the way of ventral pathways of neurons, the outer product associations stand a better chance of converging to stable and expected end states. We utilized the PCA approach by taking the SVD, incorporating equalization through the ICA, and then extending the association space out into the nullspace. As the nullspace becomes better understood there would be a good measure applied to the process to counter the unintended and spontaneous inversions of the associations. We have demonstrated the success of PICANS BAM process in two ways. First, we showed how a simple one layer association matrix can be constructed and used to recover numerals from the MNIST dataset. Second, we showed how a cascade of association matrices can be used to model complex multilayer networks. The performance of CNN, BAM and a hybrid of CNN and BAM was evaluated to show the improvement in object recognition performance when utilizing the hybrid CNN/BAM approach.

8745-77, Session PSTue

Option pricing formulas and nonlinear filtering: a Feynman oath integral perspective

Bhashyam Balaji, Defence Research and Development Canada, Ottawa (Canada)

In quantitative finance, it is assumed that various quantities such as the stock prices, the option prices, and the interest rates satisfy the stochastic differential equations (SDEs). Corresponding to these stochastic differential equations are partial differential equations (PDEs). In filtering theory, the relevant PDEs are well-known; they are the Fokker-Planck-Kolmogorov forward equation, or simply the Kolmogorov forward equation. In contrast, the relevant PDE, such as the Black-Scholes PDE, is the Kolmogorov backward equation. This is because the value of the option is known at a future time, and the price of the option now is desired. In contrast, in filtering theory, only the present estimate of the conditional probability density is known.

In some of the statistical physics and quantum field theory literature it is known that there is a Feynman path integral formula corresponding to the stochastic differential equation. The FPI formula has several advantages over other well-known approaches in the applied mathematical literature such as the Feynman-Kac formula. In previous papers, the FPI formulation has been used to arrive at novel nonlinear filtering algorithms.

In this paper, it is shown that the same formula can be used for solving the Kolmogorov backward equation. In addition, it is noted that the general FPI formula can be used to tackle more complicated models, including multiple assets that are correlated as well as volatilites that are state-dependent. Finally, the FPI perspective naturally enables one to incoporate ideas from nonlinear filtering theory. Some numerical examples illustrating the methods are also presented.

8745-78, Session PSTue

Bayesian approach to Cole-Cole model parameter estimation

Sreeraman Rajan, Bhashyam Balaji, Defence Research and Development Canada, Ottawa (Canada); Milodrag Bolic, Univ. of Ottawa (Canada)

The Cole-Cole model has applications in many fields ranging from geoscience to biomedical engineering. In the areas of biomedical engineering, the Cole-Cole model is used extensively for fitting electrical bioimpedance in humans. Electrical bioimpedance has applications in areas such as cancer detection, non-invasive glycemia monitoring, haemocrit monitoring. Generally, the electrical equivalent of the biological cell is considered in such applications and a Nyquist-like plot is used to study the frequency response of the electrical equivalent circuit. The electrical equivalent circuit uses the Cole-Cole impedance model with a modification: the capacitor in the Cole-Cole impedance model is replaced by a constant phase element. The various parameters of the Cole-Cole model have physiological significance and the estimates can be used as surrogates for analyzing the cell characteristics. Hence, the parameter estimation of Cole-Cole model is paramount. In the literature, estimation of parameters of the Cole-Cole model has been viewed as non-linear problem and solutions using non-linear least squares, Levenberg-Marquardt non-linear optimization technique have been proposed. However, there is no research to the best of our knowledge to address the Cole-Cole parameter estimation as a Bayesian estimation problem. In this paper, we will consider the Cole-Cole parameter estimation in the Bayesian framework and provide a solution using the Kalman filter approach and compare the performance of our method with some of the solutions available in the literature. This approach provides the estimates of the parameters, the confidence in the estimates and also has the ability to track the parameters if they should change over time.

8745-79, Session PSTue

Consistent estimates for oscillometric blood pressure signal model using Kalman filters

Bhashyam Balaji, Sreeraman Rajan, Defence Research and Development Canada, Ottawa (Canada); Milodrag Bolic, Univ. of Ottawa (Canada)

Elderly population and chronic patients have resorted to self-monitoring using non-invasive medical devices. One of the most commonly used home-based health monitoring device is the oscillometric blood pressure device. Accurate estimation of blood pressure is necessary if such monitoring practices need to be supported to reduce health-care costs. Modelling of blood pressure signal is important to derive good blood pressure algorithms. Such models can be used to generate surrogate blood pressure waveforms that can be used for testing the algorithms. If such models become standardized, there is a possibility of having golden standard for blood pressure measurements. Currently there are no golden standards for oscillometric blood pressure other than through auscultation. Modelling of blood pressure signals is arduous because of the nonlinear nature and the intrinsic physiological variability. Not only should the model be able to capture non-linearities, it should also be adaptable to capture the physiological variability. In this paper, we present results of the estimation of the parameters using Kalman-based estimation technique. It is found that the EKF and the UKF provide a very good performance. In particular, the filters provide consistent estimates. That is, it not only provides the estimates of the parameters, it also provides reliable bounds for the estimates.

8745-34, Session 7

Object classification using image moment functions applied to video and imagery analysis.

Olegs Mise, GE Intelligent Platforms (United States)

This paper describes classification algorithm and a framework based on Hu's moment invariants and geometric radial image moments. The developed framework has been designed for classification of objects with offline pre-loaded signatures. With some modification this algorithm can be potentially extended to be used in conjunction with the tracker data. This framework has been successfully applied to the target classification and demonstrates its performance on real video and imagery scenes.

In order to overcome the implementation constraints of low powered hardware, the developed framework uses a combination of different image moment functions. This approach significantly simplifies these limitations showing a potential to use object classification algorithms in the low powered devices.

8745-35, Session 7

Multiparametric data fusion for enhanced target identification and discrimination

Vladimir B. Markov, Stephen A. Kupiec, Advanced Systems & Technologies, Inc. (United States); Joseph R. Chavez, Air Force Research Lab. (United States)

An effective fusion of multi-parametric heterogeneous data is essential for better target identification, characterization and discrimination. In this report we discuss a practical example of fusing the data provided by imaging and non-imaging electro-optic sensors. The proposed approach allows to process, integrate and interpret such data streams from the sensors. Practical examples of improved accuracy in discriminating of similar but non-identical objects are presented.

8745-36, Session 7

A neuromorphic system for object detection and classification

Deepak Khosla, Yang Chen, Kyungnam Kim, Shinko Y. Cheng, Alexander L. Honda, Lei Zhang, HRL Labs., LLC (United States)

Unattended object detection, recognition and tracking on unmanned reconnaissance platforms in battlefields and urban spaces are topics of emerging importance. In this paper, we present an unattended object recognition system that automatically detects objects of interest in videos and classifies them into various categories (e.g., person, car, truck, etc.). Our system is inspired by recent findings in visual neuroscience on feed-forward object detection and recognition pipeline and mirrors that via two main neuromorphic modules (1) A front-end detection module that combines form and motion based visual attention to search for and detect "integrated" object percepts as is hypothesized to occur in the human visual pathways; (2) A back-end recognition module that processes only the detected object percepts through a neuromorphic object classification algorithm based on multi-scale convolutional neural networks, which is a simple yet efficient hierarchical model with learning at each layer. Our neuromorphic system was evaluated by DARPA in a systematic evaluation study under the NeoVision2 program using a variety of urban area video data collected from both stationary and moving platforms. The data are quite challenging as it includes targets at long ranges, occurring under variable conditions of illuminations and occlusion with high clutter. The experimental results show that the detection and classification performance of our system is not only exceptional, but in many cases outperforms state of the art computer vision. In addition, the proposed bio-inspired approach is good for hardware implementation due to its low complexity and mapping to off-the-shelf conventional hardware.

8745-37, Session 7

Machine vision tracking of carrier-deck assets for improved launch safety

Brynmor J. Davis, Richard W. Kaszeta, Robert D. Chambers, Bruce R. Pilvelait, Patrick J. Magari, Creare Inc. (United States); Michael Withers, David Rossi, Naval Air Warfare Ctr. Aircraft Div. (United States)

Manual safety protocols are currently used to avoid carrier-deck collisions between aircraft, or between an aircraft and a jet blast deflector (JBD). Implementation of these protocols necessarily places personnel near the launch zone, exposing them to environmental dangers including mechanical hazards and extreme sound fields. Demands on Navy deck personnel can be reduced by augmenting manual safety procedures with information provided by computer-vision assessment of the carrier deck. Specifically, automated aircraft tracking allows improved operational locations for launch control personnel and/or provides a second-look

safety check.

Here an automated, imagery-based aircraft tracking system is described and proof-of-concept scale-model data presented. A single-camera video stream is used to identify and locate aircraft on a three-dimensional model of the carrier deck. Matching of image edge features to a calibrated-camera-frame projection of the three-dimensional deck/aircraft model allows high accuracy tracking, with testing on a 1:72-scale model indicating full-scale accuracy on the order of 1 foot spatially and 1 degree in aircraft orientation angle. Further, the proposed method is insensitive to changes in illumination, robust to partial obscuration and highly parallelizable (with preliminary benchmarking indicating real-time feasibility).

The algorithm presented tracks aircraft with relation to the deck and can therefore be used to automatically evaluate deck safety criteria. For example, fouling of the JBD by aircraft, which has previously lead to costly aircraft-JBD impact, can be automatically detected. Through capabilities such as this, automated asset tracking represents a significant new tool for the assurance of carrier deck safety.

8745-40, Session 8

Qualitative evaluations and comparisons of six night-vision colorization methods

Yufeng Zheng, Alcorn State Univ. (United States); Kristopher Reese, Univ. of Louisville (United States); Erik P. Blasch, Air Force Research Lab. (United States); Paul McManamon, Exciting Technology, LLC (United States)

The current multispectral night vision (NV) colorization techniques can manipulate images to produce the colorized images that closely resemble natural scenes. The colorized NV images can enhance human vision by improving observer object classification and reaction times especially for low light conditions. This paper focuses on the qualitative (subjective) evaluations and comparisons of six NV colorization methods. The multispectral images include visible (Red-Green-Blue), near infrared, and long wave infrared images. The six colorization methods are channel-based color fusion (CBCF), statistic matching (SM), histogram matching (HM), joint-histogram matching (JHM), statistic matching then joint-histogram matching (SM-JHM), lookup table (LUT). Four categries of quality measurements are used for the qualitative evaluations, which are contrast, detail, colorfulness, and overall quality. The score of each measurement is rated from 1 to 3 to represent low, average, and high quality, respectively. Specifically, the high contrast (of rated score 3) means an adequate level of brightness and contrast. The high details represent high clarity of detailed contents while maintaining low artifacts. The high colorfulness preserves more natural colors (i.e., closely resembles the daylight image). Nine sets of multispectral NV images were used in our experiments. For each set, the six colorized images using NIR and LWIR are concurrently presented along with the reference color (RGB) image (taken at daytime). A total 67 subjects passed a screening test (“Ishihara Color Blindness Test”) and were asked to evaluate the 9-set colorized images. The primary analyses showed the quality order of colorization methods from the best to the worst: CBCF, SM, SM-JHM, LUT, JHM, HM. In the full paper we will present the details of experiment design and the results of statistical analyses. Meanwhile we will also compare the qualitative evaluations with the quantitative evaluations using a recently proposed metric, objective evaluation index (OEI). It is anticipated that this work will provide a benchmark for NV colorization and for objective metric.

8745-41, Session 8

Real-time classification of ground from lidar data for helicopter navigation

Ferdinand Eisenkeil, Univ. Konstanz (Germany); Tobias Schafhitzel, Uwe Kühne, EADS Deutschland GmbH (Germany); Oliver Deussen, Univ. Konstanz (Germany)

Helicopter pilots often have to deal with bad weather conditions or other degraded views. These situations may decrease the pilots’ situational awareness significantly; the worst case scenario would be a complete loss of visual reference during an off-field landing due to brownout or snowout, which might lead to hazardous situations. In order to increase the pilots’ situational awareness, helicopters nowadays are equipped with different sensors which are used to gather information about the environment in front of the helicopter. By the use of synthetic vision systems, the sensor data is classified and visualized on the multi functional display or the pilot’s head up display. This makes a reliable classification of the input data into obstacles and ground absolutely mandatory. In this paper, we present a regularization based terrain classifier. Regularization is a popular segmentation method in computer vision and used, e.g., in active contours. For the application with LIDAR data, it is optimized to be real-time capable by using different level of details depending on the accuracy of the sensor. After a preprocessing step, where those points are removed that impossibly can be ground, this method fits a shape under the recorded point cloud. Once this shape is calculated, the points below this shape can be distinguished from elevated objects and are classified as ground. Finally, we demonstrate the quality of our segmentation approach by its application on operational flight recordings. This method builds a part of an entire synthetic vision processing chain, where the classified points are used to support the generation of a real-time synthetic view of the terrain as an assistance tool for the helicopter pilot.

8745-42, Session 8

High-resolution land cover classification using low resolution global data

Mark J. Carlotto, General Dynamics Advanced Information Systems (United States)

A fusion approach is described that combines texture features from high-resolution panchromatic imagery with land cover statistics derived from co-registered low-resolution global databases to obtain high-resolution land cover maps. The method does not require training data or any human intervention. We use an MxN Gabor filter bank consisting of M=16 oriented bandpass filters (0-180°) at N resolutions (3-24 meters/pixel). The size range of these spatial filters is consistent with the typical scale of manmade objects and patterns of cultural activity in imagery. Clustering reduces the complexity of the data by combining pixels that have similar texture into clusters (regions). Texture classification assigns a vector of class likelihoods to each cluster based on its textural properties. Classification is unsupervised and accomplished using a bank of texture anomaly detectors. Class likelihoods are modulated by land cover statistics derived from lower resolution global data over the scene. Preliminary results from a number of Quickbird scenes show our approach is able to classify general land cover features such as roads, built up area, forests, open areas, and bodies of water over a wide range of scenes.

8745-43, Session 8

Fusion of multispectral and stereo information for unsupervised target detection in very high resolution airborne data

Dirk C. Borghys, Mahamadou Idrissa, Michal Shimoni, Royal Belgian Military Academy (Belgium); Ola Friman, Maria Axelsson, Mikael Lundberg, Swedish Defence Research Agency (Sweden); Christiaan Perneel, Royal Belgian Military Academy (Belgium)

Very high resolution multispectral imaging reached a level of reliability and accuracy for target detection and classification.However, in an urban scene, the complexity is raised, making the detection and the identification of small objects difficult.

A sub-pixel detection is required and better clutter separation. One way

to overcome this difficulty is to raise the dimensionality and to combine spectral information with 3D data.

A set of (very high resolution) airborne multispectral image sequences was acquired over the urban area of Zeebrugge, Belgium. The data consist of three bands in the visible (VIS) region, one band in the near infrared (NIR) range and two bands in the mid-wave infrared (MWIR) region. Images are obtained images at a frame rate of 1/2 frame per second for the VIS and NIR image and 2 frames per second for the MWIR bands. The sensors have a sub-decimetric spatial resolution.

The combination of frame rate with flight altitude and speed results in a large overlap between successive images. The current paper proposes a scheme to combine 3D information from along track stereo, exploiting the overlap between images on one hand and spectral information on the other hand for unsupervised detection of targets. For the extraction of 3D information, the disparity map between different image pairs is determined automatically using a MRF-based method. For the unsupervised target detection, an anomaly detection algorithm is applied. Different methods for inserting the obtained 3D information into the target detection scheme are discussed and compared.

8745-44, Session 8

Combining Structured Light and Ladar for Pose Tracking in THz Sensor Management

Philip Engström, Maria Axelsson, Mikael Karlsson, Swedish Defence Research Agency (Sweden)

Stand-off 3D THz imaging to detect concealed treats is currently under development. The technology can provide high resolution 3D range data of a passing subject showing layers of clothes and if there are concealed items. However, because it is a scanning sensor technology with a narrow field of view, the subjects pose and position need to be accurately tracked in real time to focus the system and map the imaged THz data to body parts.

Structured light is a technique to obtain 3D range information. It is, for example, used in the Microsoft Kinect for pose tracking game players in real time. Its main advantage is its simplicity. The disadvantages are its sensitivity to lighting conditions and material properties and a relatively low accuracy. Time of flight laser scanning is a technique that completes structured light well, because the accuracy is usually much higher and it is less sensitive to lighting conditions. We show that by combining the techniques it is possible to create a robust real time pose tracking system for THz sensor management. We present a proof of concept system based on the Microsoft Kinect and a SICK LMS-511 laser scanner. The laser scanner is used for 2D tracking of the subjects, this tracking is then used to initialize and validate the Microsoft Kinect pose tracking. We have evaluated the sensors individually in both static and dynamic scenes and present their advantages and drawbacks. We also present results on the performance of the complete system.

8745-45, Session 8

Application of artificial intelligence methods for feature extraction optimization

Jack E. Fulton Jr., Naval Surface Warfare Ctr. Crane Div. (United States)

The large number of mature signal processing techniques available for feature extraction applications produces complex choices during the design of systems. Designers are sometime quick to try their favorite approach that worked well for the previous design while ignoring other techniques. This work explores the use of artificial intelligence methodologies for the selection and optimization of signal processing tools for feature extraction applications. The multi-objective optimization includes the use of multiple techniques to synthesize hybrid methods to achieve performance that is objectively better than any individual technique. The selection process uses sensor, environment, and target models to dynamically create signals. The use of dynamical models allows the artificial intelligence system to optimize the selection of signal processing methods for the particular tasks. Objectives include, but are not necessarily limited to, effectiveness, efficiency, computational costs, and suitability for the system design.

Because of the large number of tools and combinations of tools available for signal processing, finding the optimal signal processing chain to meet the challenge of a particular feature extraction task is complex and has more combinations than would reasonably be considered by a design team if they were to approach the problem in a manual way. By setting up the problem as a multi-objective optimization problem, one can meet the challenge by using artificial intelligence approaches to test and evaluate combinations of methods to that lead to viable solutions. This approach allows many methods to be tested with objective measures.

8745-46, Session 9

Human activity recognition based on human shape dynamics

Zhiqing Cheng, Infoscitex Corp. (United States); Timothy Webb, Huaining Cheng, Air Force Research Lab. (United States); Stephen Mosher, Infoscitex Corp. (United States)

Human activity recognition based on human shape dynamics was investigated in this paper. The shape dynamics describe the spatial-temporal shape deformation of a human body during its movement and thus provide important information about the identity of a human subject and the motions performed by the subject. The dynamic shapes of four subjects in five activities (digging, jogging, limping, throwing, and walking) were created via 3-D motion replication. The Paquet Shape Descriptor (PSD) was used to describe subject shapes in each frame. The principal component analysis was performed on the calculated PSDs and principal components (PCs) were used to characterize PSDs. The PSD calculation was then reasonably approximated by its significant projections in the eigen-space formed by PCs and represented by the corresponding projection coefficients. As such, the dynamic human shapes for each activity were described by these projection coefficients, which in turn, along with their derivatives were used to form the feature vectors (attribute sets) for activity classification. Data mining technology was employed with six classification methods used. Seven attribute sets were evaluated with high classification accuracy attained for most of them. The results from this investigation illustrate the great potential of human shape dynamics for activity recognition.

8745-47, Session 9

Seismic signature analysis for discrimination of people from animals

Thyagaraju Damarla, U.S. Army Research Lab. (United States); James M. Sabatier, Univ. of Mississippi (United States); Asif Mehmood, U.S. Army Research Lab. (United States)

Cadence analysis has been the main focus for discriminating between the seismic signatures of people and animals. However, the cadence analysis fails when multiple targets are generating the signatures. We analyze the mechanism of human walking and the signature generated by a human walker, and compare it with the signature generated by a quadruped. We develop Fourier-based analysis to differentiate the human signatures from animal signatures. We extract a set of overly determined basis vectors to represent the human and animal signatures using non-negative matrix factorization, and use them to separate and classify both the targets. Grazing animals such as deer, cows, etc., often produce sporadic signals as they move around from patch to patch of grass and characterize them to differentiate their signatures from signatures generated by a horse steadily walking along a path. These differences in the signatures are used in developing a robust algorithm to distinguish the signatures of animals from humans. The algorithm is tested on real data collected in a remote area.

8745-48, Session 9

Anomalous human behavior detection: an adaptive approach

Coen van Leeuwen, TNO Defence, Security and Safety (Netherlands); Arvid Halma, TNO Defence, Security and Safety (Netherlands) and Research Kitchen (Netherlands); Klamer Schutte, TNO Defence, Security and Safety (Netherlands)

In order to analyze data from DARPA's Mind's Eye program we developed a system for detecting anomalous behavior in videos containing a variety of human activities.

In this semi-unsupervised task a set of normal instances is provided for training, after which unknown abnormal behavior has to be detected in a test set. The features extracted from the video data have high dimensionality, are sparse and inhomogeneously distributed in the feature space making it a challenging task. Given these characteristics a distance-based method is preferred, but choosing a threshold to classify instances as (ab)normal is non-trivial.

In this paper we present a new method: the Adaptive Outlier Distance (AOD) to detect outliers in sparse high dimensional data based on local distance ratios. The underlying assumption is that the local maximum distance is a good indicator of the variation in the normal instances in that neighborhood, and therefore a localized threshold will result in more robust outlier detection. We compare our method to existing state-of-art methods such as the Local Outlier Factor (LOF) and the Local Distance-based Outlier Factor (LDOF). The results of the experiments show that the novel approach improves the quality of the anomaly detection.

8745-49, Session 9

Behavioral profiling in CCTV cameras by combining multiple subtle suspicious observations of different surveillance operators

Henri Bouma, Jack Vogels, Olav Aarts, Chris Kruszynski, Remco Wijn, Gertjan Burghouts, TNO Defence, Security and Safety (Netherlands)

CCTV cameras are used for surveillance applications in areas, such as train stations, airports and shopping centers. The complexity of the camera surveillance task and the growing importance of the prevention of incidents may lead to unnecessary bothering of innocent pedestrians. When a surveillance operator recognizes subtle deviant behavior for a person it is insufficient for follow-up actions. However, multiple weak observations (e.g. from different operators) are fused, it can become a strong indication for threatening behavior that does need intervention.

We have conducted an experiment in which we showed to participants videos with and without incidents. The participants were asked to look for suspicious behavior and tag suspicious behavior before an incident occurred. Part of the users were instructed to respond to weak signals and create many tags, and the others were instructed to respond only to the strongest signals and create just few tags.

In this paper, we analyze the effects of the tagging instruction for these operators (many tags for weak signals or few tags for strong signals), the influence of combining multiple tags of different operators, the number of tags that gives a good indication of a person with malicious behavior, and the performance of using a semi-automatic system for combining the different observations.

8745-50, Session 9

Invariant unsupervised segmentation of dismounts in depth images

Richard L. Tutwiler, Nathan S. Butler, Ryan J. Poore, The Pennsylvania State Univ. (United States)

This paper will apply a scene invariant method for the unsupervised segmentation of dismounts in depth images. This method can be broken into two parts: scene identification and spatial segmentation. The former is accomplished by using RANSAC (RANdom SAmple Consensus) to identify a ground plane in the scene. Then by performing a prospective transformation on the point cloud a new image can be created by projecting the rotated scene onto a synthetic focal plane (using depth values as intensity values). The spatial segmentation is accomplished by performing various morphological operations to identify regions in the image, followed by passing each region through a series of filters that collectively define the shape of a person.

8745-51, Session 10

Acoustic recognition of human-object interactions in persistent surveillance systems

Amir Shirkhodaie, Amjad H. Alkilani, Tennessee State Univ. (United States)

Handling, manipulation, and placement of objects, (hereon called Human-Object Interaction (HOI)), in the environment generate sounds. Such sounds are readily identifiable by the human hearing. However, in the presence of background environment noises, recognition of minute HOI sounds is challenging, yet vital for improvement of capability of Persistent Surveillance Systems. Identification of HOI sound waves can help as precursor to detection of pertinent threats that otherwise other sensor modalities may miss to detect. In this paper, we present a robust method for detection and classification of HOI events via clustering of extracted features from training of HOI acoustic sound waves. In this approach, the recorded sound wave is preliminary filtrated for improvement of its signal-to-noise ratio. Then, the sound events are detected and segmented via tracking of filtered signal energy. Upon segmentation of the event, an Independent Component Analysis (ICA) technique is applied for separation and differentiation of two or more sound sources. Next, frequency spectrum of each separated sound sources is determined via a Fast Fourier Transform (FFT) technique. To group closely related frequencies and reduce order of dimensionality of spectral features, a Gaussian Mixture Model (GMM) technique is employed for statistical modeling of frequency spectrum of training sound waves. To expedite fast classification of sound wave features, a KD-tree classifier is also designed for spectral clustering of associated frequencies per each category of sound waves. Furthermore, to facilitate fusion of information from multi-modality sensors, the classification results are semantically annotated and presented in a modified Transducer Mockup Language (TML) format. The presented result demonstrates the proposed solution is both reliable and effective, and can be extended to future PSS applications.

8745-52, Session 10

Time series prediction of nonlinear and nonstationary process modeling for ATR

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

An algorithm is proposed for nonlinear and non-stationary processes concerning ATR. The general approach is to decompose a complex task into multiple domains in space and time based on the predictability of the object modification dynamics. The model is composed of multiple modules, each of which consists of a state prediction model and correctional Hidden Markov system. Prediction error function is used to weight the outputs of multiple hierarchical levels.

8745-53, Session 10

A multiattribute based methodology for vehicle detection and identification

Amir Shirkhodaie, Vinayak Elangovan, Bashir Alsaidi, Tennessee State Univ. (United States)

Robust vehicle detection and identification is required for the intelligent persistent surveillance systems. In this paper, we present a Multi-attribute Vehicle Detection and Identification technique (MVDI) for detection and classification of stationary vehicles. The proposed model uses a supervised Hamming Neural Network (HNN) for taxonomy of shape of the vehicle. Vehicles silhouette features are employed for the training of the HNN from a large array of training vehicle samples in different type, scale, and color variation. Invariant vehicle silhouette attributes are used as features for training of the HNN which based on an internal Hamming Distance determine degree of similarity of the a test vehicle against those its selectively trained with. Upon detection of class of the vehicle, the other vehicle attributes such as: color, tires, and orientation are determined. For vehicle color detection, provincial regions of the vehicle body are used for matching color of the vehicle under three possible conditions, shaded, sunny, and normal condition. For vehicle tires detection, geometrical and hub-patterns are detected and verified to confirm the orientation of the vehicle from the perspective it is observed. For the vehicle orientation detection, the key structural features of the vehicle are extracted and subjected to classification based on color tune, surface texture, geometrical shape, and illumination intensity. The experimental results show the technique is promising and has robustness for detection and identification of vehicles based on their multi-attribute features.

8745-54, Session 10

Advancement and results in hostile fire indication using potassium-line spectral discrimination

Joel B. Montgomery, Marjorie Montgomery, M&M Aviation (United States)

M&M Aviation has been developing and conducting Hostile Fire Indication (HFI) tests using potassium line emission sensors to advance both algorithm and sensor technologies for UAV and other airborne systems for self protection and intelligence purposes. Work began in 2008 as an outgrowth of detecting and classifying false alarm sources for tactical missile warning system using the same K-line spectral discrimination region but soon became a focus of research due to the high interest in both machine-gun fire and sniper geo-location via airborne systems. Several tests were accomplished in 2009 using small and medium caliber weapons. Based on these results, the Air Force Research Laboratory (AFRL) funded the Falcon Sentinel program in 2010 to provide for additional development of both the sensor concept, algorithm suite changes and verification of basic phenomenology including variance based on ammunition type for given weapons platform. Results showed that the system would be able to detect and declare a sniper rifle at upwards of 3km, medium machine gun at 5km, and explosive events like hand-grenades at greater than 5km. This paper will outline the development of the sensor system, algorithms used for detection and classification, and test results from various narrow-band potassium line sensors. It will also cover basic signal to noise ratios and spatial-spectral-temporal features used for extraction purposes with a comparison against larger artillery pieces done for space-based detection and location. Finally, the paper will show the future work for ATD and transition efforts after the Falcon Sentinel program ended.

8745-55, Session 10

A cross-spectral variation of the cross-ambiguity function

Douglas J. Nelson, National Security Agency (United States)

We present a new cross-spectral variation of the Cross-Ambiguity Function (CAF) and demonstrate use of the CS-CAF in obtaining improved Frequency Difference of Arrival (FDOA) estimates. Unlike the conventional CAF process that estimates the FDOA of two signals received by moving receivers, as approximately constant over a short observation time, the CS-CAF models FDOA as a slowly varying continuous function. Under the CS-CAF model, we apply cross-spectral estimation methods to estimate and track the instantaneous FDOA of the received signals. This has two important advantages. The cross-spectral frequency estimation methods are extremely accurate, and by modeling the FDOA as a continuous function of time, we resolve the issue of assigning an event time to the estimated FDOA. In addition, by recovering an FDOA component from the received signals, we may apply LaGrange interpolation to track the instantaneous phase of the FDOA component, enabling an even more accurate estimate of instantaneous FDOA.

8745-58, Session 12

Summary of applications of human, social, cultural, and behavioral modeling to information fusion *(Invited Paper)*

Erik P. Blasch, John J. Salerno Jr., Air Force Research Lab. (United States); Ivan Kadar, Interlink Systems Sciences, Inc. (United States); Shanchieh J. Yang, Rochester Institute of Technology (United States); Mica Endsley , SA Technologies (United States); Laurie H. Fenstermacher, Air Force Research Lab. (United States); Lynne L. Grewe, California State Univ., East Bay (United States)

During the SPIE 2012 conference, the panelists convened to discuss “Real world issues and challenges in Social/Cultural modeling with Applications to Information Fusion.” Each panelist presented their current trends and issues. The panel had agreement on advanced situation modeling, working with users for situation awareness and sense-making, and HCSB context in focusing research activities. Each panelist added different perspectives based on the domain of interest such as physical, cyber, and social attacks from which estimates and projections can be forecasted. Also, additional techniques were addressed such as interest graphs, network modeling, and variable length Markov Models. This paper summarizes the panelists discussions to highlight the common themes and the related contrasting approaches to the domains in which HCSB applies to information fusion applications.

8745-59, Session 12

An approach to behavioral sensor fusion: Past success and future requirements *(Invited Paper)*

Laurie H. Fenstermacher, Air Force Research Lab. (United States); Alex J. Barelka, U.S. Air Force (United States)

No Abstract Available.

8745-60, Session 12

Pattern of life from WAMI objects tracking based on visual context-awareness tracking and infusion network models *(Invited Paper)*

Jianjun Gao, Intelligent Fusion Technology, Inc. (United States); Haibin Ling, Temple Univ. (United States); Erik P. Blasch, Khanh Pham, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

With the advent of advanced optical sensors such as wide area motion imagery (WAMI), computer vision techniques are needed to augment users with salient information to make decisions (e.g., target classifications), processing with large data (e.g. registrations), and perspectives of context (e.g. terrain). Extracting pattern of life (POL) from WAMI data is a key element of high-level behavioral analysis of intelligent video surveillance. Using object tracklets, object track states, and object interactions; event recognition can be accomplished from cues over object activities. This paper integrates the L1 particle filter tracker with scene context-awareness such as roads, buildings, vehicles through data mining. In our context-aware particle filtering (CaP) tracker, we create entity network models to extract activities, patterns of life, and events. The network model structure is composed of nodes, links between nodes, node attributes, link values, and sub-networks. The definition of network structure is based on tracklets, object states, activity events, and the transition probabilities between them. Beside the CaP tracking algorithm, the network model exploitation is another key component of the complete solution. Regarding trackers and the network model, this paper presents a novel algorithmic framework for extracting patterns of life from wide area motion imagery data. The experimental results show the significance of the framework and the efficiency of integrated algorithms.

8745-61, Session 12

Learning and detecting coordinated multi-entity activities from persistent surveillance *(Invited Paper)*

Georgiy M. Levchuk, Matthew Jacobsen, Caitlin Furjanic, Aptima, Inc. (United States); Aaron F. Bobick, Georgia Institute of Technology (United States)

In persistent ground surveillance applications, detecting activities of people and vehicles, such as coordinated reconnaissance, meetings, ambush preparations, and material transportation and loading, is of highest importance. Yet, manual exploitation of wide area motion imagery (WAMI) is impossible due to sheer volume of the data. The automated algorithms are needed to analyze and summarize persistent surveillance inputs, bringing only most critical data to the analysts' attention.

Most existing methods for image- and video-based activity recognition rely on rich visual features and spatiotemporal shape motions to classify entities and their actions. Well-researched examples include distinguishing car types, people hand gestures and poses, and identifying interactive behavior such as present during multi-player games. However, WAMI sensors are lacking these data, providing only the ability to track vehicles and people, obtain general motion and temporal activity events, but challenging traditional methods with large amounts of irrelevant and ambiguous data.

In this paper, we present our enhanced model of multi-entity activity recognition, which operates on person and vehicle tracks, converts them into motion and interaction events, and represents activities in the form of role networks encoding spatial, temporal, contextual, and semantic characteristics of coordinated activities. Our model is flexible enough to capture variations of behaviors, and is used for both learning of repetitive activity patterns in semi-supervised manner, and detection of activities in data with large ambiguity and high ratio of irrelevant to relevant tracks and events. We demonstrate our models using activities captured in CLIF persistent wide area motion data collections.

8745-62, Session 13

Consumer-oriented social data fusion: controlled learning in social environments, social advertising and more *(Invited Paper)*

Lynne L. Grewe, California State Univ., East Bay (United States)

No Abstract Available.

8745-63, Session 13

Examining social dynamics and malware secrets to mitigate net-centric attacks *(Invited Paper)*

Ziming Zhao, Univ. of Information Engineering (China); Gail J. Ahn, The Univ. of North Carolina at Charlotte (United States)

No Abstract Available.

8745-64, Session 13

Influence versus intent: a comparative study for information fusion *(Invited Paper)*

Biru Cui, Rochester Institite of Technology (United States); Shanchieh Jay Yang, Rochester Institute of Technology (United States); Ivan Kadar, Interlink Systems Sciences, Inc. (United States)

No Abstract Available.

8745-65, Session 13

Cyber insider mission detection for situation awareness *(Invited Paper)*

Haitao Du, Neil Wong, Hon Chan, Shanchieh Jay Yang, Rochester Institute of Technology (United States); Changzhou Wang, Jai Choi, The Boeing Co. (United States); Tao Zhang, Peng Liu, The Pennsylvania State Univ. (United States)

No Abstract Available.

8746-1, Session 1

Frequency-dependent reflectivity image reconstruction

Paul Sotirelis, U.S. Air Force Research Lab. (United States); Margaret Cheney, Colorado State Univ. (United States); Jason Parker, Xueyu Hu, Air Force Research Lab. (United States); Matthew A. Ferrara, Matrix Research Inc. (United States)

We evaluate a recently reported algorithm for computing frequency-dependent radar imagery in scenarios relevant for performing spectral feature identification. For each image pixel in the spatial domain a computed frequency-dependent reflectivity is used to produce a corresponding spectral feature identification. We show that this novel image reconstruction technique is capable of considerable flexibility for achieving fine spectral resolution in comparison with previous techniques based on conventional synthetic aperture radar (SAR), yet new challenges are introduced with regard to achieving fine range resolution.

8746-2, Session 1

Iteratively compensating for multiple scattering in SAR imaging

Alejandro F. Martinez, Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

The Born approximation is a common approximation taken in modeling the physics of SAR imaging. In essence it says that radiation only scatters once when in space. This is a reasonable assumption for targets that lie far apart or that are far from the transmit and receive antennas, but it introduces error into the imaging process. The goal of this paper is to iteratively compensate for this error in the model by using estimates of the target distribution to estimate multiple scattering phenomena. We will use a wavelet based noise reduction technique at each iteration on the corrected data as well as the estimated image to control any excess error introduced by the estimated multiple scattering phenomena. The physical model for our work will be based on the wave equation. We will briefly derive the important features of the model as well as account for the error introduced by common approximations that are made. Typically one does not get an image that is approximately the target distribution, but rather an image that is approximately proportional to the target distribution. This means that there is a scaling parameter that must be chosen when using target distribution estimates to correct data. We will discuss methods for choosing this parameter. We will provide a few basic SAR imaging methods and perform simulation using the Gotcha Data set in combination with the iterative technique. At the end of the paper we will discuss future work involving this method.

8746-3, Session 1

Notched spectrum: from probing waveforms to receive filters

Yi Jiang, Christopher D. Gianelli, Integrated Adaptive Applications, Inc. (United States)

Increasing demand for spectrum motivates the development of both a probing waveform and receive filter design algorithm capable of efficiently producing sequences with desirable properties and prescribed spectral notch depth and width. Specifically, waveforms with peak-to-average ratio (PAR) near unity, strong autocorrelation performance, and strict adherence to spectral restrictions are designed. This waveform design algorithm can easily handle sequence lengths on the order of 100,000. Moreover, the proposed approach can achieve design flexibility by trading off PAR performance for reduced ripples in the pass bands. Similarly, receive filters with minimum phase and strict notching performance are also considered. Both the probing waveform design algorithm, and receive filter design algorithm leverage repeated use of fast Fourier transform routines, making them very computationally efficient.

8746-4, Session 1

Point source localization from de-ramped phase history bound on interferometric synthetic aperture radar (IFSAR) accuracy

Matthew P. Pepin, Majeed Hayat, The Univ. of New Mexico (United States)

The almost unique ability of azimuth deramping to preserve a smooth phase function in azimuth is exploited here to link two disparate spatial processing methods, Direction of Arrival (DOA) localization and Interferometric Synthetic Aperture Radar (IFSAR) and explore the achievable accuracy inherent in their common measurement scenario.

Deramping in range quickly provides a first component for point source localization. Deramping in azimuth is phase preserving and provides an approximate localization in azimuth that is more accurate over narrower apertures and can be corrected in scenarios involving range migration and for its point source, azimuth location dependence. In cross-track IFSAR two antenna measurements azimuth/elevation DOAs can be calculated from their smooth azimuth functions at each range with a 1 D parametric estimate (exponential model) of point sources. Joint frequency estimates (both antennas) provide the azimuth DOA while the phase difference between antenna amplitude estimates provides the elevation DOA.

The cross-track antenna measurements can also be processed via the IFSAR methodology producing two SAR images and the phase difference between the two (an interferogram). This provides two images coordinates and a height for each pixel. The connection between DOA phase history localization and IFSAR is used to attain accuracy bounds for IFSAR.

Extrapolation of the bounds is provided from two spatially un-aliased antennas to IFSAR scenarios with large baseline separations of the antennas. In addition imaging from the azimuth-elevation-range localization data and its ability to minimize layover (building tops imaged closer than their bases) is explored.

8746-5, Session 1

SAR focusing using multiple trihedrals

Kerry E. Dungan, John W. Nehrbass, Dynamics Research Corp. (United States)

A circular synthetic aperture radar data collection contains various vehicles and calibration targets placed throughout a 5 km scene. The large scene contains 14 quad-trihedral (QT) calibration targets that look similar to a point target when measured from an airborne sensor. Observations show the peak scattering, from the QTs, drifts on the order of 2 m over wide apertures and multiple orbits. This paper presents an algorithm that uses QTs to adaptively calibrate the sensor GPS location and correct phase errors in the range profile. Qualitative and quantitative results show the focusing provides a significant improvement to vehicle target discrimination.

The algorithm uses a three step process. First, the location of the calibration targets is refined based on multiple orbits of the sensor. Next, the sensor location is determined by the position that minimizes the error to the measured range to each calibration target. Finally, the cross-range error is reduces by making small phase corrections to the

range profile. Both the sensor locations and phase error corrections are applied globally to any new images that are generated throughout the large scene.

8746-6, Session 1

An algorithm for upsampling spotlight SAR imagery: a Radarsat-2 SLC perspective

Khalid El-Darymli, C-CORE (Canada) and Memorial Univ. of Newfoundland (Canada); Peter McGuire, Desmond Power, C-CORE (Canada); Cecilia R. Moloney, Memorial Univ. of Newfoundland (Canada)

This paper presents a novel algorithm for upsmapling level-1 processed Spotlight SAR imagery. A Spotlight Radarsat-2 single look complex (SLC) image is used to demonstrate our discussion. To achieve a finer resolution in the azimuth direction, the Spotlight imaging mode enables for a controllable steering of the radar antenna towards the same ground position. In effect, this creates a time-varying Doppler centroid system, wherein the Doppler centroid varies almost linearly with the platform velocity. Although the processed Spotlight Radarsat-2 SLC image is delivered referenced to zero-Doppler, linear variations in the Doppler frequency are still present along the range direction around the zero-Doppler line. The contribution of this paper is that it pinpoints this effect on SAR image upsampling, and proposes a simple algorithm to counter it.

8746-7, Session 1

An autofocus technique for video SAR

Robert Linnehan, John Miller, Edward Bishop, Volker Horndt, Thomas E. Medl, General Atomics Aeronautical Systems, Inc. (United States)

Abstract Title: An Autofocus Technique for Video SAR

Real-time, onboard processing of Synthetic Aperture Radar (SAR) images using the backprojection algorithm is becoming feasible with advent of graphics processing units. Operating in video SAR mode means a sequence of spotlight image frames is created from arbitrary synthetic aperture positions. The aircraft flight path is typically circular with the radar pointing inward and broadside to offer constant staring over a region of interest. The individual image frames can be drawn from a fixed orthogonal (x and y) grid at a desired ground reference level given the flexibility of backprojection. Since the x and y image dimensions do not necessarily correspond to cross-range and range dimensions from the radar's point of view, standard autofocus techniques that correct for azimuth blurring are not effective.

We are developing a real-time, constant-stare, Cardinal Direction Up (CDU) video SAR mode for the Lynx® Multi-mode Radar System built by General Atomics Aeronautical Systems, Inc. The CDU feature means that the tops of all frames are oriented along a chosen direction. This provides human observers with a natural geometric reference when monitoring and analyzing moving target signatures and also lends itself to coherent change detection over multiple passes. In addition, we are developing an autofocus technique that measures the phase gradient from pseudo point-scatterers within each frame, regardless of the image orientation. Therfore, blurring in the true azimuth dimension of each image, due to slowly varying phase errors during the data collection, will be mitigated before being compiled into the CDU SAR video. Ultimately, this produces SAR videos that retain their sharpness despite severe atmospheric effects during propagation and errors in the antenna's motion estimates.

8746-8, Session 1

An application of backprojection for video SAR image formation exploiting a subaperature circular shift register

John Miller, Edward Bishop, General Atomics Aeronautical Systems, Inc. (United States); Armin W. Doerry, Sandia National Labs. (United States)

This paper details a Video SAR (Synthetic Aperture Radar) mode that provides a persistent view of a scene centered at the Motion Compensation Point (MCP). The radar platform follows a circular flight path. An objective is to form a sequence of SAR images while observing dynamic scene changes at a selectable video frame rate. A formulation of backprojection meets this objective. Modified backprojection equations take into account changes in the grazing angle or squint angle that result from non-ideal flight paths.

The algorithm forms a new video frame relying upon much of the signal processing performed in prior frames. The method described applies an appropriate azimuth window to each video frame for window side lobe rejection.

A Cardinal Direction Up (CDU) coordinate frame forms images with the top of the image oriented along a given cardinal direction for all video frames. Using this coordinate frame helps characterize a moving target's target response.

Generation of synthetic targets with linear motion including both constant velocity and constant acceleration is described. The synthetic target video imagery demonstrates dynamic SAR imagery with expected moving target responses. The paper presents 2011 flight data collected by General Atomics Aeronautical Systems, Inc. implementing the video SAR mode. The flight data demonstrates good video quality showing moving vehicles.

The flight imagery demonstrates the real-time capability of the video SAR mode. The video SAR mode uses a circular shift register of subapertures. The radar employs a Graphics Processing Unit (GPU) in order to implement this algorithm.

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8746-9, Session 1

SAR digital spotlight implementation in MATLAB

Kerry E. Dungan, High Performance Technologies, Inc. (United States); Linda J. Moore, LeRoy Gorham, Air Force Research Lab. (United States)

No Abstract Available.

8746-10, Session 2

Imaging of moving targets using bi-static synthetic aperture radar

Kaan Duman, Rensselaer Polytechnic Institute (United States) and Bilkent Univ. (Turkey); Birsen Yazici, Rensselaer Polytechnic Institute (United States)

A bi-static synthetic aperture radar (Bi-SAR) system consists of a moving transmitter and a receiver that are sufficiently far apart. Such a system has a number of advantages over a mono-static synthetic aperture radar (Mono-SAR) system where the transmitter and receiver are collocated. In a bistatic configuration, the transmitter with its heavy power supply can be deployed on a separate platform than the inexpensive and expendable receivers providing robustness and scalability [1]. Electronic

countermeasures that are designed to thwart mono-static configurations are less effective against bi-static configurations [2,3].

In this paper, we present a method to reconstruct the 2-D reflectivity and velocity of multiple moving targets using a Bi-SAR system. Under the start-stop approximation for targets and antennas, we develop a novel forward model in the form of a Fourier Integral Operator that maps the velocity and reflectivity of the targets to scattered field data. We develop a filtered-backprojection type method combined with entropy measure to reconstruct the reflectivity of the scene and to determine the 2-D velocity of targets. Microlocal analysis of the image fidelity operator shows that the reflectivity images reconstruct the visible edges of the scene at the correct location and orientation whenever the velocity of the scene is determined correctly. We determine the filter such that the visible edges of the scene reflectivity are reconstructed not only at the correct location and orientation, but also at the correct strength. We verify our results with numerical simulations on moving targets.

[1] C. E. Yarman, B. Yazıcı, and M. Cheney. Bistatic synthetic aperture radar imaging for arbitrary flight trajectories. Image Processing, IEEE Transactions on, 17(1):84–93, Jan. 2008.

[2] W.W. Goj. Synthetic-aperture radar and electronic warfare. Artech House, 1993.

[3] N.J. Willis. Bistatic radar. SciTech Publishing, 2005.

8746-11, Session 2

Augmenting synthetic aperture radar with space time adaptive processing

Michael R. Riedl, Lee C. Potter, Emre Ertin, The Ohio State Univ. (United States)

Wide-area persistent radar video offers the ability to track moving targets. A shortcoming of the current technology is an inability to maintain track when Doppler shift places moving target returns co-located with strong clutter. Further, the high down-link data rate required for wide-area imaging presents a stringent system bottleneck. We present a multi-channel approach to augment the synthetic aperture radar (SAR) modality with space time adaptive processing (STAP) while constraining the down-link data rate to that of a single antenna SAR system. To this end, we adopt a multiple transmit, single receive (MISO) architecture. A frequency division design for orthogonal transmit waveforms is presented; the approach maintains coherence on clutter, achieves the maximal unaliased band of radial velocities, retains full resolution SAR images, and requires no increase in receiver data rate vis-a-vis the wide-area SAR modality. For N_T transmit antennas and N samples per pulse, the enhanced sensing provides a STAP capability with N_T times larger range bins than the SAR mode, but requires $O(log N)$ more computation per pulse.

The proposed MISO system and the associated signal processing are detailed, and the approach is experimentally demonstrated for an airborne X-band system via retrospective processing of the Air Force Research Laboratory's 2006 GOTCHA GMTI Dataset.

8746-12, Session 2

Phase wrapping ambiguity in along-track interferometry

Ross W. Deming, U.S. Air Force (United States); Roman Ilin, Air Force Research Lab. (United States); Matthew Best, US Air Force (United States)

This paper discusses GMTI target detection and geo-location from a three-channel airborne radar system. We have previously shown that a signal processing technique known as along-track interferometry (ATI) can be used to combine multi-channel data in order to suppress the clutter response, thereby allowing reliable detection of moving target signatures. Furthermore the ATI phase values can, in principle, be used to estimate both target azimuth and radial velocity, which serve as inputs to geo-location.

There are several open problems that need to be addressed. First, ATI phase can be sensitive to noise and residual clutter, resulting in random geo-location errors. Second, since ATI phase values are wrapped, i.e., they repeat in the interval [-pi, pi], the mapping from ATI phase to target azimuth is non-unique, and each detected target will map to several, equally likely, azimuth values, depending on radar system parameters. Finally, the target will drop off the GMTI map when its radial velocity dips below the minimum detectable velocity (MDV).

In this paper we discuss how a tracker can be applied during azimuth geo-location to smooth out random ATI errors due to noise and residual clutter. Furthermore, we discuss how the phase wrapping ambiguity can be resolved by combining ATI phase maps from three channels, splitting the radar bandwidth into high and low sub-bands, and appropriately combining the ATI phase values from each band. Finally, we demonstrate how SAR and GMTI maps can be combined to provide continuous tracking of move-stop-move targets as they alternate above and below the MDV. Sample results will be presented from X-band Gotcha Challenge data.

8746-13, Session 2

Using posterior distributions on target states and clutter statistics for performance prediction and efficient resource management

Gregory E. Newstadt, Univ. of Michigan (United States); Edmund Zelnio, Air Force Research Lab. (United States); Alfred O. Hero III, Univ. of Michigan (United States)

No Abstract Available.

8746-14, Session 2

Multiple-object shape and motion reconstruction with missing radar data

Gregory Arnold, Matthew A. Ferrara, Matrix Research Inc. (United States); Jason Parker, Air Force Research Lab. (United States)

Shape- and motion-reconstruction is inherently ill-conditioned such that estimates rapidly degrade in the presence of noise, outliers, and missing data.

For moving-target radar imaging applications, methods which infer the underlying geometric invariance within back-scattered data are the only known way to recover completely arbitrary target motion.

We previously demonstrated algorithms that recover the target motion and shape, even with very high data drop-out (e.g., greater than 75%), which can happen due to self-shadowing, scintillation, and destructive-interference effects.

We did this by combining our previous results, that a set of rigid scattering centers forms an elliptical manifold, with new methods to estimate a low rank subspace via convex optimization routines.

This result is especially significant because it will enable us to utilize more data, ultimately improving the stability of the motion-reconstruction process.

Since then, we developed a feature-based shape- and motion-estimation scheme based on newly developed object-image relations (OIRs) for moving targets collected in bistatic measurement geometries.

In addition to generalizing the previous OIR-based radar imaging techniques from monostatic to bistatic geometries, our formulation allows us to image multiple closely-spaced moving targets, each of which is allowed to exhibit missing data due to target self-shadowing as well as extreme outliers (scattering centers that are inconsistent with the assumed physical or geometric models).

The new method is based on exploiting the underlying structure of

the model equations, that is, far-field radar data matrices can be decomposed into multiple low-rank subspaces while simultaneously locating sparse outliers.

8746-15, Session 2

SAR based classification of ground moving targets to assist tracker performance

George S. Goley, Etegent Technologies, Ltd. (United States); Brian D. Rigling, Wright State Univ. (United States); Adam R. Nolan, Etegent Technologies, Ltd. (United States)

Tracking and SAR based identification of targets have been topics of interest but the combined process of feature aided tracking is a more recent area of research. The combination of these two types of exploitation can provide separability where either method alone would fail. The aperture synthesized through the combination of target and platform motion facilitates the application of two-dimensional target recognition algorithms. Many non-parametric inverse synthetic aperture radar imaging techniques maximize image sharpness by estimating the phase error imposed by the unknown target motion. The resultant images can suffer from small unresolved phase errors and ambiguous cross range resolution. Downstream image exploitation algorithms must be robust to these effects and their impact on the realized target separability to enable fusion with other algorithms or modalities. A set of civilian vehicles is investigated, which exacerbates image quality based ISAR algorithms due to their comparatively small radar cross section. This paper addresses the feasibility of a peak based classifier to provide separability of civilian targets moving through challenging tracking scenarios using ISAR images. Classifier performance is evaluated over a set of sensor, target, and environmental operating conditions through use of synthetically generated and measured radar data.

8746-33, Session 2

Target Migration Path Morphology of Moving Targets in Spotlight SAR

David A Garren, James W. Scrofani, Murali Tummala, John C. McEachen II, Naval Postgraduate School (United States)

It is well known that moving targets cause smeared signatures when imaged using SAR. The majority of the smearing lies in the radar cross-range direction of the SAR imagery, regardless of the particular SAR imaging mode used. However, Jao [1] has revealed that the moving target signature can have a curved "bowing" signature in the along or down range direction, as was shown specifically with examples of stripmap-mode SAR imagery. Such curvature effects within the moving target signatures are termed "range migration" effects. These range migration effects are presumed to be important when characterizing the moving targets based upon the measured curved smear signatures. The current paper provides an extension of this prior work by examining range migration effects for spotlight-mode SAR. In addition, the current paper examines issues related to non-uniform target motion on the morphology of the resulting SAR image smear induced by the target motion. In particular, the current paper analyzes the SAR smear signature for a constant-heading target that moves with an approximately uniform value, then increases to a higher speed before decreasing back to the original speed. The resulting signature smear seems to have three separate spatial regions of enhanced intensity. Furthermore, the overall morphology of the SAR smear seems to have a more complicated, non-parabolic shape than the approximately parabolic signatures resulting from the examples of uniform velocity targets. The results of this paper provide a strong impetus for future detailed studies of SAR smear phenomenology resulting from non-uniform target motion.

8746-16, Session 3

Change detection experiments using Gotcha public release SAR data *(Invited Paper)*

Ivana Stojanovic, Les Novak, Scientific Systems Co., Inc. (United States)

No Abstract Available.

8746-17, Session 3

Joint imaging and change detection for robust exploitation in interrupted SAR environments

Joshua N. Ash, The Ohio State Univ. (United States)

Modern radar systems equipped with agile-beam technology support multiple modes of operation, including, for example, tracking, automated target recognition (ATR), and synthetic aperture (SAR) imaging. In a multi-mode operating environment, the services compete for radar resources and leave gaps in the coherent collection aperture used for SAR imaging. Such gapped collections, referred to as interrupted SAR, typically suffer significant image distortion and can substantially degrade subsequent exploitation tasks, such as change detection. In this work we develop a novel form of surveillance that jointly performs imaging and noncoherent change detection in interrupted environments. We adopt a Bayesian approach that compensates for missing data via exploitation of 1) an incoherent scene prior based on a reference image and 2) the a priori notion that changes between reference and mission passes are sparse and spatially clustered. We employ generalized approximate message passing (GAMP) for computationally efficient inference on large-scale problems and demonstrate performance on measured and synthetic SAR data. The results demonstrate near optimal (ungapped) performance with pulse loss rates up to 70% and highlight orders of magnitude improvement in change-classification rates compared to traditional methods.

8746-18, Session 3

Spatially variant incoherence trimming for improved SAR CCD

Daniel B. Andre, David Blacknell, Defence Science and Technology Lab. (United Kingdom); Keith Morrison, Cranfield Univ. (United Kingdom)

Conventional Synthetic Aperture Radar (SAR) Coherent Change Detection (CCD) has been found to be of great utility in detecting changes that occur on the ground. Detectable changes of interest include vehicle tracks and water flow. The CCD procedure involves performing repeat pass radar collections to form a coherence product, where ground disturbances can induce detectable incoherence. However there is usually a difference in the radar collection geometry which can lead to incoherent energy noise entering the CCD, which reduces the detectability of tracks. When sensing flat terrain in a far-field regime, the incoherence due to collection geometry difference can be removed through a conventional global Fourier image support trimming process. However, it has been found that when the terrain is either in a near-field regime or contains non-flat topography, the optimal trimming process is substantially more involved, so much so that a new per-pixel SAR back-projection imaging algorithm has been developed. Here, the term "near-field" is taken to mean the radar imaging scenario where the radar geometry changes substantially across the scene. The new algorithm trims off incoherent energy from the SAR CCD collection pair on a per-pixel basis according to the local radar geometry and topography leaving a higher coherence CCD product. In order to validate the approach, change detection measurements were conducted with GB-SAR, a ground-based indoor radar measurement facility.

8746-19, Session 3

Reconstruction of interrupted SAR imagery for persistent surveillance change detection

Ivana Stojanovic, Scientific Systems Co., Inc. (United States); William C. Karl, Boston Univ. (United States); Les Novak, Scientific Systems Co., Inc. (United States)

No Abstract Available.

8746-20, Session 3

SAR ATR challenge problem

Adam R. Nolan, Etegent Technologies, Ltd. (United States); Lee C. Potter, The Ohio State Univ. (United States); Dan Kubacki, Michael Bakich, Air Force Research Lab. (United States)

No Abstract Available.

8746-21, Session 3

Focusing and ATR for the Gotcha 2008 wide angle SAR collection

Luzhou Xu, Christopher D. Gianelli, Integrated Adaptive Applications, Inc. (United States)

The wide angle circular spotlight synthetic aperture radar (SAR) problem is considered, and a simple approach to focusing collected phase history data is devised. The focusing technique relies on a single point scatterer in the scene of interest, and calculates the change in range to the scatterer for each coherent subaperture. A polynomial regression is then performed on the range variations, and a suitable phase correction is applied to the phase history data, which allows for the generation of well-registered 360° SAR images. Two SAR imaging algorithms which utilize the newly-focused phase history data are then compared, namely, the data-independent backprojection algorithm, and the data-adaptive sparse learning via iterative minimization (SLIM) algorithm. Additionally, both supervised and unsupervised automatic target recognition (ATR) approaches are implemented to facilitate the imaging algorithm comparison. Empirical results obtained by applying the novel focusing approach and imaging algorithms to the 2008 Gotcha wide angle SAR data set are presented and described. The experiments with this field collected data validate the utility of the proposed focusing algorithm, as well as highlight the benefits of applying data-adaptive imaging techniques in favor of their data-independent counterparts via the ATR investigation.

8746-22, Session 4

Adaptive sensing and estimation of sparse signals

Dennis Wei, Alfred O. Hero III, Univ. of Michigan (United States)

No Abstract Available.

8746-23, Session 4

Value-of-information aware active task assignment

Beipeng Mu, Girish Chowdhary, Jonathan P. How, Massachusetts Institute of Technology (United States)

No Abstract Available.

8746-24, Session 4

Change-point detection for high-dimensional time series with missing date

Rebecca M. Willett, Yao Xie, Jiaji Huang, Duke Univ. (United States)

No Abstract Available.

8746-25, Session 4

Low-rank covariance estimation with missing data

Laura Bolzano, Univ. of Michigan (United States)

No Abstract Available.

8746-26, Session 4

Information theoretic bounds on localization and telemetry via differential radar cross-section signaling

Itay Cnaan-On, Jeffrey Krolik, Matthew Reynolds, Duke Univ. (United States)

No Abstract Available.

8746-27, Session 4

Geometic image formation for target identification in multi-energy computed tomography

Brian H. Tracey, Eric L. Miller, Tufts Univ. (United States)

No Abstract Available.

8746-28, Session 4

Spatiotemporal Gaussian feature detection in sparsely sample data with application to InSAR

Scott T. Acton, Univ. of Virginia (United States)

No Abstract Available.

8746-29, Session 4

Detection in networked radar

Kaitlyn Beaudet, Lauren Crider, Douglas Cochran, Arizona State Univ. (United States)

No Abstract Available.

8746-30, Session 4

The importance of informative subspaces in matched subspace detectors

Nick Asendorf, Raj Nadakuditi, Univ. of Michigan (United States)

No Abstract Available.

8746-31, Session 4

The geometry of radar targets

Emre Ertin, The Ohio State Univ. (United States)

No Abstract Available.

8746-32, Session 4

Information-theoretic assessment of system parameter uncertainty on inverse reconstruction problems

Joel W. LeBlanc, Michigan Tech Research Institute (United States); Brian J. Thelen, Michican Tech Research Institute (United States)

No Abstract Available.

8747-1, Session 1

The full multi-state vector error covariance matrix: why needed and its practical representation

John Dolloff, Integrity Applications, Inc. (United States)

Whether statistically representing the errors in the estimates of sensor metadata associated with a set of images, or statistically representing the errors in the estimates of 3D location associated with a set of ground points, the corresponding "full" multi-state vector error covariance matrix is critical to exploitation of the data. For sensor metadata, the individual state vectors typically correspond to sensor position and attitude of an image. These state vectors, along with their corresponding full error covariance matrix, are required for optimal down-stream exploitation of the image(s), such as for the stereo extraction of a 3D target location and its corresponding predicted accuracy . In this example, the full error covariance matrix statistically represents the sensor errors for each of the two images as well as the correlation (similarity) of errors between the two images.

For ground locations, the individual state vectors typically correspond to 3D location. The corresponding full error covariance matrix statistically represents the location errors in each of the ground points as well as the correlation (similarity) of errors between any pair of the ground points. It is required in order to compute reliable estimates of relative accuracy between arbitrary ground point pairs, and for the proper weighting of the ground points when used as control, in for example, a fusion process.

This paper details the above, and presents practical methods for the representation of the full error covariance matrix, ranging from direct representation with large bandwidth requirements, to high-fidelity approximation methods with small bandwidth requirements.

8747-2, Session 1

Evaluating conflation methods using uncertainty modeling

Peter Doucette, National Geospatial-Intelligence Agency (United States) and Integrity Applications, Inc. (United States); John Dolloff, Robert Canavosio-Zuzelski, Michael J. Lenihan, Dennis J. Motsko, National Geospatial-Intelligence Agency (United States)

The problem of geospatial data conflation dates back to the early 1980s. The basic goal of conflation, which is a form of fusion, is to integrate data sets such that the outcome is an improved version of the inputs. The classic problem of geospatial feature conflation involved the matching of individual GIS features (e.g., point, line, or polygon vectors) of two or more data layers, such that attribute information from one layer could be transferred to the other. By the 2000s, the domain of geospatial data conflation had broadened considerably to include cross-vector matching, as well as feature-to-image alignment. There are several geospatial data conflation tools in the marketplace with varying automation capabilities. In order to evaluate feature matching performance quantitatively, truth needs to be established between layers. Feature match truthing is typically a manual, and thus expensive task. In this paper, we propose a novel method by which uncertainty models are used to simulate new feature data from existing feature data. To simulate new feature geometry, vector coordinates are perturbed with a strictly positive definite correlation function based upon distances between points in order to account for spatial autocorrelation. Additionally, new feature topology is simulated to allow for one-to-one, none-to-one, and many-to-one matching scenarios. Because simulated features are derived from a reference set, manual truthing is not required. This approach allows for the generation of virtually unlimited simulated data that enables better statistical significance of performance, as well as sensitivity analyses of operating parameters.

8747-3, Session 1

A standards framework for geo-registration methods

Peter Doucette, Jim Antonisse, Aaron Braun, Michael J. Lenihan, Michelle Brennan, National Geospatial-Intelligence Agency (United States)

Automating the registration of motion imagery has been the subject of considerable literature and application in fields of photogrammetry, remote sensing, and computer vision. The term 'registration' has become widespread in remote sensing and computer vision literature, where much of the focus has been with respect to the matching component. On the other hand, traditional photogrammetry uses terms such as orientation, resection, and rectification, which represent different components of registration. Geo-registration of image data is foundational to geopositioning, and fusion-based detection applications. The proliferation of micro-UAVs and video sensors of all types, has significantly raised the challenge bar for rigorous geo-registration. Registration includes temporal as well as spatial positioning, and includes positioning in 3D as well as the 2D problem. Among the many registration methods applied in practice, there are different levels of capability in terms of positional accuracy, error prediction, and latency. In this paper, we propose the derivation of taxonomies for registration concepts, methods, and application to facilitate the development of basic standards for their efficient use, as well as management of user expectations in different mission contexts. For example, targeting applications represent one end of the application spectrum, for which reliable sensor metadata is typically required in order to propagate error for positional accuracy estimation. At the other end of the spectrum is the 'situational awareness' application, in which reliable sensor metadata is unavailable. In this scenario, accuracy estimation may be sacrificed for time-critical situations. The paper concludes with some implications of the taxonomy for future work.

8747-4, Session 1

Uncertainty quantification techniques for population density estimates derived from sparse open source data

Robert N. Stewart, Devin A. White, Marie L. Urban, Oak Ridge National Lab. (United States); April M. Morton, Oak Ridge National Lab. (United States) and California State Polytechnic Univ. (United States); Eddie A. Bright, Budhendra L. Bhaduri, Oak Ridge National Lab. (United States)

The Population Density Tables (PDT) project at Oak Ridge National Laboratory is developing population density estimates for specific human activities under normal patterns of life based largely on information available in the open source domain. Currently, activity-based density estimates are derived from simple summary data statistics such as range and mean. Researchers have improved activity estimation and uncertainty quantification by adopting a Bayesian framework that considers both data and sociocultural knowledge. Under a Bayesian approach, knowledge about population density may be encoded through the process of expert elicitation. Due to the scale of the PDT effort, which considers over 250 countries, spans 40 human activity categories, and includes numerous contributors, an elicitation tool is required that can be operationalized within an enterprise data collection and reporting system. This tool anticipates that the contributor has minimal statistical knowledge, involves minimal input by a statistician or facilitator, considers human difficulties in expressing qualitative knowledge in a quantitative setting, and provides methods by which the contributor can appraise whether their understanding and associated uncertainty is well captured. This paper discusses an algorithm that transforms answers to simple, non-statistical questions into a bivariate Gaussian distribution

as the prior for a Beta distribution with fitted parameters and associated covariance metrics that can be propagated into a broader uncertainty-aware fusion or conflation activity. This approach may be applicable to a wide array of geospatial problem domains.

8747-5, Session 1

Geo-accurate 3-dimensional reconstruction via image-based geometry

Derek J. Walvoord, Adam Rossi, Bradley D. Paul, Bernard V. Brower, Matthew F. Pellechia, ITT Exelis (United States)

Recent technological advances in persistent surveillance systems and both on-board and off-line computing capabilities have shaped an increased focus in new methods of exploiting geospatial data, bridging traditional photogrammetric techniques and state-of-the-art multiple view geometry methodology. The structure-from-motion (SfM) problem in computer vision addresses scene reconstruction from uncalibrated cameras, and several methods exist to remove the inherent projective ambiguity. However, the reconstruction remains in an arbitrary world coordinate frame without any knowledge of its relationship to a fixed earth-based coordinate system. We present a novel approach for obtaining geoaccurate image-based 3-dimensional reconstructions in the absence of ground control points (GCPs) by using a SfM framework and the physical sensor model of the collection system.

Absolute position and orientation information provided by the global positioning system (GPS) and inertial measurement unit (IMU) of the imaging platform may be used to reconstruct the scene in the desired coordinate system. Rather than performing triangulation from pixels of multiple image-to-ground functions (each with their own random error) a relative 3-dimensional point cloud is computed via image-based geometry, i.e., geometry derived from image feature correspondences. Triangulation of the selected image features through the image-to-ground function of the physical sensor model is then performed as a post-processing procedure to derive a second point cloud in fixed earth-based coordinates. The transformation between the point clouds is then derived to correct the relative point cloud; it effectively scales, translates, and rotates the relative model. Imagery from the Exelis Wide-Area Airborne Sensing (WAAS) system and the Wildfire Airborne Sensing Program (WASP) of the Rochester Institute of Technology is used to demonstrate reconstruction results and provide discussion for areas of future work.

8747-6, Session 1

Guidance in feature extraction to resolve uncertainty

Boris Kovalerchuk, Central Washington Univ. (United States) and BKF Systems (United States); Michael Kovalerchuk, BKF Systems (United States)

Automated Feature Extraction (AFE) plays a critical role in image understanding. AFE has a long-term history in roads and building extraction from overhead imagery. This history had shown that often an image itself is not sufficient for unambiguous AFE. Often the imagery analysts (IA) extract features much better than AFE algorithms do. The fundamental difference is that IAs use additional information that is either absent in the image or requires abilities to extract it from the image. While it was recognized that such information is needed, the actual use of it in AFE algorithms is still very limited. Often the direct use of the information that IAs easily use is not feasible in AFE algorithms. The formalization, extraction, and processing of this information can be more complex than the original AFE task, and that leads to the “complexity trap”. This can happen when the shadow from the buildings is used as guidance for extraction of buildings and roads. The idea of this work is first to analyze what additional information is available and can be processed by the AFE algorithm without going to the complexity trap. This work proposes an AFE algorithm to extract roads and trails by using the GMTI tracking information as well as older and inaccurate maps of roads and trails as the additional guiding information. The algorithm exploits ideas of the algebraic structural approach combined with a dynamic logic of phenomena that process multilayered uncertain information.

8747-7, Session 1

A fast, accurate, cross-modality image geo-registration and target/object detection algorithm

Troy R. Mckay, CACI International Inc. (United States); Herb Hirsch, HEC, Inc., CACI Consultant (United States)

CACI’s registration and target/object detection algorithm uniquely departs from traditional methods. It does not extract and analyze phase relationships or spatial features such as polygons, vertices, or edges within an image. Rather, it operates upon a unique interpretation of image complexity which permits cross-modality (SAR to Visual, for example) operation.

The algorithm uses signal processing (instead of image processing), and complexity. It scans pixel rows and columns in an image, treating each row and column scan as a signal (pixel value versus pixel location, like signal amplitude versus time). Then, it calculates complexity metrics for each “signal.” Using these metrics, it works in both amplitude and frequency domains but avoids the high computing cost and processing time of conventional time-domain or frequency-domain processing (like spatial comparison methods or Fourier transforms). Finally it builds registration or target/object detection features by organizing each complexity value in a series, according to the row or column “signal” from which it was calculated. Comparison of these feature data through mathematical correlation reveals the registration location or the sought target or object. Registration of sensor images to geo-referenced images achieves geo-location. It out-performs the speed of conventional registration and target recognition methods, achieving video-rate registration and target/object recognition with no special processing hardware.

We first define the algorithm mathematically, compare it to other registration or target/object recognition methods, and finally apply it to some images to demonstrate its accuracy and processing speed behavior and performance. We also discuss anticipated enhancements we plan for future optimization.

8747-8, Session 1

Improved evaluation of geo-registration algorithms for airborne EO/IR imagery

Clark N. Taylor, Air Force Research Lab. (United States)

Geo-registration, or the ability to estimate the geo-coordinates (e.g., Latitude, Longitude, and Altitude in WGS-84) of every pixel within a video frame or image is a critical technology to systems collecting imagery from an airborne platform. While significant work has been performed on geo-registration for several years now, it is important to perform systematic evaluation of differing geo-registration algorithms to (1) quantify the performance of current state-of-the-art algorithms and (2) help vector the development of new technologies to the technical areas that can most effectively improve geo-registration approaches.

Unfortunately, performing a high-quality comparison between two geo-registration approaches has at least two significant difficulties. First, the results of any algorithm are highly dependent on not only the algorithm but the input data used to test the algorithm. Differences in image quality, the platform used to collect the imagery (and its associated metadata), the type of terrain being imaged, the flight pattern used during collection, and how well synchronized the metadata is with the video are all characteristics of the data that can significantly affect the quality of the geo-registration results. Therefore, a comparative evaluation cannot, for example, be performed by simply comparing published results on two algorithms because the difference in results may be due to differing test data rather than algorithm performance.

Second, most evaluations performed to date have consisted of manually identifying a small set of objects for which "true" geo-location information is known and can be easily identified in aerial imagery (step 1). A few instances of the object appearing within geo-referenced imagery is then found (step 2), and the estimated geo-location is computed (step 3). The difference between this estimated location and the true location is then computed and used as the evaluation output (step 4). Unfortunately, these steps are all performaed manually, making the evaluation time-consuming and therefore expensive to perform. In addition, even when they are performed, the amount of data resulting from these evaluations is typically very small (on the order of 10s of points), leading to questions about whether the results are even statistically significant.

To overcome this problem, we have developed a Geo-Registration Evaluation Toolbox (GRET) that enables an evaluation of geo-location accuracy on 1000s of points at low cost. Steps 1 and 2 (identifying an object whose geo-location is known and finding this object within the imagery) are still performed manually. However, this user-created data is stored in an XML file and is used by automated software tools to execute steps 3 and 4. This simplifies evaluation by requiring manual intervention only once for each data set rather than once for each algorithm being evaluated. This change in methodology significantly reduces the cost of evaluating a geo-registration algorithm and enabled multiple algorithms to be evaluated on the same dataset, enabling fair and statistically significant comparisons between algorithms.

This paper will describe in more detail both the methodology and the software developed as part of the GRET toolkit. Preliminary results showing an evaluation of 6 different geo-registration algorithms across 1000s of geo-located points will be presented, demonstrating the type of information that can be derived from a large-scale evaluation.

8747-9, Session 2

Geodata fusion study by the Open Geospatial Consortium

George Percivall III, Open Geospatial Consortium, Inc. (United States)

No Abstract Available.

8747-10, Session 2

Overview of contextual tracking approaches in information fusion

Erik P. Blasch, Air Force Research Lab. (United States); Jesus Garcia Herrero, Univ. Carlos III de Madrid (Spain); Lauro Snidaro, Univ. degli Studi di Udine (Italy); James Llinas, Univ. at Buffalo (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States); Kannappan Palaniappan, Univ. of Missouri-Columbia (United States)

Many information fusion solutions work well in the intended scenarios; but the applications, supporting data, and capabilities change. One example is weather data for electro-optical trackers of which standards have evolved over decades. The operating conditions of: technology changes, sensor/target variations, and the contextual environment can inhibit performance if not included in the design, or enhanced to increase performance. In this paper, we seek to define and categorize different types of contextual information. We describe five contextual information categories that support information fusion: (1) domain knowledge from a user to aid the information fusion process through selection, cueing, and analysis, (2) environment-to-hardware processing for sensor management, (3) known distribution of entities for threat assessment, (4) historical traffic behavior for situation awareness patterns of life (POL), and (5) road information for target tracking and identification. Appropriate characterization and representation of contextual information is needed for future high-level information fusion systems design to take advantage of the large data content available for a priori knowledge algorithm initiation.

8747-11, Session 2

Geometric exploration of virtual planes in a fusion-based 3D data registration framework

Hadi AliAkbarpour, Univ. de Coimbra (Portugal); Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Jorge M. Dias, Univ. de Coimbra (Portugal)

Performing three-dimensional reconstruction of the objects within an aerial scene is still one of the key challenges of computer vision and of importance for Geospatial Information Systems. In this paper we present a homography-based approach for 3D urban reconstruction. A hybrid sensor, mountable on an airborne platform, is described and consists of three sensors: camera, inertial sensor (IS) and GPS. The heterogeneous data coming from each of these three sensors are fused using the concept of projective homography. In each position it provides a constraint set of Euclidean planes over which the image data are mapped. 3D reconstruction is then accomplished by fusion the corresponding data across the multiple Euclidean planes. Unlike existing approaches, our method constructs the homography transform matrices directly using the principal sensor measurements and geometric constraints without requiring any correspondence-based estimation method (i.e. no need for feature matching and explicit point correspondences between frames).

Due to inaccuracies in the sensor observations, the estimated homography transforms have measurement uncertainties. As a consequence, the planes registered using these transforms will be subject to reconstruction errors. Modeling such uncertainties and their propagation through the measurement and reconstruction process is of importance in the fusion stage of combining data collected from different locations around the scene. For the fusion process we use statistical geometry and probabilistic approaches to model the uncertainties in the various homography transformations within the framework and their error propagations in the registered data. As a result the registered data will be extended with some probabilistic values showing the degree of their reliability.

8747-12, Session 3

Impact of feature descriptors on low pixel-count persistent surveillance tracking system performance

Jason A. Edelberg, Christopher Miller, U.S. Naval Research Lab. (United States); Kyle Novak, Tekla Research Inc. (United States); Michael Wilson, U.S. Naval Research Lab. (United States)

Persistent surveillance systems frequently trade resolution for larger area coverage. This trade often yields a situation where the objects to be tracked have a low pixel count, often fewer than ten per side (<100 pixels total) and commonly much fewer than that. With such low pixel counts, true target recognition becomes difficult which is why the tracking systems employed on persistent surveillance imagery are often change-detection based. These change-detection tracking systems often struggle to maintain track during quick maneuver situations, extended stopping situations, periods of obscuration and dense traffic. Various feature descriptors, including template matching, HoG, LBP, and others, are studied that have been tuned to the special case of very low pixel count target detection. This dynamic feature-based detection algorithm is incorporated into an existing change-detection based tracking system. This augmented tracking system has been applied to VNIR and MWIR wide area data under a variety of conditions. Analysis of the improvement these feature descriptors have on both the augmented detector performance and tracker performance is presented.

8747-13, Session 3

Processing of aerial H.264 data for ground object tracking

Paul B. Deignan Jr., L-3 Communications Integrated Systems (United States); R. Daniel Creider, Texas A&M Univ.-Commerce (United States)

The H.264 compression algorithm produces motion vectors between frames that carry information both for the reconstruction of subsequent images and also for the relative spatial movement of objects within a scene. The group and entity movement of objects can be tracked in the particular or through statistical inference. We adopt the later technique due to the practical availability of artifacts of the compression problem. However, the extraction of motion vectors is not without complication. We present methodologies as well as an empirical illustration of the development of an algorithm for detecting and tracking ground motion of objects from an aerial platform using only information produced in the process of H.264 compression and discuss some limitations of the technique.

8747-14, Session 3

A position-independent image complexity seLector (PICSEL) for enhanced visualization and intuitive object detection in images

Troy R. McKay, CACI International Inc. (United States); Herb Hirsch, HEC, Inc., CACI Consultant (United States)

The PICSEL algorithm applies compact and fast-executing algorithms to create a “virtual terrain” in an image. It visually alters image areas so image analysts may intuitively locate, sort, classify, and identify objects, targets, or areas of interest. It also discriminates between areas which may be lossy-compressed or losslessly-compressed, thus improving image compression effectiveness.

Consider a spatially or geographically-distinctive area, like Tampa Bay. The Florida peninsula and Tampa Bay are easy to recognize, so visually locating the city of Tampa on the bay is easy. But if the city of Tampa was nestled among similar urban areas, it would be difficult to find. PICSEL creates virtual islands, peninsulas, bays, and lakes in images. Areas of interest appear as bright, high-contrast “land,” and non-interest areas appear as dark, low-contrast, “submerged” regions.

Our work to date has developed, tested, and evaluated PICSEL’s effectiveness in an early prototype configuration. PICSEL has demonstrated the ability to (1) help image analysts intuitively locate objects or areas of interest, for improved analyst efficiency, and (2) greatly-reduce image file size, for improved image compression and substantially-faster image dissemination.

We first describe the goals, benefits, and challenges of PICSEL’s virtual terrain rendering. Then we apply it to some images to demonstrate and explain its behavior. We also discuss anticipated optimization and normalization techniques - the enhancements that will improve the PICSEL technique in the future.

8747-15, Session 3

Activity from motion: reconstructing dynamic situation from distributed video sources

Georgiy M. Levchuk, Matthew Jacobsen, Aptima, Inc. (United States)

Social media sources, such as online postings of imagery, audio, and video, provide the alternative to proactive persistent surveillance that is currently capable of monitoring wide areas for long periods of time. However, reconstruction of dynamic scenes from such data is a very challenging task, particularly because online sources rarely contain accurate location and time information.

Imagery reconstruction has made significant progress in the last decade: researchers advanced original algorithms that can reconstruct single 3D objects (Snavely, Seitz, and Szeliski, 2006) to reconstructing entire cities from large photo collections in less than a day (Agarwal et al., 2009, 2011). However, these models have largely ignored that the scenes like cities can change drastically over time. Most recently, researchers developed approaches to reconstruction of 4D cities from 2D photo collections, where the 4th dimension encodes the evolution of the cities in history, as the buildings get constructed and demolished (Schindler, and Dellaert, 2010). These models can currently capture only slowly evolving changes in the city’s architectural landscape, and are unable to reason about dynamic activities of moving targets nor incorporate video data as input.

In this paper, we present activity-from-motion (AfM) model that can reconstruct dynamic situation evolution in the area given local video clips and imagery inputs from open sources, such as Flickr, YouTube, etc. Our model stitches the multimedia sources in space and time, learns repetitive activity patterns from stitched data, and allows finding the areas with activities that match the analysts’ queries.

8747-16, Session 3

Feature selection for appearance-based vehicle tracking in geospatial video

Mahdieh Poostchi, Kannappan Palaniappan, Filiz Bunyak, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

Current video tracking systems often employ a rich set of intensity, edge, texture, shape and object level features combined with descriptors for appearance modeling. This approach increases tracker robustness but is computationally expensive for real-time applications and localization accuracy can be affected by including distracting features in the feature fusion or object classification processes. This paper explores offline feature subset selection for video tracking to reduce the dimensionality of the feature space and to discover a relevant representative lower dimensional subspace for online tracking. We compare the complete FOCUS to the sequential heuristic SFFS, SFS and RELIEF feature selection methods. The experiments prove that the use of offline feature selection not only reduces the computational complexities, but also results in improved online tracking performance.

8747-17, Session 3

Particle filter-based vehicle tracking by fusing spatial features with a nonlinear motion model

Raphael Viguier, Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Emmanuel Duflos, Philippe M. Vanheeghe, École Centrale de Lille (France)

Tracking in wide area motion imagery faces many challenges including low resolution, multiple small-sized targets, low frame rate and complex backgrounds. Feature-based tracking techniques generate multiple peaks and have difficulty in distinguishing the target from distractors. Consequently, the wider the search area, the higher will be the number of false detections. It is therefore critical to use a refined motion model in order to eliminate spurious matches, reduce the size of the search region and at the same time estimate an accurate probability density of the predicted position to improve the target to track association. We introduce an orientation and magnitude based representation of the vehicle dynamics which leads to a non-linear motion model. We use a particle filter to handle both non linearity of the motion model and fusion with object feature likelihood maps within the search window that are often multi-modal. In the first step of particle filter prediction, we randomly sample small changes in velocity orientation and magnitude.

Then the probability map built from the appearance-based features is directly used as a likelihood estimatate to update particle weights. After resampling, the probability for a point to be chosen as the target location becomes proportional to the initial number of particles on it as much as the feature-based similarity with the target template. This approach shows promising results by reducing the false alarm rate and simultaneously reducing the size of the search window. The improved prediction provided by the particle filter-based probability density estimation compensates for the reduced reliability of feature-based histogram matching due to appearance changes, especially during turns. Preliminary experiments using wide area motion imagery demonstrate that the particle filter combined with a non-linear motion model out-performs a Kalman filter-based prediction using a linear motion model.

8747-18, Session 3

Vehicle detection and orientation estimation using the radon transform

Rengarajan V. Pelapur, Kannappan Palaniappan, Filiz Bunyak, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

Vehicle detection is important from the point of view of traffic analysis and event detection. Our detector uses a host of image based features which have proven effective in target tracking in wide-area imagery such as block-based intensity, gradient magnitude for edge-based features, gradient orientation information using Histogram of Oriented Gradients, eigenvalues of the Hessian matrix for shape information, and local binary patterns for texture. These features are used to train a classifier and is in turn used for detection.

The training method is novel due to the explicit orientation estimation that is done on objects to maintain an overall wide range of vehicle orientations. Explicit orientation estimation is beneficial to explore since the majority of feature descriptors are designed to be rotationally invariant. Additionally, automatic orientation estimation can speed up manual ground-truth collection that is often necessary for validation and performance analysis as well as improve the quality of the manual tracks. The typical method of manual tracking involves marking only centroids since this is the simplest, or drawing and moving an axis-aligned bounding box drawn around the object of interest, general polygons are too time consuming to draw or correct on each frame. A good compromise is to use an oriented bounding box which takes vehicle geometry and pose into account. The results show that the estimation is accurate within an overall average of +/- 4.5 degrees for various types of imagery and about 89% of the objects have an estimation error under +/- 1 degree for satellite imagery.

8747-19, Session 4

Evaluation fusion techniques for multisensor satellite image data

Benjamin W. Martin, The Univ. of Tennessee Knoxville (United States); Ranga R. Vatsavai, Christopher T. Symons, Oak Ridge National Lab. (United States); Itamar Arel, The Univ. of Tennessee Knoxville (United States)

Image data fusion is a topic of interest in many areas including environmental monitoring, emergency response, and defense. In addition, there are many types of satellite sensors each of which can offer unique benefits that other types of image data cannot offer. Given the respective strengths and weaknesses of the different types of image data, it is beneficial to fuse many types of data to extract as much information as possible from the data.

Our work focuses on the fusion of multi-modal image data into a unified representation that incorporates the potential strengths of a particular series of data sets in order to minimize classification error. We train a machine learning algorithm to optimally fuse data while using classifier error as feedback for the fusion learning algorithm. The complete fusion system is divided into two stages: a stage in which the classifier is updated such that it minimizes classification error given a fixed fusion learning system, and a stage where the fusion learner is updated in order to minimize the classification error given a fixed classifier configuration. This alternating update of the classifier and the fusion learner optimizes the fusion methodology based on classifier performance and therefore maximizes the quality of the fusion for both the input data and the classifier.

8747-20, Session 4

Usage of data-encoded web maps with client side color rendering for combined data access, visualization, and modeling purposes

Denis V. Pliutau, Narasimha S. Prasad, NASA Langley Research Ctr. (United States)

Current approaches to satellite observation data storage and distribution implement separate visualization and data access methodologies which often leads to the need in time consuming data ordering and coding for applications requiring both visual representation as well as data handling and modeling capabilities. We describe an approach we implemented for a data-encoded web map service based on storing numerical data within server map tiles and subsequent client side data manipulation and map color rendering. The approach relies on storing data using the lossless compression Portable Network Graphics (PNG) image data format which is natively supported by web-browsers allowing on-the-fly browser rendering and modification of the map tiles. . The method is easy to implement using existing software libraries and has the advantage of easy client side map color modifications, as well as spacial sub-setting with physical parameter range filtering. This method is demonstrated for the ASTER-GDEM elevation model and selected MODIS data products and represents an alternative to the currently used storage and data access methods. One additional benefit includes providing multiple levels of averaging due to the need in generating map tiles at varying resolutions for various map magnification levels. We suggest that such merged data and mapping approach may be a viable alternative to existing static storage and data access methods for a wide array of combined simulation, data access and visualization purposes.

8747-21, Session 4

Correlation of partial frames for fusion, change detection, and video compression

Boris Kovalerchuk, Central Washington Univ. (United States) and BKF Systems (United States); Sergei Kovalerchuk, BKF Systems (United States)

Correlating video frames from sensors located on different moving platforms is important for improving algorithms for change detection, tracking, and discrimination of objects as well as for evaluating existing algorithm for these tasks and data compression with limited downlink bandwidth. Downloading partial frames requires less bandwidth, but it requires pre and post processing and the correlation of partial frames is more challenging than the correlation of full frames. It is even a more challenging for partial frames with objects that are far from the sensor (at the sensor resolution limits where objects are visible as single pixels). In such cases the algorithms cannot exploit the internal characteristics and structure of the objects. This work proposes an algorithm to correlate partial frames with such small objects using the algebraic structural approach developed by our team that is exploiting structural relations between objects. The proposed algorithm is fully affine invariant, which includes any rotation, shift, and scaling.

8747-22, Session 4

Subdimensional geo-localization from finite set statistics

Frank A. Boyle, Paul B. Deignan Jr., L-3 Communications Integrated Systems (United States)

In practical circumstances, a problem that often occurs is to geo-localize an entity from surface-level imagery given wide area overhead information and other a priori information that might be used to relate the two views. Given a finite set of GMTI returns and surface-level imagery of a common region of space, we propose a statistical algorithm for the association of surface-level one-dimensional measurements of the finite set to entities of the shared-dimensional wide area overview. Specifically, the problem of fused tracking without reliable range information from a surface-level view of a subset of entities is solved by the association of projections of 3-dimensional movement and position measurements of the GMTI and surface-level imagery. In this process the position of the surface level observer is refined. We expand this algorithm to a set of surface level observers distributed over the region of interest and propose a system of continuous tracking of entities over congested areas. The fusion search algorithm exploits the invariant metric properties of projection in a matched-filter procedure as well as the partial-ordering of local apparent depth of objects. We achieve O(N) convergence thereby making this algorithm practical for large-N searches. The algorithm is demonstrated analytically and by simulation.

8747-23, Session 4

KOLAM: a cross-platform architecture for scalable visualization and tracking in wide-area imagery

Kannappan Palaniappan, Fraser Joshua, Anoop Haridas, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States); Raghuveer M. Rao, U.S. Army Research Lab. (United States)

KOLAM is an open, interoperable, scalable and extensible framework for visualization and target tracking in high-resolution, large volume wide format video also known as wide-area motion imagery (WAMI). KOLAM was originally developed for the interactive visualization of extremely large geospatial imagery of varying spatial and spectral resolution. KOLAM is cross-platform, supporting multiple operating systems and GPU hardware independent. The visualization tool supports embedded datasets scalable from hundreds of gigabytes to petabytes in size on clusters, workstations, desktops and mobile computers. In addition to rapid roam, zoom, animate and hyper-jump spatial operations, KOLAM supports an arbitrary number of simultaneously viewable embedded layers or channels, interactive color map and histogram enhancement, spherical projections and view-dependent rendering of terrain maps. The KOLAM software architecture was extended to support airborne wide-area motion imagery by organizing very large format video frames as a temporal sequencing of pyramid data structures. The current version of KOLAM supports animation, target tracking and trajectory visualization; the latter comprising the outputs of both tracker algorithm execution and ground-truth generation. Among the current critical needs for working with WAMI is an assisted tracking and visualization tool that allows analysts to rapidly track multiple targets, review tracking results and apply visual analytic tools to the generated track data. KOLAM provides one-click manual tracking, which is combined with multiple automated tracking algorithms to assist the analyst and increase human effectiveness.

8747-24, Session 4

A semi-automated building outline tool (SABOT)

Scott Simmons, Mike Thompson, Deborah Lamb, Troy R. McKay, CACI International Inc. (United States); Herb Hirsch, HEC, Inc., CACI Consultant (United States)

Image Analysts (IAs) in many operations need to create geometric representations of buildings of interest from reconnaissance or surveillance imagery. This is called “collecting” the buildings, and typically, is done by manually digitizing multiple points around the borders of buildings via mouse “clicks.” The click points form vertices of polygons which outline building shapes. This is a time-consuming and sometimes fatiguing process. An automated means to “click” only once, somewhere within a building’s visual image footprint, and automatically obtain the outline was sought.

Many technical challenges had to be overcome to realize this automated capability. These included factors such as different building sizes, shapes, and orientations; often unclear or distorted building borders; similar textures on the inside and outside of building perimeters; shadow effects across different portions of buildings; obscurations such as nearby natural or man-made structures like ridges, trees, and other buildings; and general image quality factors such as contrast, brightness, intensity range and degrees of crispness. Through a series of incremental developments and testing we addressed these challenges to realize a substantially capable solution.

We first describe the amount of imagery wherein buildings need to be collected, why they need to be collected, and how to improve collection efficiency. Then we review the technical challenges and how our development and testing led us through them to a solution. Next we present results using screen captures from the current version of the tool operating on actual imagery. Finally we summarize improvements we anticipate, to enhance and optimize SABOT’s performance.

8747-26, Session 4

Mining pattern in a persistent surveillance system with smart query and visual analytics

Mohammad S. Habibi, Tennessee State Univ. (United States)

In Persistent Surveillance System (PSS) the ability to detect and characterize events geospatially help take pre-emptive steps to counter adversary’s actions. Interactive Visual Analytic (VA) model offers this platform for pattern investigation and reasoning to predict such occurrences. The need for identifying and offsetting these threats require collecting information from diverse sources in real or near time, which brings with it increasingly abstract data. These abstract semantic data have a degree of inherent uncertainty and imprecision, and require methods of elimination before arriving to detect an event or activity. The technique used here uses Euclidean and Vector Space Modeling for classification of features in semantic messages, and is the basis for developing semi-structured data for further analysis using semi-supervised learning. Depending upon the analysts’ classification of events or alarms relative spatial-temporal collaboration is established to detect sequential patterns. In this paper a-priori Temporal-Dynamic Time Warping (DTW) method is used for mining sequential patterns and Gaussian Mixture Model (GMM) for expectation maximization of events from neighborhood-proximity semantic frames. The generated patterns are represented using interactive graphing visual tools and are evaluated by means of a case study concerning activity detection. Experimental results show the effectiveness of proposed approach and the discovery of matching subsequences within a sequentially generated pattern.

8748-1, Session 1

Tree-based adaptive measurement design for compressive imaging under device constraints *(Invited Paper)*

David Bottisti, Robert R. Muise, Lockheed Martin Missiles and Fire Control (United States)

We look at the design of projective measurements for compressive imaging based upon image priors and device constraints. If one assumes that image patches from natural imagery can be modeled as a low rank manifold, we develop an optimality criterion for a measurement matrix based upon separating the canonical elements of the manifold prior. We then characterize this manifold based upon prior training imagery under a tree-based framework which can be implemented adaptively. We also illustrate how these adaptive measurements can incorporate prior knowledge regarding the constraints of the device being used to collect the measurements. Simulated performance results are presented and compared against a standard imaging paradigm as well as more convention compressive imaging techniques.

8748-2, Session 1

High-speed optical correlator with custom electronics interface design *(Invited Paper)*

Tien-Hsin Chao, Thomas T. Lu, Jet Propulsion Lab. (United States)

No Abstract Available.

8748-3, Session 1

Light-driven robotics for nanoscopy *(Invited Paper)*

Jesper Glückstad, Darwin Palima, Technical Univ. of Denmark (Denmark)

Realising the vision of light-driven micro-robotics for nanoscopy requires the optimization of optical forces and optical torques that, in turn, requires optimization of the underlying light-matter interaction. The requirement of having strongly focused laser beams in high NA optical trapping systems exemplifies the need for optimal light-shaping. Contrary, the recent report on stable optical lift shows that optical manipulation can also be achieved using unshaped light but by using an appropriately shape-optimized structure instead. Hence, a generic approach for optimizing light-matter interaction should involve the combination of optimal light-shaping with the use of optimized shapes for optimally versatile micro-robotic structures. We have designed different three-dimensional micro-structures and fabricated them by two-photon polymerization. These photo-polymerized structures can be conveniently handled using our BioPhotonics Workstation to show proof-of-principle demonstrations illustrating the 6DOF optical actuation of these light-fabricated three-dimensional structures. We have exploited the light shaping capabilities available on the BioPhotonics Workstation to demonstrate a new strategy for controlling microstructures that goes beyond the typical refractive light deflections that are utilized in conventional optical trapping and manipulation. We propose and outline the design of intricate micro-structures with nanoscopic features for so-called structure-mediated access to the nanoscale.

8748-4, Session 1

Big data research and use: cases *(Invited Paper)*

Ashit Talukder, National Institute of Standards and Technology (United States)

No Abstract Available.

8748-5, Session 2

Coherent optical implementations of the fast Fourier transform and their comparison to the optical implementation of the quantum Fourier transform

Rupert C. Young, Philip M. Birch, Christopher R. Chatwin, Univ. of Sussex (United Kingdom)

Optical structures to implement the discrete Fourier transform and fast Fourier transform algorithm for discretely sampled data sets are considered. It is shown that the decomposition of the FFT algorithm into the basic butterfly operations allows the algorithm to be fully implemented by the successive coherent addition of two wavefronts, as well as their subtraction after one has been appropriately phase shifted, so facilitating a robust and simple optical hardware implementation based on wave guided hybrid structures as used in coherent optical detection modules. Further, a comparison is made to the optical structures proposed for the optical implementation of the quantum Fourier transform and they are shown to be the same.

8748-6, Session 2

Adapted all-numerical correlator for face recognition applications

Marwa Elbouz, ISEN Brest (France); Fatma Bouzidi, ISEN Brest (France) and Univ. de Sfax (Tunisia); Ayman Alfalou, ISEN Brest (France); Christian Brosseau, Univ. de Bretagne Occidentale (France); Isabelle Leonatd, ISEN Brest (France); Badr-Eddine Benkelfat, TELECOM & Management SudParis (France)

In this study, we suggest and validate an all-numerical implementation of a VanderLugt correlator which is optimized for face recognition applications. The main goal of this implementation is to take advantage of the benefits (detection, localization, and identification of a target object within a scene) of correlation methods and exploit the reconfigurability of numerical approaches. This technique requires a numerical implementation of the optical Fourier transform. We pay special attention to adapt the correlation filter to this numerical implementation. One main goal of this work is to reduce the size of the filter in order to decrease the memory space required for real time applications. To fulfil this requirement, we code the reference images with 8 bits and study the effect of this coding on the performances of several composite filters (phase-only filter, binary phase-only filter). The saturation effect has for effect to decrease the performances of the correlator for making a decision when filters contain up to nine references. Further, an optimization is proposed based for an optimized segmented composite filter. Based on this approach, we present tests with different faces demonstrating that the above mentioned saturation effect is significantly reduced while minimizing the size of the learning data base

8748-22, Session 2

Robust 3D reconstruction using LiDAR and N - visual image

Prakash Duraisamy, Stephen Jackson, Kamesh Namuduri, Univ. of North Texas (United States); Mohammed S. Alam, Univ. of South Alabama (United States); Bill Buckles, Univ. of North Texas (United States)

OCT is a non invasive technique in which contrast measurement is a challenging problem due to noisy environments. The contrast measurement basically validates the how far noise is removed and in addition it helps to understand true body condition. The conventional contrast measurement which works for ordinary visual images is basically failed for OCT images. In our work, we introduced SVD approach to measure the contrast. The algorithm works well and remove the offset faced by conventional method.

8748-9, Session 3

Smart pattern recognition *(Invited Paper)*

Ayman Alfalou, ISEN Brest (France); Christian Brosseau, Univ. de Bretagne Occidentale (France); Mohammad S. Alam, Univ. of South Alabama (United States)

In this paper, we propose to validate the concept of a novel optimized composite correlation filter, called asymmetric segmented phase-only filter (ASPOF), for various applications such as face recognition and underwater mine detection. To achieve this, we propose numerical implementation of optical Fourier transform based on the Fraunhofer diffraction. Numerical implementation of the optical Fourier transform operation has been found to significantly improve the detection performance and make it less sensitive to the saturation phenomenon caused by the increased number of references used to formulate the composite filter. In addition, the proposed implementation allows us to make the correlator easily reconfigurable for various scenarios. Various tests performed using the area-peak-to-correlation energy criterion and ROC curves for different datasets confirm the validity of the proposed technique.

8748-11, Session 3

Optimized fusion method based on adaptation of the RMS time-frequency criterion for simultaneous compression and encryption of multiple images

Mohammed Aldossari, Ayman Alfalou, ISEN Brest (France); Christian Brosseau, Univ. de Bretagne Occidentale (France)

An extension of the recently proposed method of simultaneous compression and encryption of multiple images [Opt. Express 19, 24023 (2011)] is developed. This analysis allows us to find a compromise between compression rate and quality of the reconstructed images for target detection applications. This spectral compression method can significantly reduce memory size and can be easily implemented with a VanderLugt correlator (VLC). For that purpose, we determine the size of the useful spectra for each target image by exploiting the root-mean-square time-frequency criterion. This parameter is used to determine the allowed area of each target image within the compressed spectrum. Moreover, this parameter is adapted in order to minimize overlapping between the different spectra. Finally, the spectra are merged together by making use of a segmentation criterion. The latter compares the local energy relative to each pixel for each spectrum. Furthermore, it optimizes assignment of the considered pixel by taking into account the adjacent areas to the considered pixel. This permits to avoid the presence of isolated areas and small sized areas (less than 10 pixels). We report on a set of tests with several video sequences. We use peak signal-to-noise ratio for comparing compression rates. Finally the encryption part is optimized by using and merging several encryption keys (according to the number of multiple images considered). The validation of this approach was realized by using a VLC architecture, phase-only correlation filter, and peak-to-correlation energy as decision criterion.

8748-13, Session 4

A new morphology algorithm for shoreline extraction from DEM data

Amr H. Yousef, Khan M. Iftekharuddin, Mohammad A. Karim, Old Dominion Univ. (United States)

Digital elevation models (DEMs) are a digital representation of elevations at regularly spaced points. They provide an accurate tool to extract the shoreline profiles. One of the emerging sources of creating them is light detection and ranging (LiDAR) that can capture a highly dense cloud points with high resolution that can reach 15 cm and 100 cm in the vertical and horizontal directions respectively in short periods of time. In this paper we present a new morphology algorithm to segment the DEM shapes and to convert them into binary images based on a tidal datum at the study area. Unlike similar approaches, it will detect and eliminate the outliers that result from waves, ships, etc. In addition, it eliminates docks, bridges and fishing piers along the extracted shorelines by means of Hough transform. Based on a specific tidal datum, the algorithm will segment the DEM data into water and land objects. Without sacrificing the accuracy and the spatial details of the extracted boundaries, the algorithm should do a set of morphology closings operations to isolate the water and land objects with different neighborhood connections depending on the slope of disconnected segment of the shoreline. Then, it removes the small children water objects from the parent land object as well as small children land objects from the water parent based on the histogram of the identified objects areas with a predefined threshold. Finally, the shoreline profile is extracted by tracing the boundary pixels between the land and the water segments. For different range of years, we qualitatively and quantitatively assess the extracted shorelines by superimposing them on the available aerial photographs.

8748-14, Session 4

Superresolution technique using neighborhood estimation and filtering

Mohammed N. Islam, Farmingdale State College (United States)

The goal of a superresolution technique is to enhance the resolution of a given image or video recorded by either a low quality camera system or from a long distance. The high-resolution image/video is generated by estimating additional pixels based on the available pixels of the low-resolution image utilizing some image processing algorithms.
The objective of the paper is to develop an efficient and simple superresolution technique for computer vision applications, like target detection and tracking. Pixels of the high-resolution image are created based on the neighborhood estimation of the low-resolution image pixels. Spatial as well as frequency-domain techniques are utilized to generate the pixels. Quality of the enhanced image is further improved by applying different filters, including Gaussian, Sobel, Prewitt and log. Performance of the proposed superresolution technique is investigated through computer simulation and quantified using parameters, like signal-to-noise ratio. The simple architecture of the proposed technique will offer an efficient and inexpensive software tool for practical applications.

8748-15, Session 4

Image registration under poor illumination using calibrated cameras

Prakash Duraisamy, Stephen Craig Jackson, Univ. of North Texas (United States); Mohammad S. Alam, Univ. of South Alabama (United States); Bill Buckles, Univ. of North Texas (United States)

Image registration is basic step in image fusion and many 2D applications. Registering the image is a challenging problem, however registering the 2D image with recent robust algorithms like SIFT (Scale invariant Feature Transform) works well in most situations. In our work, we made an comparison study between calibrated and uncalibrated (SIFT) approach and we defined which approach will work better under various scene environment. IN our approach we used K-matrix to improve the registration and remove the offset faced by uncalibrated approach. Experiments are tested on both synthetic and real world environments.

8748-16, Session 5

Defining properties of speech spectrogram images to allow effective pre-processing prior to pattern recognition

Mohammed H. Al-Darkazali, Rupert C. Young, Christopher R. Chatwin, Philip M. Birch, Univ. of Sussex (United Kingdom)

The speech signal of a word is a combination of frequencies which can produce specific transition shapes. These can be regarded as a written text in some unknown 'script'. Before attempting methods to read the speech spectrogram image using image processing techniques we need first to define the properties of the speech spectrogram image as well as the reduction of the clutter of the spectrogram image and the selection of the methods to be employed for image matching.

Thus methods to convert the speech signal to a spectrogram image are initially employed, followed by reduction of the noise in the signal by capturing the energy associated with formants of the speech signal. This is followed by normalisation of the size of the image and its resolution of in both the frequency and time axes. Finally, template matching methods are employed to recognise portions of text and isolated words. The paper describes the pre-processing methods employed and outlines the use of normalised grey-level correlation for the recognition of isolated words.

8748-17, Session 5

An image hiding method based on cascaded iterative Fourier transform and public-key encryption algorithm

Bing Zhang, Jun Sang, Chongqing Univ. (China); Mohammad S. Alam, Univ. of South Alabama (United States)

An image hiding method based on cascaded iterative Fourier transform and public-key encryption algorithm was proposed. Firstly, the original secret image was encrypted into two phase-only masks and via cascaded iterative Fourier transform (CIFT) algorithm. Then, the public-key encryption algorithm RSA was adopted to encrypt into. Finally, a host image was enlarged by extending one pixel into pixels and each element in and was multiplied with a superimposition coefficient and added to and subtracted from two different elements in the pixels of the enlarged host image. To recover the secret image from the stego-image, the two masks were extracted from the stego-image without the original host image and recovered to obtain the secret image. By applying public-key encryption algorithm, the security of the CIFT-based image hiding was enhanced. Also, compared with the image hiding method based on optical interference, the proposed method may reach higher robustness by employing the characteristics of the CIFT algorithm. Computer simulations show that this method has good robustness against image processing.

8748-18, Session 5

Joint Transform Correlation for face tracking: elderly fall detection application

P. Katz, M. Aron, Ayman Alfalou, ISEN Brest (France)

In this paper, an iterative tracking algorithm based on a non-linear JTC (Joint Transform Correlator) architecture is proposed and validated. This algorithm is based on the computation of a correlation plane where the reference image is updated at each frame. For that, we propose to use the JTC technique in real time to track a patient (target image) in a special room, i.e. fitted with several video cameras. The correlation plane is used to localize the target image in the current video frame (Frame i). Then, the reference image to be exploited in the next frame (Frame i+1) is updated according to the previous one (Frame i). In an effort to validate our algorithm, we divided our work into two parts:

(i) a large study, using different sequences with several situations, on the JTC parameters is achieved in order to quantify their effects on the tracking performances (decimation, non-linearity coefficient, size of the correlation plane, size of the region of interest...).

(ii) the tracking algorithm is integrated into an application of elderly fall detection: the first reference image is a face detected by means of Haar descriptors, and then localized into the new video image thanks to our tracking method. In order to avoid a bad update of the reference frame, a method based on a comparison of image intensity histograms is proposed and integrated in our algorithm. This step ensures a robust tracking of the reference frame.

8748-20, Session 5

Enhanced information security employing orthogonal code, steganography, and joint transform correlation

Mohammed N. Islam, Farmingdale State College (United States); Mohammad F. Islam, George Washington Univ. (United States); Kamal Shahrabi, Farmingdale State College (United States)

A novel and robust technique is proposed in this paper for securing confidential information by utilizing orthogonal coding scheme, encoded steganography and nonlinear encryption through joint transform correlation. Different biometric signatures are encoded using individual orthogonal codes and then multiplexed together. The encrypted and multiplexed image is hidden inside a cover image employing a steganography technique, where one from the three least significant bits is chosen using another secret key. A color cover image is utilized which is decomposed into three color components, red, green and blue, so that three different sets of biometric signatures can be embedded into each of the color components. The color stego image is finally encrypted using multiple phase-shifted reference joint transform correlation (MRJTC) technique. The proposed encryption technique is a nonlinear process which increases the security strength significantly against any unauthorized access. The encoded steganography technique reduces the vulnerability that an intruder can retrieve any information from a given image through any steganalysis attack. Finally, the orthogonal coding scheme enhances the robustness by making the biometric information almost inaccessible without authorization.

8748-19, Session 6

Human gait recognition by pyramid of HOG feature on silhouette images

Guang Yang, Yafeng Yin, Jeanrok Park, Hong Man, Stevens Institute of Technology (United States)

As a biological feature, gait recognition has a great advantage of identify people at a distance without high resolution images. Therefore, human gait recognition has attracted much attention in recent years, especially in the field of human recognition in the remote sensing scenarios. In this paper, we propose a human gait recognition framework with hidden Markov models (HMM) trained the pyramid of Histogram of Gradient (pHOG) feature on the silhouettes images. By background subtraction, the silhouette of human gaits which is considered as region of interest (ROI) in each frame is extracted and normalized from the raw video sequence. After removing the shadow and noise in each ROI, pHOG feature is computed based on the silhouettes images. Then the pHOG features of each sequence will be used to train a corresponding HMM. In the test stage, pHOG feature will be extracted from each test data and used to calculate the posterior probability toward to each trained HMM model. Experimental results on the CASIA dataset demonstrate that with our proposed framework the recognition rate can achieve a very high accuracy and has outperformed other gait recognition methods.

8748-21, Session 6

Optical image processing and pattern recognition algorithms for optimal optical data retrieval

Brian P. Walker, Thomas T. Lu, Sean Stuart, George F. Reyes, Tien-Hsin Chao, Jet Propulsion Lab. (United States)

No Abstract Available.

8748-23, Session 6

Small feature recognition of moving targets

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

“Small Feature Recognition Technique Based on Hidden Markov Chains of Movable Targets”

This paper presents an approach related to automated recognition of small features of movable targets including fast moving objects such as airplanes, etc. Small features recognition is a challenging problem in both fields: pattern recognition of particular configurations and of complexes comprising a number of configurations. Specific target details, although well characterized by their features, are often arranged in an elaborated way which makes the recognition task very difficult and welcomes new ideas (approaches). On the other hand, the variety of small characters (features) intrinsically linked to the technology development of the identified targets and is unavoidable. Due to the complexity of possible technological designs, the feature representation is one of the key issues in pattern recognition. Hidden Markov model approach formed the foundation of the proposed method.

8748-25, Session P-TUE

Comparison of correlation peaks characteristics for scaled images recognition using MACE, GMACE and MINACE filters

Petr A. Ivanov, Yaroslavl State Technical Univ. (Russian Federation)

The problem of pattern recognition using optoelectronic correlators of images with the help of invariant correlation filters is one of the most popular approaches for recognition of geometrically distorted images during last year’s. In this approach the optoelectronic correlator provides calculation of the correlation function of input image with some effective image that called correlation filter. In presented paper there are used MACE, GMACE and MINACE types of invariant correlation filter for recognition of scaled images. There was created a database that contains grayscale images with different resolution with change of scale with step of 1% in range of 50% to 150% of original image size both for true class and false class objects. There was hold a computer modeling of images recognition, calculation of correlation functions for mentioned filter types and calculated peak values, some characteristics of peak quality and number of cases if image is recognized or not. There is presented a comparison of results for different filter types and according to given data is shown that MINACE approach is better. Also there are presented results of testing of mentioned filters on another database that contains rotated grayscale images. The images in this database were distorted with in plane rotation with different steps in degrees in range of 0 to 360 degrees both for true class and false class objects. There is also presented analysis about how to use the received results in future investigations.

8748-26, Session P-TUE

MINACE filter realization as computer generated hologram for 4-f correlator

Nikolay N. Evtikhiev, Dmitriy V. Shaulskiy, Evgeny Y. Zlokazov, Rostislav S. Starikov, National Research Nuclear Univ. MEPhI (Russian Federation)

Optical correlators are well known to be perspective for real time image recognition. Application of distortion invariant filters (DIF) provides image recognition with increased speed of correlation image matching. Minimum noise and correlation energy filters (MINACE filters) provide good recognition in the case of grayscale input images. This paper is subjected to synthesis and realization of MINACE filters in 4-f correlator as computer generated holograms (holographic filters).

8748-27, Session P-TUE

Distortion invariant correlation filters application for quality inspection of master-matrix for security holograms

Evgeny Y. Zlokazov, Dmitriy V. Shaulskiy, Rostislav S. Starikov, National Research Nuclear Univ. MEPhI (Russian Federation); Sergey B. Odinokov, Alexander Y. Zherdev, Vasiliy V. Koluchkin, Ivan A. Shvetsov, Bauman Moscow State Technical Univ. (Russian Federation); Andrey V. Smirnov, Krypten (Russian Federation)

Application of security holograms for document and product authenticity protection is perspective due to difficulties of such a holograms falsification. Mass production of security holograms uses widespread technology of hot foil stamping. The quality of such holograms significantly depends on perfection of nickel master-matrix to be used. We represent the method of automatic quality inspection of nickel

master-matrix which is based on photomicrographs of surface ripples. The method is based on combination of spatial frequency analysis and application of distortion invariant filters. The results of method application are shown.

8748-28, Session P-TUE

Efficient mine detection using wavelet PCA and morphological top hat filtering

Nizam U. Chowdhury, Mohammad S. Alam, Univ. of South Alabama (United States)

An efficient unsupervised technique is proposed for land mine detection from highly cluttered inhomogeneous environment. The proposed technique uses multispectral data for which feature extraction is necessary to classify large volume of data. We applied wavelet based principal component analysis to reduce the dimension of the data as well as to reveal information about target from background clutter. To increase the discrimination between target and clutter a linear transformation of feature extracted bands is performed. Therefore, morphological algorithm is used to extract the maximum information of target. The proposed technique shows better detection performance while enhancing the processing speed. Test result using various multispectral data sets show excellent performance and verify the effectiveness of the proposed technique.

8748-29, Session P-TUE

JTC based concealed object detection in terahertz imaging

Md. Habib U. Habib, Mohammad S. Alam, Waleed K. Al-Assadi, Univ. of South Alabama (United States)

Detection of concealed objects under cloth or inside paper/lather/plastic box is a challenge for security applications. With terahertz (THz) imaging technology, it is possible to spot concealed objects inside plastic box, underneath cloths paper or similar scenarios. THz frequency domain (~100 GHz - 10 THz) shows a unique feature in the under-used domain of the electromagnetic spectrum which helps to acquire image of concealed objects. This property of THz wave makes it useful in variety of applications. Previously millimeter wave imaging and infrared (IR) imaging were used for detection of concealed features in an image with limited success rate. THz imaging helps solving the problem to a great extent because it can transmit through substances like cloths, paper, plastic, dried food etc. THz images have poor quality and low signal-to-noise-ratio. Noises and related artifacts must be reduced for proper detection of concealed objects. In this paper, a new technique for artifact reduction and detection of concealed object is proposed by utilizing nonzero-order fringe adjusted joint transform correlation (NFJTC) technique. In the proposed NFJTC technique, the joint power spectrum (JPS) is modified to obtain the nonzero-order fringe-adjusted joint power spectrum. NFJTC is already been used for object detection but never been used to detect concealed object. Test results using real life THz imaging confirm the effectiveness of the proposed technique.

8748-30, Session P-TUE

Dim small target detection based on stochastic resonance

Nong Sang, Huazhong Univ. of Science and Technology (China); Ruoling Wang, Wuhan Univ. (China); Haitao Gan, Jian Du, Huazhong Univ. of Science and Technology (China); Qiling Tang, South-Central Univ. for Nationalities (China)

Dim small target detection, which is characterized by complex background and low Signal-to-Noise Ratio (SNR), is critical for many applications. Traditional detection algorithms assume that noise is not useful for detecting targets and try to remove the noise to improve SNR of images using various filtering techniques. In this paper, we introduce a detection algorithm based on Stochastic Resonance (SR) where stochastic resonance is used to enhance the dim small targets. Our intuition is that SR can achieve the target enhancement in the presence of noise. Adaptive Least Mean Square (ALMS) filtering is first adopted to estimate the background, and the clutter is suppressed by subtracting the estimated background image from the source image. Adaptive SR (ASR) method is then employed to enhance the target and improve the SNR of the image containing the target and noise. ASR tunes and adds the optimal noise intensity to increase the power of the targets and therefore improve the SNR of the image. Several experiments on synthetic and natural images are conducted to evaluate our proposed algorithm. The results demonstrate the effectiveness of our algorithm.

8748-31, Session P-TUE

Spectral fringe-adjusted joint transform correlation based efficient object classification in hyperspectral imagery

Paheding Sidike, Mohammad S. Alam, Univ. of South Alabama (United States)

The spectral fringe-adjusted joint transform correlation (SFJTC) has been used effectively for performing deterministic target detection in hyperspectral imagery. However, experiments show decreased performance when noise-corrupted spectral variability is present in the target signatures. In this paper, we propose to use a modified spectral fringe-adjusted joint transform correlation based target detection algorithm, which employs a new real-valued filter called the logarithmic fringe-adjusted filter (LFAF). Furthermore, the maximum noise fraction (MNF) technique is used for preprocessing the hyperspectral imagery, which makes the SFJTC technique more insensitive to spectral variability in noisy environment. Test results using real life oil spill based hyperspectral image datasets show that the proposed scheme yields better performance compared to alternate techniques.

8749-1, Session 1

Quantum energy teleportation enabled by thermal discord

Michael R. Frey, Bucknell Univ. (United States); Masahiro Hotta, Tohoku University (Japan)

A Heisenberg-coupled qubit pair is a standard model used, for example, to treat quantum dots and optical lattices. M. Hotta [Physics Letters A, 372, 2008] showed mathematically that quantum energy teleportation (QET) is possible between the two particles in this model—with no energy carrier and however widely spaced the particles. Hotta's demonstration of QET relies on the system's ground state (zero temperature) entanglement. We consider more generally a Heisenberg-coupled qubit pair in thermal equilibrium with a heat bath at any given temperature T. We show that QET is generally possible with the Hotta protocol at any finite T, which suggests that QET has a degree of physical robustness. QET is possible even at temperatures above the entanglement threshold. This establishes that entanglement is not essential to QET. The system state of the qubit pair has positive thermal discord at all finite temperatures, leading to the conclusion that the essential enabler of QET is discord in general and, at temperatures above the entanglement threshold, dissonance in particular.

8749-3, Session 1

Theory for entanglement of electron dressed with circularly polarized light on graphene and three-dimensional topological insulators

Andrii Iurov, Godfrey A. Gumbs, Hunter College (United States)

We have formulated a theory for investigating the conditions which are required to achieve entangled states of electrons on graphene and three-dimensional (3D) topological insulators. We consider the quantum entanglement of spins by calculating the exchange energy. A gap is opened up at the Fermi level between the valence and conduction bands at zero doping when graphene as well as 3D topological insulators are irradiated with circularly-polarized light. This energy band gap is dependent on the intensity and frequency of the applied electromagnetic field. The electron-photon coupling also gives rise to a unique energy dispersion of the dressed states which is different from either graphene or the conventional two-dimensional electron gas (2DEG). In our calculations, we obtain the dynamical polarization function for imaginary frequencies. The polarization function is determined by both the energy dispersion and the overlap of pseudo-spin wave functions. The correlation energy is calculated in the random phase approximation (RPA). The application of the derived results to quantum computation will be discussed.

8749-4, Session 1

The correlation conversion property of quantum channels: distillable entanglement from classical correlation

Laszlo Gyongyosi, Budapest Univ. of Technology and Economics (Hungary) and Hungarian Academy of Sciences (Hungary); Sandor Imre, Budapest Univ. of Technology and Economics (Hungary)

Transmission of quantum entanglement will play crucial role in future networks and long-distance quantum communications. Quantum key distribution, the working mechanism of quantum repeaters or the various quantum communication protocols are all based on quantum entanglement. On the other hand, quantum entanglement is extremely sensitive to the noise of the communication channel over which it is transmitted. To share entanglement between distant points, high fidelity quantum channels are needed. In practice these communication channels are noisy, which makes no possible – or to extremely hard and expensive to distribute entanglement. In this work we show that quantum entanglement can be generated by a fundamentally new idea, exploiting the most natural effect of the communication channels: the noise. The noise transformation of communication links that are not able to transmit quantum entanglement can be used to generate entanglement from purely classically correlated, unentangled input states. We called this new phenomenon to correlation conversion property (CC-property) of communication channels. Our results have serious impacts and fundamental consequences on future's quantum communications, and on the development of global-scale quantum communication networks.

8749-5, Session 1

Handy elementary algebraic properties of the geometry of entanglement

Howard A. Blair, Syracuse Univ. (United States); Paul M. Alsing, Air Force Research Lab. (United States)

We explore metric-based entanglement measures of pure states in terms of our characterization of the separable states as well as the relationship between our characterization and SVD- and Schmidt-decompositions. We also explore the implication of our characterization for the computational complexity of testing separability and factoring states. We call the collection of separable vectors of a multipartite quantum system, which is a hyperbolic surface in an exponentially high dimensional linear space, the separation surface. A vector in the linear space is representable as an n-dimensional hypermatrix with respect to bases of the component linear spaces. A vector will be on the separation surface iff every determinant of every 2-by-2 2-dimensional submatrix of the hypermatrix vanishes. This highly rigid constraint can be tested in time asymptotically proportional to d^2, where d is the number of components of the system. The constraint on 2-by-2 determinants entails an elementary closed form formula for a parametric characterization of the entire separation surface with d-1 parameters in the characterization. For separable states, the state of a component of the system can be calculated in time O(cd), where c is the dimension of the component, and d is the number of components. If all components of the system have approximately the same dimension, the time complexity of calculating a component state as a function of the parameters is asymptotically proportional to the time required to sort the basis.

8749-6, Session 1

Entangled photons in remote information exchange

Reinhard K. Erdmann, Advanced Automation Corp. (United States); Richard J. Michalak, David H. Hughes, Air Force Research Lab. (United States)

Implications of entanglement for information exchange are key to both applications and the foundations of QM. A realizable experiment where Alice sends a polarization entangled photon to Bob and retains the other, illustrates non-local correlations more clearly with the separation exaggerated (~1 light year). Alice's measurement determines Bob's outcome (instantly), when the same bases are used. Thus Alice can acquire remote information, not only of Bob's photon state, but any macroscopic event predicated on it ("Schrödinger Cat"). Alice can therefore trigger and then know what transpired a year before any classical light signal from the (life-death) event could reach her. Such 'steering' effects can be generalized to other photon based formats; Alice can use two sources of photon pairs for entanglement swapping, so when a pair of photons is sent to Bob, it becomes (remotely) entangled at the instant she makes a projection measurement on the retained

pair. Bob can implement similar devices for bilateral effects. Although this information relay is non-signaling, and does not violate Relativity, it demonstrates information exchange with no counterpart in classical phenomena. Entanglement apparently enables forms of information connectivity that although quite general are not typically observable; photons are convenient illustrators with minimal interaction-decoherence effects. It is emphasized that QM can also describe classical phenomena as a special case, and definite 'real' photon states as well as entangled. Accordingly it is shown that the described results could be achieved in principle with photons that were not initially entangled with each other, or with any other photons.

8749-7, Session 2

Dynamic high-dimensional quantum key distribution

Jacob Mower, Massachusetts Institute of Technology (United States) and Columbia Univ. (United States); Zheshen Zhang, Massachusetts Institute of Technology (United States); Pierre Desjardins, Columbia Univ. (United States); Catherine Lee, Massachusetts Institute of Technology (United States) and Columbia Univ. (United States); Jeffrey H. Shapiro, Massachusetts Institute of Technology (United States); Dirk R. Englund, Massachusetts Institute of Technology (United States) and Columbia Univ. (United States)

Quantum key distribution (QKD) protocols employ quantum states to establish a secret key shared by two parties. High-dimensional correlations further enable (1) the generation of multiple bits per photon (bpp) and (2) potentially higher secret-key transmission rates. Temporal and spectral correlations are particularly appealing because they are robust during propagation through single-mode fibers and potentially turbulent free space. We present QKD protocols that use the temporal and spectral degree of freedom of single- and entangled-photons.

Because the temporal and spectral domains are continuous, the sender and receiver must discretize their measurements to minimize errors due to both imperfect correlations in the resource state and noisy detectors. However, with our dispersive optics protocol, they can also dynamically tune this discretization to account for the properties of the transmission channel. For example, they can maximize the secret key capacity by changing the dimensionality of their system exclusively during post-processing. This protocol allows sender and receiver to share > 100 Mb/s, with > 2 bpp (secure) even considering strong attacks on the transmission. We describe practical implementation of the protocols using existing technology.

8749-8, Session 2

Practical error correction strategies for QKD key production

Alan Mink, Anastase Nakassis, National Institute of Standards and Technology (United States)

We develop strategies to maximize overall secure key production within the time constraints available in the error correction stage of the Quantum Key Distribution (QKD) protocol. In QKD applications that allow limited quantum channel communications time, such as between a satellite and ground station or a cell phone and a bank ATM, maximizing the amount of extracted secure key is a prime concern. For these cases, one can allocate a significant amount of time to the error correction phase to tenaciously reconcile the data using one-way error correction codes such as Low Density Parity Check (LDPC) . In terrestrial applications that have continuous quantum channel connections, where stations are permanently linked via fiber or free-space, one has a limited amount of time to accomplish error correction before the next set of data arrives to be reconciled. We analyze a number of sets of LDPC matrices and evaluate their performance characteristic using a number of different parameters such as efficiency, speed, memory requirements and computational platforms. We also provide LDPC algorithm implementations for the following platforms: CPUs, FPGAs and GPUs.

8749-9, Session 2

Verification of light shift imbalance induced blockade in an atomic ensemble via collective state Rabi oscillations

May E. Kim, Yanfei Tu, Shih Tseng, Resham Sarkar, Mohamed Fouda, Selim M. Shahriar, Northwestern Univ. (United States)

Collective excitation of an ensemble of atoms has potential advantages over excitation of single atoms because of the fact that the vacuum Rabi frequency scales with the square-root of the number of atoms in the ensemble. However, it suffers from the constraint that when the excitation field contains many photons, there is a cascade of many transitions. Earlier, we had shown how to circumvent this constraint via a process called light-shift imbalanced induced blockade (LIB), which restricts higher order transitions in the collective excitation so that the ensemble behaves effectively as a single atom. This process does not depend on dipole-interaction among atoms, and can work with any density of atoms, and is not degraded by a distribution of mean separation between atoms. Under LIB, the collective excitation can be used for realizing a quantum computer with a relatively large cavity [1]. It can also be used for realizing an ultrasensitive atom interferometer with a Compton frequency that scales with the number of atoms [2]. Here, we present a technique for demonstrating LIB using Raman-Rabi oscillations in a lambda system, via coincidence detection in a Hanbury-Brown-Twiss setup. The approach we present is similar to the technique recently employed for demonstrating collective excitation in Rydberg-blockaded atoms [3]. We will describe results of numerical simulations, and present details of our experimental efforts towards this demonstration. In particular, we will illustrate how the fidelity of the LIB process depends on the number of atoms in the ensemble [1, 4].

References:

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8749-10, Session 2

Gaming quantum neural networks

Faisal S. Khan, Khalifa Univ. of Science, Technology and Research (United Arab Emirates); Ahmed El Hady, Max-Planck-Institut für Dynamik und Selbstorganisation (Germany)

Gaming the quantum is a new, game theory inspired approach to the study of potential equilibrium behavior of quantum informational processes. Non-cooperative game theory in particular, with its focus on the identification of equilibrium plays in a game as those plays in which every player gives a best response to all other players' strategic choices, offers a natural setting for studying optimal outcomes under given constraints. On the other hand, quantum neural networks such as quantum perceptron have been recently reported. Quantum neural networks are neural networks built on the principles of quantum information processing. They have been shown to improve the computational efficiency of neural networks and also to be a source of a novel class of quantum algorithms. In this paper, we bring together

elements of gaming the quantum from a non-cooperative game theoretic perspective and quantum perceptron. We show that the learning process of quantum perceptron can be treated as a game where a best response play corresponds to the desired state the quantum perceptron learns. Converging to a desired state can thus be regarded as a zero sum quantum game. Further, the best response (or desired state) is achieved by updating the weights of the perceptron, a process that can be regarded as a process of a distance minimization. The aforementioned efforts to develop a conjecture between gaming the quantum and quantum perceptron open up novel venues of interaction between game theory, statistical learning theory and quantum mechanics. In our opinion, such an interaction will contribute to the development of a theory of learning of interacting quantum agents

8749-11, Session 3

A quantum algorithm for Floer homology based on quantum knots

Samuel J. Lomonaco Jr., Univ. of Maryland, Baltimore County (United States) and Princeton Univ. (United States); Louis H. Kauffman, Univ. of Illinois at Chicago (United States)

We use the mosaic construction for quantum knots to create a quantum algorithm for computing the Floer Homology of knots.

8749-12, Session 3

Topological quantum computation and the fractional quantum hall effect

Louis H. Kauffman, Univ. of Illinois at Chicago (United States); Samuel J. Lomonaco Jr., Univ. of Maryland, Baltimore County (United States)

This talk will review the mathematical structure of models for the fractional quantum Hall effect, using Chern Simons theory, and will relate the topological structure of the Jones polynomial and the Temperley Lieb recoupling theory to the structure of anyons (as quasi-particles) in these models. The purpose of this talk is to clarify these connections and to relate this information with our work on the Fibonacci model and with our work on quantum knots. In the case of the Fibonacci model, we have explored in a purely knot theoretic manner in our previous papers, founding it on the bracket state sum model of the Jones polynomial and its extension to the Temperley Lieb recoupling theory. This combinatorial structure is related to the background conformal field theory that relates this braiding to the behaviour of the Laughlin wave functions and to collective excitations of electrons in the Hall effect. The intent of this paper is to draw a clear and concise picture of these relationships.

8749-14, Session 3

Effects of gauge theory based number scaling on geometry

Paul Benioff, Argonne National Lab. (United States)

Earlier work on the effects of number scaling in physics is extended to include geometry. The basic model used consists of separate mathematical systems of different types assigned to each point of a space time manifold, M. Each system type consists of a base set, operations, relations and constants that satisfy relevant axioms. Separate systems, Sx, of each type, S, are assigned to each x in M. The model limits the mathematics available to observers at point z to systems associated with z. The idea of separate Sx comes from extending gauge theory, with separate vector spaces, Vx, at each point, x, to include separate complex number systems, Cx, to each point, x. The freedom of basis choice in Vx is extended to choice freedom of scaling factors between the different Cx. This is expressed by a real scaling factor, exp(T(y)-T(x)), that relates Cx to Cy. Gauge theory describes T as a scalar boson field. Scaling occurs in the transfer of quantity descriptions at y to z, or in quantities described by integrals or derivatives over space time. Here, scaling effects on physics and geometry are described with emphasis on geometry. Included are line elements, curve lengths, and distances. Specific examples described are T induced expansion of space and T induced black and white scaling holes in space. The possible mimicking of the effect of dark energy on space by T scaling is noted.

8749-15, Session 3

A phase-unlocked Hong-Ou-Mandel interferometer

Timothy M. Yarnall, MIT Lincoln Lab. (United States); Ayman F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Giovanni Di Guiseppe, Univ. degli Studi di Camerino (Italy)

There exists a fundamental dimensional mismatch between the Hong-Ou-Mandel (HOM) interferometer and two-photon states: while the latter are represented using two temporal (or spectral) dimensions, the HOM interferometer allows access to only one temporal dimension owing to its single delay element. We introduce a linear two-photon interferometer containing two independent delays spanning the two-photon state. By 'unlocking' the fixed phase relationship between the interfering two-photon probability amplitudes in a HOM interferometer, one of these probability amplitudes now serves as a delay-free two-photon reference against which the other beats, thereby resolving ambiguities in two-photon state identification typical of HOM interferometry. We discuss the operation of this 'phase-unlocked' HOM on a variety of input states focusing on instances where this new interferometer outperforms a traditional HOM interferometer: frequency-correlated states and states produced by a pulse doublet pump. Additionally, this interferometer affords the opportunity to synchronize two-photon states in a manner analogous to an HOM interferometer; moreover, it extends that capability to the aforementioned class of states.

8749-35, Session 3

The quantum-classical boundary

Howard E Brandt, Independent (United States)

There is no generally accepted theory of why the world of macroscopic objects is not usefully described in terms of quantum states. It has however been speculated that for the description of many-body systems of sufficient complexity, quantified by the number of atoms of which it is composed, quantum mechanics can be replaced by classical mechanics. Of course for highly correlated mesoscopic systems such as Bose condensates, a quantum description is needed.

I claim that for objects consisting of Avogadro's number of atoms, the quantum state represented by the density matrix has vanishing quantum coherence, so that for all practical purposes the system is best described by classical mechanics. I argue that this follows from a reasonable upper bound on physically possible proper acceleration [1].

[1] H. E. Brandt, "Microcausality in Quantum Field Theory," Physica Scripta, Vol. T151, 014011 (5 pp), (2012), and references therein.

8749-16, Session 4

Progress in analytical investigations of the achievement of fault tolerance in quantum computing

Gerald N. Gilbert, Yaakov S. Weinstein, The MITRE Corp. (United States)

We describe progress made in understanding and assuring fault tolerance in quantum computation. We introduce and explore analytical techniques for explicitly determining the logical state of a quantum computer undergoing dynamical evolution according to an arbitrary quantum algorithm. 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).

8749-17, Session 4

Implementation of quantum game theory simulations using python

Alejandro Madrid Sánchez, Univ. EAFIT (Colombia)

This paper provides some examples about quantum games simulated in Python's programming language. The quantum games have been developed with the Sympy Python library, which permits solving quantum problems in a symbolic form. The application of these methods of quantum mechanics to game theory gives more possibility to achieve results not possible before. To illustrate the results of these methods, in particular, there have been simulated the quantum battle of the sexes, the prisoner's dilemma and card games. These solutions are able to exceed the classic bottle-neck and obtain optimal quantum strategies. This way, python demonstrated that is possible to do more advanced and complicated quantum games algorithms.

8749-18, Session 4

Quantum Fourier transform (QFT) over Galois fields

Sergio Rodriguez, Univ. EAFIT (Colombia)

Galois fields are constantly gaining importance in quantum computing due to their wide usage in quantum error correction algorithms, and so it becomes relevant to define the QFT over Galois fields because of its main role in many of the most important quantum algorithms, like Shor's algorithms. The present article illustrates how to generalize the QFT so it can be applied over Galois fields and explains several examples of the application of the QFT over the simplest Galois fields; it also shows how to implement Shor's algorithms over in Galois fields. In particular the QTF will be defined for the Galois fields F2 and F4, and the quantum factoring algorithm will be applied to the same fields. As a sub product the new form for the Hadamard matrix for the F2 and F4 fields will be derived accordingly.

8749-19, Session 4

Possible quantum algorithm for the LIpshitz-Sarkar-Steenrod square for Khovanov homology

Juan F. Ospina, Univ. EAFIT (Colombia)

Recently the celebrated Khovanov Homology was introduced as a target for Topological Quantum Computation given that the Khovanov Homology provides a generalization of the Jones polynomal and then it is possible to think about of a generalization of the Aharonov.-Jones-Landau algorithm. Recently, Lipshitz and Sarkar recently introduced a space-level refinement of Khovanov homology. which is called Khovanov Homotopy. This refinement induces a Steenrod square operation Sq^2 on Khovanov homology which they describe explicitly and the some computations of Sq^2 were presented. Particularly, examples of links with identical integral Khovanov homology but with distinct Khovanov homotopy types were showed. In the presente work we will present possible quantum algorimhs for the LIpshitz-Sarkar-Steenrod square for Khovanov Homolog and their possible simulations using computer algrebra.

8749-20, Session 4

Dependence of quantum error correction criteria on concentration of qubits in an ion-trap quantum computer

Naoki Fukuda, Shota Sakaguchi, Koji Nakamae, Osaka Univ. (Japan)

In an ion-trap quantum computer, quantum bits (qubits) are arranged on a two-dimensional lattice to perform gate operations. Several qubit gates form the quantum circuit corresponding to a quantum algorithm. Movement and standby of ion arise by the operation which participates in two or more qubits on a two-dimensional lattice. Therefore, when doing the error rate analysis of a quantum circuit, it is necessary to take those factors into consideration. Many researches are made on the optimization of ion movement and standby scheduling and the error rate analysis under an optimal initial arrangement of qubits for a specific algorithm. When doing two or more quantum algorithms continuously on the same two-dimensional lattice, the arrangement of trapped ions after some specific algorithm execution is generally not optimal for the following algorithm. In this paper, we investigate the relation between the criteria for quantum error correction and the degree of qubit concentration under a random initial arrangement of qubits. The quantum circuits with and without quantum error correction (QEC) for the Grover search algorithm were used. Simulated results show that the average error rate for the circuit with QEC is minimized at some value of concentration, while that without QEC decreases as the degree of concentration increases.

8749-21, Session 4

A quantum way to searching software engineering

Nan Wu, Haixing Hu, FangMin Song, Nanjing Univ. (China); Xiangdong Li, New York City College of Technology (United States)

The Search Based Software Engineering (SBSE) is used in the software engineering to identify optimal solutions. The SBSE uses search based optimization algorithms, such as Tabu Search, Genetic Algorithms and Particle Swarm Optimisation, etc. In this paper, we propose a rapid modified Grover quantum searching method as an application in the SBSE. Theoretically, this method can be applied to any search-space structure and any type of searching problems. It is also valuable when used in the fields of engineering's request, estimation, software testing and system maintenance.

8749-22, Session 5

Effective Jaynes-Cummings model from on-chip filter in a dc SQUID phase qubit

Benjamin K. Cooper, Rangga P. Budoyo, Univ. of Maryland, College Park (United States); Vitaley Zaretskey, Univ. of

Maryland, College Park (United States) and Lab. for Physical Sciences (United States); Cody J. Ballard, J. R. Anderson, Chris J. Lobb, Fred C. Wellstood, Univ. of Maryland, College Park (United States)

We discuss experiments performed on a dc SQUID phase qubit with lumped element LC filtering on its current bias leads.

Spectroscopic studies of the qubit reveal several extraneous features. We examine these features in the context of an enlarged circuit model that includes the on-chip filter as part of the quantum system. From this model we extract an effective Jaynes-Cummings Hamiltonian for the system and discuss the spectroscopic results in light of this model.

8749-23, Session 5

Optimal scheme for generating photonic cluster states

Dmitry Uskov, Brescia Univ. (United States); Michael L. Fanto, Air Force Research Lab. (United States); A. Matthew Smith, Paul M. Alsing, U.S. Air Force (United States)

We report on theoretical research in photonic cluster-state computation. Finding optimal schemes of generating non-classical photonic states is of crucial importance for this field since physically implementable photon-photon entangling operations are currently limited to measurement-assisted stochastic transformations. A critical parameter for assessing the efficiency and feasibility of such transformations is success probability of desired measurement outcome. Due to fast progress in quantum optical technology there are several experimental groups which are capable of generating multi-qubit cluster states (up to six qubits). Separate photonic qubits are being fused into a single cluster by destructive C-phase gate(s) with success probability of each gate equal to 1/9. This design mechanically follows the original theoretical scheme of cluster state generation proposed more than a decade ago by Raussendorf, Browne and Briegel. The efficiency of destructive C-Phase gate in application to photonic transformations was never analyzed until now. Our results demonstrate that this method is by far not the optimal one. Employing numerical optimization we identified the most efficient method of cluster state generation. Success probability of a single optimal fusion gate in our method is equal to 1/2 for fusing uncoupled dual-rail qubits and 1/4 for coupling photonic Bell pair states generated via type-II down-conversion.

8749-24, Session 5

Beyond qubits with spatial modes of light

Enrique J. Galvez, Michael A. Senatore, Xinru Cheng, Brett Rojec, Colgate Univ. (United States)

We present our investigations on exploring higher-dimensional Hilbert spaces of two photons. We do this with spatial modes of light. Photon pairs are prepared in hyperentangled states of polarization and spatial mode to produce states or polarization qubits and spatial mode qutrits, ququarts, or in general, qunits. This is because spatial modes reside with a space that is, in principle, of infinite dimension. The main experimental challenge is to encode desired spatial modes onto two photons. These are inherently entangled by the process of parametric down-conversion, so we project their spatial mode onto the fundamental mode. Beyond this point, the apparatus takes advantage of the polarization entanglement of the photons to encode spatial modes via polarization optics. Spatial modes are encoded via phase sculpturing of the photon field with spatial light modulators.

8749-25, Session 5

Wave functions as theoretical entities taking part in classical computations

John M. Myers, Harvard Univ. (United States); F. Hadi Madjid, Consultant (United States)

Quantum mechanical wave functions enter into computer calculations: a wave function expressed in a program can take part in the computer-mediated operation of a feedback loop. The realization of the SI second depends on such a feedback loop. The feedback takes a momentary detection rate as an outcome that indicates the state of a quantum system composed of the outer electron of cesium 133 in the presence of microwave radiation emitted by a variable oscillator. From the detection rate, a wave function is chosen, in which the difference between the oscillator frequency and a cesium resonance appears as a parameter. We describe the impact of unpredictable outcomes of occurrences of measurements on the wave function used in the operation of the cesium atomic clock that realizes the SI second. Implications for axioms of quantum theory are delineated.

8749-26, Session 5

Multi-photon interactions in travelling wave resonators

Stefan F. Preble, Edwin Hach, Rochester Institute of Technology (United States); Ali Elshaari, Benghazi Univ. (Libyan Arab Jamahiriya)

Here we present a fully quantum mechanical transfer function model for travelling wave whispering gallery mode resonators. Micro-resonators, such as ring and disk resonators, have been key to the development of high performance chip-scale photonic systems due to their compact footprint, sensitivity and low power operation. In this work we present the first understanding of these resonators to any arbitrary multi-photon state. This was achieved by developing a model that utilizes an efficient scheme for determining the quantum electrodynamic transfer functions relating the Bosonic input/output mode operators in the resonator. This approach has been applied to the understanding of both single photon and two-photon states. In this work we will present a key result on a resonant Hong-Ou-Mandel effect that is inherently realized for any resonator-waveguide coupling constants and can operate over a wide range of resonance conditions. Furthermore, the transfer function approach allows for the straightforward understanding of any resonator-waveguide network with arbitrary modes. This will directly enable the application of quantum resonators to the realization of robust, scalable and efficient Linear Optical Quantum Computing (LOQC) gates. Consequently, it is expected that resonators can be used for both Nonlinear Sign Shift and CNOT gates. And these gates can robustly controlled and efficiently tuned using standard electro-optic effects available in a variety of material systems, such as, Silicon.

8749-27, Session 5

Quantum frequency conversion of photons entangled with atomic memory ensembles

Qudsia Quraishi, Dan Stack, U.S. Army Research Lab. (United States); Ian Grissom, Univ. of Maryland, College Park (United States); Patricia J. Lee, U.S. Army Research Lab. (United States)

One prominent method for storage of quantum information has been entanglement established between a single photon and a quantum memory given by an ensemble of laser cooled atoms [1]. Telecom photons are certainly advantageous to entangle two remote quantum memories, however atomic memories often emit wavelengths unfavorable for long haul transmission. Four wave mixing acts as a telecom quantum frequency converter while preserving the encoded qubit [4]. Experimental verification of storage and retrieval of single photons entangled with the atoms was aggressively pursued [3,4] after being first theoretically proposed [1]. We review the status of our setup which uses laser cooled Rb87 as the quantum memory and four-wave mixing to perform quantum frequency conversion. A single photon is emitted by, and entangled with, a spin-wave in the atomic ensemble. Using quantum frequency conversion, the photon is converted into the telecom band. The long-lived (>microsecond) spin-wave can be read out later by a second read-laser which drives the emission of a second photon and simultaneously reinitializes the ensemble into the initial state. Using a PPLN, the telecom photon is converted back into an IR photon. Such a scheme offers the advantage of a relatively long lived memory coupled with a telecom single photon for use in quantum repeaters [4].

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[4] M. D. Eisaman et al., Nature 438, 837 (2005).

8749-28, Session 6

Three dimensional computational ghost imaging with a signal-pixel detector

Zhipeng Chen, Hu Li, Jianhong Shi, Guihua Zeng, Shanghai Jiao Tong Univ. (China)

Conventional ghost imaging can only obtain two dimensional image because it only use spatial correlation characteristics of light source. We describe a three dimensional computational ghost imaging arrangement, which can obtain three dimensional image of target using only a single-pixel detector. In this configuration, the reflectivity information of target can be obtained relying spatial correlation, and the elevation information of one can be obtained relying temporal correlation. We use a spatial coherent, temporal coherent, monochrome continuous wave laser as light source, and the light is split into N beams, then sends into fiber phase modulator to form spatial random, phase random fiber array. The light generated from this array is collimated after a certain distance of free propagation, and then the collimated light is sends to target in far field. The echo light reflected from the target is collected by bucket detector (a single-pixel photodetector). At the same time, the light field intensity in reference path can be computed using the information of fiber phase modulator. Finally, the three dimensional target image can be reconstructed through correlation computation between single-pixel data in target path and array data in reference path. Hence, based on computational ghost imaging, we can only use a single-pixel detector to obtain the three dimensional image of target. In the further, this technology maybe finds application in remote sense domain.

8749-29, Session 6

Demonstration of multiple nonorthogonal state discrimination below the standard quantum limit

Francisco E. Becerra, Jingyun Fan, National Institute of Standards and Technology (United States); Julius Goldhar, Univ. of Maryland, College Park (United States); Gerald B. Baumgartner, Jon Kosloski, Lab. for Telecommunications Sciences (United States); Alan L. Migdall, National Institute of Standards and Technology (United States)

Quantum mechanics sets limits on how well we can determine the state of a quantum system. In particular, nonorthogonal states, such as coherent states, cannot be discriminated with total certainty because of their intrinsic overlap. Thus, any kind of deterministic measurement that aims to determine the state of the system will have some probability of erroneously identifying this state. When the discrimination is performed by directly measuring the physical property differentiating these nonorthogonal states, the minimum probability of error corresponds to the standard quantum limit (SQL). In the case of coherent states, measurement of the phase or intensity using coherent or direct detection can ideally reach the SQL. However, quantum mechanics allows, in principle, to discriminate nonorthogonal states with error probabilities below the SQL.

Here we describe the first realization of a quantum receiver that unconditionally discriminates multiple nonorthogonal states with error probabilities below the SQL. The receiver uses adaptive measurements to discriminate four nonorthogonal coherent states different phases. This scheme performs adaptive measurements using a local oscillator phase-reference field, where information gained in each measurement is used to modify subsequent measurements, and can discriminate multiple nonorthogonal states surpassing the SQL. We implement this strategy using fast feedback and photon-counting to demonstrate the first quantum receiver that unconditionally discriminates four nonorthogonal coherent states below the SQL for a wide range of input powers surpassing this limit by as much as 6 db.

8749-30, Session 6

Hyper-entanglement based system with enhanced resolution, signal to noise ratio, and measurement time

James F. Smith III, U.S. Naval Research Lab. (United States)

A hyper-entanglement based atmospheric imaging/detection system involving only a signal and an ancilla photon will be considered for optical and infrared frequencies. Only the signal photon will propagate in the atmosphere and its loss will be classical. The ancilla photon will remain within the sensor experiencing low loss. Closed form expressions for the wave function, normalization, density operator, reduced density operator, symmetrized logarithmic derivative, quantum Fisher information, quantum Cramer-Rao lower bound, coincidence probabilities, probability of detection, probability of false alarm, probability of miss, probability of error after M measurements, signal to noise ratio, quantum Chernoff bound, time-on-target expressions related to probability of error and resolution will be provided. The effect of noise in every mode will be included as well as loss. The system will provide the basic design for an imaging/detection systems functioning at optical or infrared frequencies that offers better than classical range and bearing resolution. Optimization of the enhanced resolution will be included. The signal to noise ratio will be increased by a factor equal to the number of modes employed during the hyper-entanglement process. Likewise, the measurement time will be reduced by the same factor. The hyper-entanglement generator will typically make use of entanglement in polarization, energy-time, orbital angular momentum, etc. Mathematical and numerical results will be provided describing the system's performance as a function of propagation loss, system loss, noise, and target reflectivity.

8749-31, Session 6

Increasing the accuracy of measurements, based on the solution of Pauli's quantum equation

Sergey Ermishin, Alexandra Korol, Althaven Technology (Belarus)

There is measurements principle, that ensure increasing accuracy of measurements based on redundant measurements. Increasing accuracy of measurements by methods of mathematical data processing insures minimum expenses on the effect of accuracy of measurements. The effect of increasing the accuracy does not correspond with the costs of additional measurements. Quantization of the parent entity on structural intervals is needed for solve the task of increasing the accuracy of two measuring instruments. Main properties of the solution is discrete method with a surge of probability within the parent entity and comparison a graph of the probability distribution for the diffraction grids with the

graph of probability density function. Method base on the analog of Pauli equation solution.The method of electronic reference measurements with quantum computing applied to mathematical data processing allows to greatly increase the credibility and accuracy of measurements at low cost. The simulation and experimental results are discussed.

8749-32, Session 6

Quantum image processing using Gaussian-Hermite filters

Esteban Soto Tirado, Univ. EAFIT (Colombia)

Some new filters for image processing are obtained from the wave functions of the two-dimensional quantum oscillator. Such filters are gaussians multiplied by Hermite polynomials and for this reason they will called Gaussian-Hermite filters. These new quantum filters can be used as smoothing filters and they show good performance when elimination of noise is concerned. Besides of this the new quantum filters can be used to define blurred derivatives and blurred Laplacians for images and in this case the quantum filters are excellent edge detectors. Finally the quantum filters and their derivatives are used to define quantum curvature filters as the Ricci-scalar-curvature filter and the Gaussian-curvature filter. In this last case the quantum filters perform well as curvature detectors and contrast enhancement operators. Our experimental results show that the quantum filters are more efficient than the classical filters and we claim that the quantum image processing will be a very important trend in the near future sensing technology.

8749-34, Session 6

The photonic nanowire: an emerging platform for highly efficient single-photon sources for quantum information applications

Niels Gregersen, Jesper Mørk, Technical Univ. of Denmark (Denmark); Julien Claudon, Commissariat à l'Énergie Atomique (France); Mathieu Munsch, Commissariat à l'Énergie Atomique (Switzerland); Nitin Singh Malik, Joël Bleuse, Emmanuel Dupuy, Adrien Delga, Jean-Michel Gerard, Commissariat à l'Énergie Atomique (France)

The development of highly efficient solid-state sources of single photons is a major challenge within the fields of quantum information processing and communication. Optimizing the coupling between a localized quantum emitter and a well defined optical channel represents a powerful route to realise such bright sources of non-classical light states. Reversibly, the efficient absorption of a photon impinging on the emitter is key to realise a spin-photon interface, the node of future quantum networks.

In this context, the tailored fiber-like photonic nanowire embedding a single quantum dot has recently demonstrated an appealing potential. This structure features no cavity and relies on a geometrical screening of radiation modes rather than resonant effects to ensure a strong coupling between the quantum dot and the optical waveguide mode. This approach renders the system broadband, a huge practical advantage. Additionally, the implementation of a sharp needle-like taper allows for strongly directed light emission, however, the performance of this taper is sensitive to minute geometrical details on the order of 1 degree.

We now introduce the photonic trumpet, the result of the opposite tapering strategy, and show that this structure offers a unique combination of broad operation bandwidth, relaxed fabrication tolerances, high extraction efficiency and clean Gaussian far-field emission. We demonstrate a first implementation of this approach through the demonstration of a very bright single-photon source. It features a first-lens external efficiency of 0.75 ± 0.1 and a record-high external coupling efficiency to a Gaussian beam of 0.61 ± 0.08.

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Part of Proceedings of SPIE Vol. 8750 Independent Component Analyses, Compressive Sampling, Wavelets, Neural Net, Biosystems, and Nanoengineering XI

8750-1, Session 1

Group theoretical methods and wavelet theory (coorbit theory and applications) *(Invited Paper)*

Hans G. Feichtinger, Univ. Wien (Austria)

It is a long way since wavelet theory and time-frequency analysis have found a great deal of attention, as two different ways of decomposing signals in orthogonal or also non-orthogonal ways. The unifying theory, covering both cases, destilling from these two situations the common group theoretical background lead to the theory of coorbit spaces. Starting from an integrable and irreducible representation of some locally compact group (such as the "ax+b"-group or the Heisenberg group) one can derive families of Banach spaces having natural atomic characterizations, or alternatively a continuous transform associated to it.

While unification of these two groups, also making the analogy to Banach spaces of analytic functions invariant under the Moebius group have been at the heart of the orginal theory recent years have seen further new instances and generalizations. Among them shearlets or the Blaschke product should be mentioned here.

The talk will try to summarize a few of the general principles which can be derived from the general theory, but also highlight the difference between the different groups and signal expansions arising from corresponding group representations. There is still a lot to be done, also from the point of view of applications and the numerical realization of such non-orthogonal expansions.

8750-2, Session 2

Composite wavelet representations for reconstruction of missing data *(Invited Paper)*

Wojtek Czaja, Julia Dobrosotskaya, Benjamin Manning, Univ. of Maryland, College Park (United States)

We shall introduce a novel methodology for data reconstruction and recovery, based on composite wavelet representations. These representations include shearlets and crystallographic wavelets, among others, and they allow for an increased directional sensitivity in comparison with the standard multiscale techniques. Our new approach allows us to recover missing data, due to sparsity of composite wavelet representations, especially when compared to inpainting algorithms induced by traditional wavelet representations, and also due to the flexibility of our variational approach. Applications of this new recovery method include image inpainting for high-dimensional data, such as, e.g., hyperspectral satellite imagery.

8750-3, Session 2

Multiscale and multidirectional tight frames for image analysis *(Invited Paper)*

Edward H. Bosch, Alexey Castrodad, National Geospatial-Intelligence Agency (United States); Wojtek Czaja, Julia Dobrosotskaya, Univ. of Maryland, College Park (United States); John S. Cooper, National Geospatial-Intelligence Agency (United States)

We propose an original idea for constructing 2D tight frames that provide a new way to analyze, visualize and process data at multiple scales and directions. We consider a comprehensive approach to the directional signal analysis and redundant representation, giving preference to the designs that allow for associated fast discrete transforms. This model combines the advantages of multiscale directionality and non-locality with the convenience of sparse representations.

The new methods described in our work are based on the previous research by the first author, which demonstrated that by employing the proper choice of functional components in directional signal representations, we can isolate directional information, while at the same time, effectively characterizing the underlying variation. This makes it applicable to many geostatistical problems.

The innovation resides in our ability to analyze multiscale, multidirectional information in data, and to perform lossless and lossy reconstruction in a simple and computationally efficient manner. The specific construction involves: design of direct and inverse fast transforms implemented by sparse matrices, study of built-in angular representation content, and local rescaling for enhanced directional resolution. The proposed model yields computationally efficient multirectional data representations that are well suited for the solution of diverse inverse problems, in particular, for image enhancement or restoration.

8750-4, Session 3

Multi-frequency resolution method for distortion-free signal extraction from convolutive mixtures *(Invited Paper)*

Soo-Young Lee, KAIST (Korea, Republic of)

Although the frequency-domain blind signal extraction (fdBSE) algorithm has been quite successful to extract a speech signal from convolutive mixtures, the inherent scaling problem results in severe distortion in the extracted speech signals. In this paper a new algorithm for distortion-free fdBSE is reported based on multivariate frequency-domain independent component analysis (ICA). The scaling indeterminacy of frequency-domain ICA has been resolved by conducting ICAs in multiple frequency resolutions and imposing specific relationship among the multi-resolution frequency components. The resulting fdBSE algorithm demonstrated much less signal distortion and much better speech quality.

8750-5, Session 3

Emotional state and its impact on voice authentication accuracy *(Invited Paper)*

Miroslav Voznak, Pavol Partila, Technical Univ. of Ostrava (Czech Republic); Marek Penhaker, VSB-Technical Unversity of Ostrava (Czech Republic); Tomas Peterek, VSB-Technical University of Ostrava (Czech Republic); Karel Tomala, Filip Rezac, Jakub Safarik, Technical Univ. of Ostrava (Czech Republic)

The paper discusses a system enabling to determine the emotional state from voice, and its application in improving biometric authentication accuracy. Today, because of concerns about security risks in both private companies and government institutions, security systems of the highest quality are implemented with the aim to authorize individuals and permit them access to the premises of institution or to the information and communication network. The most hi-tech way to authenticate and identify authenticated users (workers, employees, contractors, etc.) is biometrics. Biometric systems contain very accurate identification features such as fingerprint or retinal scans but are also above standard and require expensive equipment. On the other hand, the integration of biometric systems based on voice identification does not currently require much effort as the basic service in communication infrastructure is voice service. However, voice authentication is considered to be less precise because it can be affected by noise and the speaker's emotional state. During the first registration, voice parameters are recorded in a neutral emotional state. Speech processing algorithm, further described in this article, extracts segmental parameters from speaker sound signal. These parameters, such as Mel Frequency Cepstrum Coeficients, Zero Crossing Rate, and Fundamental Frequency train and shape Kohonen's self-organizing map. The neural network classifier detects whether the speaker who wishes to authenticate is in a stressful emotional state. The functionality between parameters in different emotional states is expressed by regression analysis. This relationship prevents unjust rejection and our approach could improve the successfulness of biometric systems based on voice identification.

8750-6, Session 4

Audio source separation with multiple microphones on time-frequency representations *(Invited Paper)*

Hiroshi Sawada, Nippon Telegraph and Telephone Corp. (Japan)

This paper presents various source separation methods that utilize multiple microphones. We classify them into two classes. Methods in the first one apply independent component analysis (ICA) or Gaussian mixture model (GMM) to frequency bin-wise observations, and then solve the permutation problem to reconstruct separated signals. The second method extends non-negative matrix factorization (NMF) to a multi-microphone situation, in which NMF bases are clustered according to their spatial properties. We have a unified understanding that all methods analyze a time-frequency representation with an additional microphone axis.

8750-7, Session 5

Optimization of object region and boundary extraction by energy minimization for activity recognition

Fatema A. Albalooshi, Vijayan K. Asari, Univ. of Dayton (United States)

Automatic video segmentation for human activity recognition has played an important role in several computer vision applications. Active contour model (ACM) has been used extensively for unsupervised adaptive segmentation and automatic object region and boundary extraction in video sequences. This paper presents optimizing Active Contour Model using Hopfield Neural Network (HNN) for automatic object region and boundary extraction in human activity video sequences. Taking advantage of the collective computational ability and energy convergence capability of the Hopfield Neural Network, energy function of Active Contour Model is optimized with lower computational time. The system starts with initializing HNN state based on the initial boundary points and ends up with final states of neurons which represent actual boundary points of human body region. The initial contour of the Active Contour Model is computed using background subtraction based on Gaussian Mixture Model (GMM) such that background model is built dynamically and regularly updated to overcome different problems including illumination changes, camera oscillations, and changes in background geometry. The recurrent nature of the Hopfield neural network is useful for dealing with optimization problems due to its dynamic nature, thus, ensuring convergence of the system. With the parallel processing potential of Hopfield neural networks, the proposed boundary detection and region extraction can be used for real time processing. This method results in an effective segmentation that is less sensitive to noise and complex environments. Experiments on different databases of human activity show that our method is effective and can be used for real-time video segmentation.

8750-8, Session 5

Automated analysis of texture features for non-masses

Anke Meyer-Baese, The Florida State Univ. (United States)

The evaluation of texture features of non-masses represents a challenging task for an automated analysis and is of crucial importance for advancing current computer-aided diagnosis (CAD) systems.

Compared to the well-characterized mass-enhancing lesions, non-masses have not well-defined and blurred tumor borders and a kinetic behavior that is not easily generalizable and thus discriminative for malignant and benign non-masses. A solution to this problem is provided by texture signatures sensitive to direction changes applied directly to the tumor such that they to capture the joint spatio-temporal behavior of these lesions. We additionally consider the impact of non-rigid motion compensation on a correct diagnosis and provide an automated CAD system of high specificity and sensitivity.

8750-9, Session 6

Wavelet neural networks for stock trading and prediction *(Invited Paper)*

Lipo Wang, Nanyang Technological Univ. (Singapore)

This paper explores the application of a wavelet neural network (WNN), whose hidden layer is comprised of "adaptive wavelons" – neurons using adjustable wavelets as activation functions, to stock prediction. We discuss some basic rationales behind technical analysis, and based on which, inputs of the prediction system are carefully selected. This system is tested on Istanbul Stock Exchange National 100 Index and compared with traditional neural networks. The results show that the WNN can achieve very good prediction accuracy.

8750-10, Session 6

Comparative analysis of filtered back-projection algorithms in optoacoustic endoscopy using ultrasonic optic sensors for Intravascular Imaging *(Invited Paper)*

Horacio Lamela Rivera, Pablo González, Pedro F. Escudero, Antonio Rincon, Omar de Varona, Daniel C. Gallego, Univ. Carlos III de Madrid (Spain)

OptoAcoustic Imaging (OAI) is a new biomedical imaging technology based on the use of laser-generated ultrasound. It is a hybrid modality, combining the high-contrast and spectroscopic-based specificity of optical imaging with the high spatial resolution of ultrasound imaging. It offers visualization of optical contrast in tissues, as a consequence, it has greater specificity than conventional ultrasound imaging with the ability to detect haemoglobin, lipids, water and other light-absorbing chromophores (Dima & Ntziachristos, Expert Opinion on Medical Diagnostics, May 2011).

In the context of intravascular imaging, OAI provides interesting advantages compared to ultrasound imaging and other classical techniques in fields such as atherosclerosis diagnosis and treatment (van Soest et al., SPIE Photons Plus Ultrasound: Imaging and Sensing 2011 Vol. 7899) or coronary stents assessment and check, which luck endogenous ultrasound contrast (Karpiouk AB, Wang B, Emelianov SY., Rev Sci Instruments 2010).

In this work, we present the results of an optoacoustic intravascular endoscope based on a laser beam rotated within the vessel and moved lengthwise through it, and an interferometric ultrasonic sensor (H. Lamela, D. Gallego, A. Oraevsky, Optics Letters 2009; D. Gallego, H. Lamela, M. Wang, J. Hiltunen, M. Kinnunen, R. Myllylä, SPIE PW 2012 Vol. 8370), modeling an integrating line sensor. The system is tested over

different absorbent geometries, showing the capabilities and limitations of the algorithms.

To obtain optoacoustic intravascular images in this scheme, some approximate time-domain filtered back-projection (FBP) reconstruction algorithms will be used. In order to sharpen object boundaries while simultaneously preserving high contrast of the reconstructed objects, a wavelet transform implementation using a wavelet family resembling the theoretical N-shaped OA signal can be used. Wavelet transform has been established in the signal processing community as a superior tool for localization of specified signal profiles. Comparison of results provided by the universal back-projection formula and a wavelet-based radial BP algorithm will be presented.

8750-11, Session 6

Artificial neural networks (AANs) as compared to partial least squares (PLS) for spectral interference correction *(Invited Paper)*

Z. Li, Vassili Karanassios, Univ. of Waterloo (Canada)

Spectral interferences arising from direct or wing-type spectral overlaps are a key concern in elemental analysis by inductively coupled plasma (ICP) and microplasma optical emission spectrometry. Spectral interferences are addressed using a variety of methods, including artificial neural networks (ANNs) [1] and partial least squares (PLS). In this paper, the application of ANNs and PLS for spectral interference correction is described in some detail and the two methods will be compared and contrasted.

1. Z. Li, S. Huang and V. Karanassios, Further development of artificial neural networks for spectral interference correction in optical emission spectrometry, Proc. of SPIE, 8401, 84010Y1-84010Y7 (2012) (doi: 10.1117/12.919570)

8750-12, Session 6

Analysis and removing noise from the speech signal using wavelet transforms

Karel Tomala, Miroslav Voznak, Pavol Partila, Filip Rezac, Jakub Safarik, Technical Univ. of Ostrava (Czech Republic)

The paper discusses the use of DWT (Discrete Wavelet Transform) and SWT (Stationary Wavelet Transform) wavelet transforms in removing noise from voice samples and evaluation of its impact on speech quality. One significant part of QoS (Quality of Service) in communication technology is the speech quality assessment. However, this part is seriously overlooked as telecommunication providers often focus on increasing network capacity, expansion of services offered and their enforcement in the market. Among the fundamental factors affecting the transmission properties of the communication chain is noise, either at the transmitter or the receiver side. A wavelet transform (WT) is a modern tool for signal processing. WT was originally used mainly in image compression but gradually its activity and usage expanded to include audio signals. One of the most significant areas in which wavelet transforms are used is applications designed to suppress noise in signals. To remove noise from the voice sample in our experiment, we used the reference segment of the voice which was distorted by Gaussian white noise. An evaluation of the impact on speech quality was carried out by an intrusive objective algorithm PESQ (Perceptual Evaluation of Speech Quality). PESQ algorithm is specified in recommendation ITU-T P.862 and provides speech quality scores by comparing reference (sent) and degraded (received) speech samples. The input or test speech signals have to be high-quality, well-calibrated and well-defined speech signals conforming to those specified in P.862. DWT and SWT transformation was applied to voice samples that were devalued by Gaussian white noise. Afterwards we determined the effectiveness of DWT and SWT by means of objective algorithm PESQ. The decisive criterion for determining the quality of a voice sample once the noise had been removed was MOS (Mean Opinion Score) which we obtained in PESQ. The contribution of this work lies in evaluation of efficiency of wavelet transformation to suppress noise in voice samples.

8750-13, Session 7

Blind deconvolution using convex programming *(Invited Paper)*

Justin K. Romberg, Georgia Institute of Technology (United States)

We consider the problem of recovering two unknown vectors, w and x, of length L from their circular convolution. We make the structural assumption that the two vectors are members known subspaces, one with dimension N and the other with dimension K. Although the observed convolution is nonlinear in both w and x, it is linear in the rank-1 matrix formed by their outer product wx^*. This observation allows us to recast the deconvolution problem as low-rank matrix recovery problem from linear measurements, whose natural convex relaxation is a nuclear norm minimization program.

We prove the effectiveness of this relaxation by showing that for ``generic" signals, the program can deconvolve $w$ and $x$ exactly when the maximum of $N$ and $K$ is almost on the order of $L$. That is, we show that if $x$ is drawn from a random subspace of dimension $N$, and $w$ is a vector in a subspace of dimension $K$ whose basis vectors are ``spread out" in the frequency domain, then nuclear norm minimization recovers wx^* without error.

8750-14, Session 8

Compressive sensing effects on human visual system-based passive ranging

Jae H. Cha, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Passive ranging in the computer vision is known to have the Marr's paradox, when two or more distant light sources exist in the field of view. As a matter of fact, human visual system (HVS) can easily resolve the paradox by varying the head position from the left to the right that removes the ambiguity due to true point targets mixed with false triangulation ghost targets. HVS compares the relative point target displacements due to the left and right head movements, which is equivalent to using 3 pairs of eyes. On the other hand, an optics bench experience tells us that one can also perform this HVS feat with one eye closed. This fact suggests that HVS pair of eyes might be oversampling of two-eye video image data. Therefore, we explore whether the compressive sensing (CS) mathematics, introduced recently in 2007 by Candes, Romberg, Tao & Donohoe, can reduce the amount of simulated HVS video image data, their storage requirement, and computational burden. Here, from the perspective of a novel HVS approach to the persistent surveillance for affordable passive ranging, we analyze the information-specific minimum sensing methodology via CS and demonstrate its effectiveness in terms of storage size, processing speed and measurement accuracy.

8750-15, Session 8

Feature-organized sparseness for efficient face recognition from multiple poses

Tomo Iwamura, Japan Ministry of Defense (Japan)

Current compressive sensing (CS) is not post-processing compression by the standard JPEG 2000, rather at image acquisition level as a pre-processing to minimize the redundancy as in CRT&D algorithms (IEEE/IT, 2007). We found a sparse representation of facial database as advocated by Ma et al (IEEE/PAMI, 2009) to be useful representation for a secured entry door, in case of a noisy facial input and a missing part due to the sun-glass covered eyes pixels.

In this research paper, we discovered, based on the experience of Human Visual System (HVS), that a robust class separation of faces may be based on the mutual distances among parts of the faces, rather than detail pixels. For example, the mutual distances among eyes, nose and mouth on a individual that will be insensitive to the skewed projections taken by different camera angles, may therefore help us separate young children from matured adults. We assert that such a sparse representation that can preserve the parts' mutual distance is the main topological reason for the rapid facial recognition in a large database. Recently, a massive parallel camera's System of Chip (SOC) that can cut faces by color tone of all faces into identical sizes boxes in 0.04 sec. Then, if we follow our thesis of robust representation in terms of parts' size and topological distances, then we have a rapid and natural sparse representation to accomplish an instantaneous recognition, as demonstrated early in an underground parking lot by Mitsubishi surveillance camera.

This realization will be useful for a Smartphone camera spotting a friendly face among a crowd in stadium.

8750-16, Session 8

Adaptive sparse signal processing of on-orbit lightning data using learned dictionaries

Daniela I. Moody, David A. Smith, Los Alamos National Lab. (United States)

For the past two decades, there has been an ongoing research effort at Los Alamos National Laboratory to learn more about the Earth's radiofrequency (RF) background utilizing satellite-based RF observations of terrestrial lightning. The Fast On-orbit Recording of Transient Events (FORTE) satellite provided a rich RF lighting database, comprising of five years of data recorded from its two RF payloads. While some classification work has been done previously on the FORTE RF database, application of modern pattern recognition techniques may further lightning research in the scientific community and potentially improve on-orbit processing and event discrimination capabilities for future satellite payloads. We now develop and implement new event classification capability on the FORTE database using state-of-the-art adaptive signal processing combined with compressive sensing and machine learning techniques. The focus of our work is improved feature extraction using sparse representations in learned dictionaries. Conventional localized data representations for RF transients using analytical dictionaries, such as a short-time Fourier basis or wavelets, can be suitable for analyzing some types of signals, but not others. Instead, we learn RF dictionaries directly from data, without relying on analytical constraints or additional knowledge about the signal characteristics, using several established machine learning algorithms. Sparse classification features are extracted via matching pursuit search over the learned dictionaries, and used in conjunction with a statistical classifier to distinguish between lightning types. We present preliminary results of our work and discuss classification performance and future development.

8750-18, Session 9

Hyperspectral waveband group optimization for time-resolved human sensing

Balvinder Kaur, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Jill K. Nelson, George Mason Univ. (United States); Andrew J. Hutchinson, Van A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Vasiliki N. Ikonomidou, George Mason Univ. (United States)

Pulse and respiration rates provide vital information for evaluating the physiological state of an individual during triage. Traditionally, pulse and respiration have been tracked by means of contact sensors. Recent work has shown that visible cameras can passively and remotely obtain pulse signals under controlled environmental conditions [1, 3, 5, and 9]. This paper introduces a methodology for determining pulse and respiration signals from skin reflectivity data captured in the silicon range (400nm-1100nm). Based on the physiological understanding [3, 5, 6, and 7] of human skin and reflectivity at various skin depths, we optimize a group of bands to determine pulse and respiration with high Peak Signal-to-Noise Ratio (PSNR) and correlation values [2 and 4]. This work, collected under an approved IRB protocol, provides not only a new image processing tool for determining pulse and respiration signals from skin reflectivity in the hyperspectral visible range, but also enhances non-contact, remote, passive, and real-time measurement of pulse and respiration for security and medical applications.

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8750-19, Session 9

Decoupling sparse coding of SIFT descriptors for large-scale visual recognition

Zhengping Ji, James Theiler, Rick Chartrand, Los Alamos National Lab. (United States); Garrett Kenyon, Los Alamos National Laboratory (United States); Steven P. Brumby, Los Alamos National Lab. (United States)

Sparse coding draws amount of research attention in recent years, and has been widely applied to generate better representation for visual recognition problems. The conventional sparse coding is to reconstruct image patches (in format of raw pixels) using a linear combination of a set of basis functions and a sparse coefficient vector. In this paper, we devise sparse coding algorithms to learn a new dictionary of basis functions given the SIFT descriptors extracted from images. The learned dictionary is used to code SIFT-based inputs for the feature representation that is further pooled via spatial pyramid matching kernels and fed into SVM for the object classification on large-scale ImageNet database. We investigate the advantage of SIFT-based sparse coding approach by combining different dictionary learning methods and SIFT feature coding algorithms. With respect to the classification performance, it shows that the choice of feature coding algorithms is more important than that of dictionary learning. Based on this observation, we further evaluate the classification performance using a dictionary imprinted with random SIFT samples, which means no learning involves in the dictionary generation. Surprisingly, compared to several learned dictionaries, we reach a comparable performance using this computationally “cheap” random dictionary coupled with aforementioned SIFT feature coding algorithms. Our results also include state-of-the-art performance on different subsets of ImageNet database.

8750-20, Session 9

A study of the coherence parameter of the progressive compressive imager based on Radon transform

Vladimir Farber, Ben-Gurion Univ. of the Negev (Israel); Elman Eduard, Ben Gurion Univ of the Negev (Israel); Yair Rivenson, Adrian Stern, Ben-Gurion Univ. of the Negev (Israel)

We have recently introduced a progressive compressing sensing method based on an appropriate sampling scheme of optical Radon projections. The progressive compressive sampling technique has permitted what is to bets of our knowledge the first demonstration of optically Megapixel size compressive sensing imaging. The progressive compressing sensing technique is based on an earlier technique that basically captures optically Radon projections at equiangular steps. A line array sensor is used to collect the optical Radon projections Progressive information acquisition is obtained by choosing the angular sampling to be of the size of the golden angle. This way new information is acquired with each angular sampling step thus permitting gradual improvement of the reconstructed image. In this paper we investigate the coherence parameter of the progressive sampling scheme based on golden angles sampling steps. A comparison between the progressive sampling schemes with the conventional one based on uniform sampling is given in terms of their coherence parameter

8750-21, Session 9

Mammogram superresolution reconstruction based on compressive sampling

Yan Shen, Houjin Chen, Chang Yao, Jupeng Li, Beijing Jiaotong Univ. (China); Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

Detection of calcification in mammogram is important in breast cancer determination. An improved super-resolution reconstruction method of mammogram based on compressive sampling is proposed to accurately extract calcification in mammogram. Mammogram patches can be represented as a sparse linear combination of elements chosen from over-complete dictionary. The sparse representation for each patch of the low-resolution can be used to generate the high-resolution image patch. The dictionaries for low and high resolution image patches are trained jointly. The sparse representation of a low resolution image patch can be applied with the high resolution image patch. The learned dictionary pair is a more compact representation of the patch pairs. First of all, the super-resolution model is established according to the characteristic of mammogram and compressive sampling. Secondly, the low and high resolution dictionary are trained together, the high dictionary is obtained to reconstruct the mammogram. Thirdly, solve the optimization problem to get the high-resolution reconstructed patch, the detail algorithm is given for mammogram super-reconstruction. Finally, put the patches together to obtain the final high-resolution mammogram. Compared with other super-resolution methods, the proposed method can reduce the computational cost efficiently and reserve the edges of calcification. The calcification in mammogram can be extracted and judged accurately.

8750-22, Session 9

Noise SAR imagery compressing and reconstruction based on compressed sensing

Huihuang Zhao, Hengyang Normal Univ. (China); Juan Lopez, Yufeng Cao, Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

Compressed sensing (CS) is a sampling paradigm that provides the signal compression at a rate significantly below the Nyquist rate. It is based on that a sparse or compressible signal can be represented by the fewer number of bases than the one required by Nyquist theorem, when it is mapped to the space with bases incoherent to the bases of the sparse space. Synthetic aperture radar (SAR) systems are all-weather, night and day, imaging systems. Due to the low computational resources of the acquisition platforms and the steadily increasing resolution of SAR systems, the data cannot generally be processed on board and must be stored or transmitted to the ground where the image formation process is performed. The amount of image data produced is now constrained by on board storage capabilities and transmission links. However, in practical applications, the transform coefficients of SAR images usually have weak sparsity, especially when it includes speckle noise that arises from an imaging device and strongly hinders data interpretation. Exactly reconstructing these noise images is very challenging. In this paper, we introduce an improved approach to radar noise imaging based on the concept of CS. Orthogonal matching pursuit is applied to each signal in the ensemble to reconstruct noisy outputs. And in CS, an incoherent linear projection is used to acquire an efficient representation of a compressible signal directly using just a few measurements. Interestingly, random projections play a major role. The noise image is then reconstructed by solving an inverse problem. The experiments will be conducted to compare with the conventional methods in Noise SAR image compressing and reconstruction.

8750-43, Session 9

Compressive feedback for real-time control: compressive sensing beyond sensing

Ning Xi, Michigan State Univ. (United States)

The ultimate goal of sensing is to use sensory information to make decision either by human or computer. The compressive feedback means the feedback information in a control system is compressed or obtained from compressive sensing. This new feedback method can significantly reduce sensing time. Therefore, high performance real time control can be achieved even for systems with slow sensory feedbacks. The question is how to use such compressive information to control a real-time system. In this talk, the theoretical foundation as well as implementation methods for modeling, analysis and design of compressive feedback will be presented. Two application examples, automatic target tracking control and high precision nano motion control, will be discussed. The experimental testing results will also be presented.

8750-23, Session 10

Three dimensional self-assembly at the nanoscale *(Invited Paper)*

David H Gracias, Johns Hopkins University (United States)

No Abstract Available.

8750-24, Session 11

Gadolinium nanoparticles studies by using coded optoacoustic signals with two lasers for dual-mode biomedical imaging

Pedro F. Escudero Sr., Daniel C. Gallego, Horacio Lamela Rivera, Fernando Herranz, Univ. Carlos III de Madrid (Spain); Hugo Amary Groult, Jesús Maria Ruiz-Cabello, Nacional de Investigaciones Cardiovasculares (Spain)

Since the medical use approval of Gadolinium (Gd) in 2004 by the Food and Drug Administration (FDA), there has been remarkable growth in the utilization and development of agents to be used as contrast elements in Magnetic Resonance Imaging (MRI). Nanoparticles of Gadolinium (Gd-NP) with varying chemical compositions (Gd3+, ZnGdFe, Gd2O3), size, and shape structures, (Reynolds et al, 2000, Hemmer et al., 2010, Hejase et al., 2012) have been used as contrast media. Labeling and tracking of tumor cells by MRI are some examples of current biomedical applications (Vuu et al., 2005, Ghaghada et al. , 2009). Dual modalities and triple-modalities of images had been proposed to characterize Gd-NP coated with a shield of golden, golden cores coated with silica and Gd shields (Kircher et al, 2012).

With aim to use Gd-NP in optoacoustic application, previous studies had been performed by our group GOTL about quantify and characterize absorbents, by using of a Q-switched Nd:YAG laser to generate a optoacoustic signal, because it can provide an energy of millijoules within a pulse duration of tens of nanoseconds (Lamela et al, 2011). However, such lasers are bulky and expensive. As an alternative, diode lasers with pulsed excitation are available for optoacoustic applications.

In this work, we will present results on Gd nanoparticles studies on absorption measurements by using two laser diodes of two different wavelengths stimulated by half of coded excitation, which has been widely applied in conventional ultrasound imaging (Chiao et al., 2005). Moreover we will study as well orthogonal Golay codes to excite a Gd-NP solution at two wavelengths simultaneously in order to speed up optoacoustic imaging (Mienkina et al, 2010). The high pulse repetition frequency (PRF) of a diode laser makes it able to produce coded laser pulses, to generate the optoacoustic effect in Gd-NP solution, in order to find the absorption properties of Gd-NP.

8750-25, Session 11

Optimization of block-matching algorithms using custom instruction-based paradigm on NIOS II microprocessors

Diego González, Univ. Complutense de Madrid (Spain); Guillermo Botella, Uwe Meyer-Baese, Anke Meyer-Baese, The Florida State Univ. (United States)

This paper focuses on the optimization of matching-based motion estimation algorithms through Altera Custom Instructions based-paradigm.

A complete profilling is achieved before the optimization in order to find the code time leaks, afterward is developping a custom instruction set which will be added to the specific design enhancing the original system. The final system obtained is compared with C2H (C to Hardware acceleration paradigm) presented in previous works. Hardware resources and final perfromance of the final design are shown. This contribution, thus, outlines a low cost system, mapped on a Very Large Scale Integration (VLSI) technology which accelerates software algorithms by converting them to custom hardware logic block.

8750-26, Session 11

Segmentation and kinetic analysis of non-mass-enhancing lesions in dynamic contrast enhanced magnetic resonance Imaging

Anke Meyer-Baese, The Florida State Univ. (United States); Sebastian M. Goebl, Ludwig-Maximilians-Univ. München (Germany)

Non-mass-enhancing lesions are diagnostically challenging lesions since they exhibit a non-typic behavior in terms of kinetics and have a blurred morphologic appearance. Independent component analysis represents an excellent tool for non-mass-enhancing lesion segmentation in breast DCE-MRI. The extracted independent components can be employed either for lesion segmentation representing cluster-enhancement maps or as concentration time courses describing lesion enhancing curves.

In terms of segmentation, we show that the achieved results outperform the Chan-Vese model, the most flexible segmentation algorithm so far. ICA is able to remarkably capture the spiculated nature of the lesions and not smooth out relevant egdes as Chan-Vese. The determined area-under-the-curve values demonstrate this fact: 0.72 with Chan-Vese versus 0.8 with ICA. Further we apply the theory of phenomenological universalities for feature extraction from the kinetic curves and evaluate these based on ICA-segmentation and Chan-Vese-segmentation. The final evaluation based on a computer-aided-diagnosis system demonstrated that ICA segmentation in combination with kinetic feature extraction represent a powerful aid for clinical research.

8750-27, Session 11

A Modified PSO based Particle Filter Algorithm for Object Tracking

Yufei Tang, The Univ. of Rhode Island (United States); Siyao Fu, Central Univ. of Nationalities (China); Bo Tang, Haibo He, The Univ. of Rhode Island (United States)

In this paper, a modified particle swarm optimization (PSO) approach, particle swarm optimization with e-greedy exploration (ePSO), was used to tackle the object tracking. In the modified ePSO algorithm, the cooperative learning mechanism among individuals has been introduced, namely, particles not only adjust its own flying speed according to itself and the best individual of the swarm but also learn from other best individuals according to certain probability. This kind of biologically-inspired mutual-learning behavior can help to find the global optimum solution with better convergence speed and accuracy. The ePSO algorithm has been tested on benchmark functions with various dimensions and demonstrated its effectiveness in high-dimension multi-modal optimization. In addition to the standard benchmark study, we also combined our new ePSO approach with the traditional particle filter (PF) algorithm on the object tracking task, such as car tracking in complex environment. Comparative studies between our ePSO combined PF algorithm with those of existing techniques, such as the particle filter (PF) and classic PSO combined PF will be used to verify and validate the performance of our approach.

8750-28, Session 11

Visual saliency approach to anomaly detection in an image ensemble

Anurag Singh, Univ of Louisiana at Lafayette (United States); Michael Pratt, Henry Chu, Univ. of Louisiana at Lafayette (United States)

Visual saliency is a bottom-up process that identifies those regions in an image that stand out from their surroundings. We adapt a computational visual saliency algorithm to anomaly detection in an image ensemble,

such as an image sequence. In our work, we over segment an image to represent it as a collection of "super pixels" (SPs). Each SP is classified as salient if it is sufficiently different in color from all other SPs and if its most similar SPs are all nearby. We test our method on a collection of image sequences collected by a vehicle. Instead of finding salient SPs in a single frame, we consider an SP in a frame as salient if it stands out from all frames in the collection. We further restrict the method to a region of interest, such as the road ahead of the vehicle. Our collection consists of an ensemble of images from different road segments (referred to as "long term memory") and a sequence of immediate past frames (referred to as "short term memory"). We demonstrate the efficacy of our method on detecting anomalies on the road lane ahead that might correspond to shadows, other vehicles, etc.

8750-29, Session 11

Fast algorithm for entropy estimation

Evgeniy Timofeev, Yaroslavl State Univ. (Russian Federation); Alexei Kaltchenko, Wilfrid Laurier Univ. (Canada)

Proposed is a new fast algorithm for entropy estimation of a given input word. The algorithm utilizes k-nearest neighbor search of a given dictionary. The time complexity of the search is independent of the dictionary size.

8750-30, Session 12

Low-rank modeling and its applications in medical image analysis *(Invited Paper)*

Xiaowei Zhou, Weichuan Yu, Hong Kong Univ. of Science and Technology (Hong Kong, China)

Computer-aided medical image analysis has been widely used in clinics to facilitate objective disease diagnosis. This facilitation, however, is often qualitative instead of quantitative due to the analysis challenges associated with medical images such as low signal-to-noise ratio, signal dropout, and large variations. Consequently, physicians have to rely on their personal experiences to make diagnostic decisions, which in turn is expertise-dependent and cannot be reproduced.

Recently, low-rank modeling based approaches have achieved great success in natural image analysis. There is a trend that low-rank modeling will find its applications in medical image analysis. In this review paper, we like to review the recent progresses along this direction. Concretely, we will first explain the mathematical background of low-rank modeling, categorize existing low-rank modeling approaches and their applications in natural image analysis. Then, we will describe the challenges in medical image analysis. After that, we will illustrate some application examples of using low-rank modeling in medical image analysis. Finally, we will discuss some possibilities of developing more robust analysis methods to better analyze cardiac images.

8750-17, Session 13

Robust compressive sensing of noisy images

Charles C. Hsu, Harold Szu, Charles C. Nguyen, The Catholic Univ. of America (United States)

We wish to explore the research of the robustness property of the image compressive sensing (CS) on the applications of real world perimeter surveillance. We ask two typical questions on the CS area: How many measurements are necessary? How large is the recovery error? Since the Restricted Isometry Property (RIP) introduced by Candès and Tao for random matrices can be used to solve the sparse approximation (SA) problem by l1-regularized least-squares, an unconstrained lasso. Recently Yaniv Plan has examined CS, SA, and Low-rank matrix recovery (LRMR) from a theoretical perspective to demonstrate the efficacy of convex optimization in particular l1 and nuclear-norm minimization based programs in CS, SA, and LRMR (Caltech 2011 Thesis). In this paper, we'd like to explore the numerical simulations on the validity of the Plan-generalized RIP model with a white additive and non-white noise. The main objective of this study and research is to investigate Plan's generalized RIP theorem in support of environmental sensors for security and surveillance with a minimum number of non-redundant and yet informative perimeter surveillance sparse sequence.

8750-32, Session 13

Visual analysis of large graphs in phosphoproteomic data analysis

Anke Meyer-Baese, The Florida State Univ. (United States)

The analysis of large graphs plays an important role in bioinformatics of cancer research. Effective visual analysis of such graphs requires appropriate visual presentations in combination with algorithmic graph analysis methods.

Cancer stem cells (CSC) represent a very small percentage of the total tumor population however they pose a big challenge in treating cancer. The analysis and the understanding of the global interactional behavior of these networks remains a challenging task and has to be accomplished based on sophisticated graph techniques.

The present contribution presents graph visualization techniques according to the type of data supported. The visualization techniques represent a useful platform showing interaction approaches suitable for visual graph exploration. This research enhances our understanding of the differences in phenotype changes and determining the responses of metabolites to certain treatments for the aggressive glioblastoma CSCs. Thus, these new paradigms are providing unique understanding of the mechanisms involved in CSC maintenance and tumorigenicity and are thus opening a new window to biomedical frontiers.

8750-34, Session 14

Health sensor for human body by using infrared, acoustic energy and magnetic signature

Jerry Wu, The George Washington Univ. (United States); Harold Szu, The Catholic Univ. of America (United States)

There is a general chain of events that applies to infections. Human body infection could causes by many different types of bacteria and virus in different areas or organ systems. In general, doctor can't find out the right solution/treatment for infections unless some certain types of bacteria or virus are detected. These detecting processes, usually, take few days to one week to accomplish. However, some infections of the body may not be able to detect at first round and the patient may lose the timing to receive the proper treatment. In this works, we propose a novel health sensor which summarizes human's infrared, acoustic energy and magnetic signature and find out, in minutes, the most possible area or organ system that cause the infection. Therefore, the detection process by doctor will be shortened and it raises the possibility to give the proper treatment to the patient in the earliest timing.

8750-35, Session 14

Monitoring and diagnosis of Alzheimer disease using noninvasive compressive sensing EEG *(Invited Paper)*

Francesco Carlo Morabito, Univ. Mediterranea di Reggio Calabria (Italy); Giuseppe Morabito, Univ. degli Studi di Pavia (Italy); Harold Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Recent advances in Compressive Sensing (CS), a lossy sub-Nyquist signal compression scheme, appear to improve its usefulness for both early diagnosis and continuous wireless telemonitoring of neurological patients, in particular for wearable EEG in personalized medicine [2].

Some authors noted that physiological signals, like EEG, are not sparse neither in time nor in transform domains. This would imply an insufficient quality of the recovered EEG with respect to clinical requirements [5]. However, some other authors find EEG signals sparse in a Gabor frame. A summary of performance of different version of CS are reported in [1], by taking into account a total of 57 hours of EEG: in summary, they concluded that a qualitatively acceptable reconstruction is achieved with a reduction of about one third of the time samples for a single channel recording. If the original signal has N components, with sparsity k, and k < N, CS allows a compression (sparsity) ratio ?=k/N. This could in principle be useful to reduce the transmission rate during a daily remote monitoring, by using a l1-norm convex programming recovery at the monitoring centre.

In this work, we analyse the compressibility of EEG signals from two different perspectives, that, in our opinion, may improve the applicability of CS-EEG:

1) EEG are multivariate non-stationary signals with high inter-channel correlations; they show joint sparseness that is a property potentially useful as a regularization constraint to improve reconstruction performance; furthermore, the map of correlations is quite associated to the electrodes distribution in different brain areas. The measure of sparseness may monitor the variations of correlations among electrodes being the hallmark of specific diseases;

2) Like for the tracking of motion in images where reconstruction exploits redundancy in successive samples of the image, the use of Motion Organized Sparseness (MOS), [3], with its relationships to Independent Component Analysis (ICA), may allow a "guided" reconstruction aiming at real-time applications of wearable EEG.

In particular, we shall propose the use of both purely random sampling and organized sparseness for CS-EEG of three categories of subjects (AD, Mild Cognitive Impaired, and Normal Controls, Nolds) to characterize the different patterns of sparseness. Indeed, EEG from AD patients show higher correlations (synchronization) among electrodes as well as flow directionality modifications. That means, in principle, a reduced ?=k/N with respect to MCI and Nolds. The follow up of patients MCI may also show modification of the sparseness pattern thus indicating a more probable conversion MCI-to-AD. In previous works [4], we measured a reduced complexity of AD EEG through the concept of Permutation Entropy (PE). PE is reduced in AD patients with respect to both MCI and Nold. A correlation between PE and ?=k/N can be found.

The results of our study on a database of about 50 AD patients, 40 MCI and 40 Nolds, obtained through a cooperation agreement with the IRCCS Neurolesi "Bonino-Pulejo" of Messina, Italy, will be reported in the final paper. The impact of CS EEG is clearly more relevant for high-resolution EEG, where a judicious choice of the involved matrices may highly improve the telemonitoring performance. This point will also be discussed in the final presentation.

[1] Abdulghani AM, Casson AJ, Rodriguez-Villegas E, "Quantifying the feasibility of compressive sensing in portable EEG systems". In: Schmorrow DD, Estabrooke IV, Grootjen M (Eds) 5th Int. Conf. on foundations for augmented cognition, LNCS 5638. Springer, Berlin/Heidelberg, pp 319–328, 2009.

[2] Casson A.J., Yates D.C., et al., "Wearable Electroencephalography", IEEE Eng. Med. Biol. Mag., vol.29, no.3, pp.44-56, 2010.

[3] Szu H., Hsu C. et al, "capturing significant events with neural networks", Neural Networks, Vol.29-30, pp.1-7, 2012

[4] Morabito F.C., Labate, D., La Foresta F. Bramanti A., Morabito G., Palamara I. "Multivariate Multi-Scale Permutation Entropy for Complexity Analysis of Alzheimer's Disease EEG", Entropy , 14, pp.1186-1202, 2012

[5] IEEE Signal Processing Magazine, Sensing, Sampling, and Compression, Vol.25, No.2, March 2008

8750-36, Session 14

Principles of biomedical wellness homecare system

Harold Szu, The Catholic Univ. of America (United States)

The 4 P's principles of Medicine": medicine that will be more Predictive, Personalized, Preemptive, and Participatory

8750-37, Session 15

Embryonic stem cells self-assembly model *(Invited Paper)*

Yoshiki Sasai, RIKEN (Japan)

No Abstract Available.

8750-38, Session 16

Understanding 3D Human Torso Shape via Manifold Clustering

Sheng Li, Northeastern Univ. (United States); Peng Li, U.S. Army Natick Soldier Research, Development and Engineering Ctr. (United States); Yun Fu, Northeastern Univ. (United States)

Discovering the variations in human torso shape plays a key role in many design-oriented applications, such as suit designing. With recent advances in 3D surface imaging technologies, people can obtain 3D human torso data that provide more information than traditional measurements. However, how to find different human shapes from 3D torso data is still an open problem. In this paper, we propose to use spectral clustering approach on torso manifold to address this problem. We first represent high-dimensional torso data in a low-dimensional space using manifold learning algorithm. Then the spectral clustering method is performed to get several disjoint clusters. Experimental results show that the clusters discovered by our approach can describe the discrepancies in both genders and human shapes, and our approach achieves better performance than the compared clustering method.

8750-39, Session 16

Inclusion Principle for Statistical Inference and Learning

Xinjia Chen, Southern Univ. and A&M College (United States)

In this paper, we propose a general approach for statistical inference and machine learning based on accumulated observational data. We demonstrate that a large class of machine learning problems can be formulated as the general problem of constructing random intervals with prespecified coverage probabilities for the parameters of the model for the observational data. We show that the construction of such random intervals can be accomplished by comparing the endpoints of random intervals with confidence sequences for the parameters obtained from the observational data. The application of such approach in machine learning is illustrated by examples.

8750-40, Session 16

Simultaneous inference of population proportions and its applications in machine learning

Xinjia Chen, Southern Univ. and A&M College (United States)

In this paper, we develop an exact computational approach for simultaneous inference of population proportions. The main idea of this computational approach is to use branch and bound technique for rigorous checking of coverage probabilities and the probabilities of making wrong decisions. The applications of the method in machine learning is illustrated by examples.

8750-41, Session 16

Entropy estimation and Fibonacci numbers

Evgeniy Timofeev, Yaroslavl State Univ. (Russian Federation); Alexei Kaltchenko, Wilfrid Laurier Univ. (Canada)

A new metric is introduced on a space of right-sided infinite sequences drawn from a finite alphabet. Emerging from a problem of entropy estimation of a discrete stationary ergodic process, the metric is important on its own part and exhibits some interesting properties. Notably, the number of distinct metric values for a set of sequences of length n is equal to F_{n+3} - 1, where F_n is a Fibonacci number.

This study arises from a problem of nonpametric entropy estimation [1] of a discrete stationary process, which generates sequences drawn from a finite alphabet. The estimation accuracy depends on a choice of an underlying metric on a space of right-sided infinite sequences drawn from the alphabet. In this paper, we introduce a new metric, which will have the following properties:

1) The metric is equivalent to a usual metric based on the fist mismatch.

2) For any nonnegative integer m = 0, 1, 2, …, the number of distinct values of the truncated metric is equal to a Fibonacci number F_{n+3} - 1 (with F_0 = 0; F_1 = 1).

We point out that the search for new metrics with special properties is additionally motivated by the following finding in [1]: accurate entropy estimation is obtainable if the averaged inverse function of the measure of a ball is smooth (continuously differentiable).

[1] E. A. Timofeev, Statistical Estimation of measure invariants, St. Petersburg Math. J., 17, no 3 (2006), 527-551.

8750-42, Session 16

User friendly practices of biomedical wellness homecares

Jeffrey C. Jenkins, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Harold Szu, The Catholic Univ. of America (United States)

We review BMW user friendly 4 None practices

8751-1, Session 1

Optimization of background subtraction for image enhancement

Larry Venetsky, Ross Boczar, Robert Lee-Own, Naval Air Warfare Ctr. Aircraft Div. (United States)

Analysis of foreground objects in scenery via image processing often involves a background subtraction process. This process aims to maximize blob (connected component) content of the foreground objects in the post-subtraction image. Quality blob content is often needed to define regions of interest for object recognition and tracking. In our application, we are attempting to extract aircraft and other objects from aircraft carrier deck images. This paper examines three techniques which optimize the subtracted background – a) genetic algorithm (biased stochastic search), b) a mathematical analytic solution based on convex optimization, and c) a related application of the CVX solver toolbox. Given an initial background image, each algorithm adjusts the image in order to find an optimal background solution. Metrics are defined which give a measure of fitness for possible solutions. These metrics reflect both local and global properties of the candidate background images, and are used in each optimization algorithm to evaluate the goodness of potential solutions. The genetic algorithm and CVX solver use these metrics directly, while slight modification of the metrics allows for the derivation of an alternative analytic solution. A set of images, with varying lighting conditions and foreground object density levels, are used to evaluate each optimization algorithm. Over this set of images, the CVX solver and analytic solutions outperform the genetic algorithm for most of the image space. This suggests a possible implementation architecture that uses multiple optimization techniques with subsequent arbitration to produce the best background subtraction.

8751-2, Session 1

Statistical recognition of 3D objects using integral imaging

Cuong M. Do, Univ. of Connecticut (United States)

A model of three-dimensional (3D) object recognition using integral imaging is presented. Multiple elemental images are captured at different perspectives for reconstruction and recognition. Computational results are presented and discussed for performance evaluation.

8751-4, Session 1

Spatial Context for Moving Vehicle Detection in Wide Area Motion Imagery with Multiple Kernel Learning

Pengpeng Liang, Temple Univ. (United States); Dan Shen, Intelligent Fusion Technology, Inc (United States); Erik P. Blasch, Khanh Pham, Air Force Research Lab. (United States); Zhonghai Wang, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Haibin Ling, Temple Univ. (United States)

Moving vehicle detection from wide area motion imagery (WAMI) is an important and challenging task in persistent surveillance. Previously, we verified that context information is useful to improve the performance of the WAMI object detection task. In this paper, we present a novel Temporal Context (TC) method which captures the road information. In contrast with previous methods to exploit road information, TC does not need a road map or to use the Geospatial Information Systems (GIS) information. We first use background subtraction to generate the target candidates, then build TC based on positive-classified candidates by using Histograms of Oriented Gradient (HOG) with a Support Vector Machine (SVM). For each positive candidate, a region around the candidate is divided into several subregions based on the direction of the candidate. Then each subregion is divided into 12 bins with a fixed length. Finally, the TC histogram is built according to the positions of the candidates in 8 consecutive frames. In order to benefit from both the appearance and context information, we use multiple-kernel learning to combine the TC and HOG for improved object detection. To evaluate the effect of TC, we use the publicly available CLIF 2006 dataset, and label the vehicles in 204 frames which are 1200 2672 subregions that contain an expressway in the original 4008 2672 pixel image. The experiments demonstrate that the proposed TC method is useful to remove the false positives that are away from the road; and the combination of TC and HOG with multiple kernel learning outperforms the use of TC or HOG only.

8751-5, Session 2

Hybrid optimized genetic algorithm for bayesian network structure learning

Feng Lin, Zhejiang Univ. (China); Chunyan Zhou, Shaoxing Vocational & Technical College (China); Wei Sun, K. C. Chang, George Mason Univ. (United States)

Bayesian network is one of the most important theoretical models on figuring out the uncertain problems, and the Bayesian network structure learning is the core of Bayesian network theory. At present, the search&score algorithm for structure learning proved to be one of the most effective methods. It was proposed in this framework the method of learning Bayesian network structure based on hybrid genetic and fish swarm algorithm. This method firstly use the maximum weight spanning tree to generate the candidate networks, and then use the artificial fish swarm algorithm referring to the ideas of crossover and mutation methods of genetic algorithm to optimize the initial populations. Because of the randomness of the stage of the searching food in the artificial fish swarm algorithm, we bring the cloud-based adaptive theory into this stage to improve it. Simulation experiments demonstrate that this approach has quite a good optimization ability in Bayesian network structure learning

8751-6, Session 2

Fusing video and text data by integrating appearance and relational similarity

Georgiy M. Levchuk, Aptima, Inc. (United States); Aaron F. Bobick, Georgia Institute of Technology (United States); Mathew Jacobsen, Aptima, Inc. (United States)

The automated event and activity recognition from video and text data sources are key enablers of situation understanding in complex dynamic environments. To enable close-loop solution in which patterns of emerging activities are learned without need for manual data preparation, and text data is converted into context and enriching features, new technologies are needed that can fuse video and text sources. This fusion is achieved by associating the entities and events mentioned/detected in text and video data. However, this association is challenging due to frequent absence of any meaningful correspondence features between video and text entities in a single instance of the video-text data pair.

In this paper, we present a model that performs joint probabilistic association between entities mentioned in text (e.g., “three ambulances arrived at the scene”) and entities detected in video data (e.g., “3 vehicles arriving detected”). This model minimizes the appearance and relationship similarity errors, where appearance similarity is calculated

between entities from different video-text pairs using pixel information in video and semantic similarity in text data, while the relationships similarity includes correspondences between the interactions and relative spatial positioning of the objects detected in video and mentioned in text for the same video-text pair. The joint association is obtained by finding the matching between video and text entity-relationship networks. The use of similarity, interaction, and relative positioning relations uniquely resolves the ambiguity present in text data and variability of visual appearance of objects, events, and activities.

8751-9, Session 2

Applications of the Self Organizing Map (SOM) in Unattended Ground Sensor (UGS) systems

Brent W. Roeder, McQ, Inc. (United States)

Many Unattended Ground Sensors (UGS) leverage multiple sensing modalities (e.g. seismic, magnetic, imagery, radar, etc.) to detect and classify targets of interest. One of the most effective means of reducing a sensor's probability of false alarm while increasing its probability of detection is through multisensor fusion. The types of sensor information available for this kind of processing by UGS systems are continually changing. Typically, as new sensing modalities become available, a new custom fusion algorithm must be developed that is compatible with the new sensor types. What is needed is an algorithm that can fuse current and future sensory data without the need for modification for each new sensing type. An Artificial Intelligence (AI) algorithm that we have shown to be particularly well suited for this purpose is the Self Organizing Map (SOM). The SOM (also known as the Kohonen Network) is an unsupervised learning algorithm developed by Teuvo Kohonen and others in the early 1980's. In this paper, we describe the results of our research efforts that demonstrate the effectiveness of the SOM at processing disparate kinds of data. As part of our research, both hardware and software implementations were performed and their performance characterized against various data types. We will present these results and then show a path to using the SOM for multisensor fusion in UGS systems.

8751-10, Session 3

Trusted computation through biologically inspired processes

Gustave Anderson, Luna Innovations Inc. (United States)

(Introduction) -

Supply chain threats and statically configured systems have invalidated the assumption that a well-funded adversary has no reasonable avenue of attack even if the software protections are structured properly and augmented with secure hardware. In today's cyber-attack environment, one must assume that a subset of the system is currently, or will eventually be compromised. Luna is developing a of a fault tolerant, federated cloud computing architecture, which supports design separation for high reliability and information assurance. By leveraging a hybrid fault model with multiple, parallel execution paths and resultant execution trace comparison, Luna has created a cognitive trust architecture that identifies suspect nodes and assures trusted execution. Furthermore, the modeled architecture may be scaled through proactive thread diversity for additional assurance during threat escalation. The solution provides dynamic protection through distributing critical information across federated cloud resources that adopt a metamorphic topology, redundant execution, and the ability to break command and control of malicious agents.

(Biologically Inspired Approach) -

Our cognitive trust approach to ensure continued operation under the assumption of imminent compromise is modeled after the human immune system. The immune system is a system of biological structures and processes that protects against disease. For the immune system to function properly it must first detect the presence of a wide variety of agents. Conversely to compromise the system, pathogens must rapidly evolve and adapt to avoid detection and neutralization by the immune system. To rapidly evolve, pathogens must gather increasingly more information about the systems which they are trying to compromise. The more genetic information required for compromise; the increased risk of exposure

(Critical Assets) -

Currently most security solutions attempt to find the mythical silver bullet and achieve the ever elusive "perfectly secure" system. In the end, there is no such thing. Next generation security systems must be mindful of what are the critical assets regardless of whether they are data or systems or the like. With knowledge of the critical assets, the security system should then spend the vast majority of its effort detecting and protecting against attacks which attempt to compromise the critical assets. We assert that only then a "cost of compromise" vs "cost of prevention" analysis may be profitable.

In our scenario, the critical assets are (1) the IP of the algorithm and (2) the unimpaired execution of that algorithm. As a result, we spend minimal effort trying to prevent the compromise of nodes in our network; rather, we assume that a subset of the system is currently owned by the adversary. Consequently, our approach, like the immune system, is to make it mathematically infeasible for an adversary to simultaneously remain covert and exploit our critical assets.

8751-11, Session 3

A developmental approach to learning causal models for cyber security

Jonathan Mugan, 21CT (United States)

To keep pace with our adversaries, we must expand the scope of machine learning and reasoning to address the breadth of possible attacks. One approach is to employ an algorithm to learn a set of causal models that describes the entire cyber network and each host end node. Such a learning algorithm would run continuously on the system and monitor activity in real time. With a set of causal models, the algorithm could anticipate novel attacks, take actions to thwart them, and predict the second-order effects of those actions. Designing such an algorithm is a complex task because computer systems generate a flood of information, and the algorithm would have to determine which streams of that flood were relevant in which situations.

This paper will present the results of efforts toward the application of a developmental learning algorithm to the problem of cyber security. The algorithm is designed to allow an agent to learn about the computer system in which it resides through active exploration. The algorithm is developmentally restricted to learn new information only at the edge of its current knowledge. This developmental learning restriction is inspired by the work of the psychologist Jean Piaget. Piaget described how children construct knowledge in stages and learn new concepts on top of those they already know. Developmental learning allows our algorithm to focus on subsets of the environment that are most helpful for learning given its current knowledge. In experiments, the algorithm was able to learn the conditions for file exfiltration.

8751-12, Session 3

Computational intelligence and neuromorphic computing potential for cybersecurity applications

Robinson Pino, Michael Shevenell, ICF International (United States); Hasan Cam, U.S. Army Research Lab. (United States); Mark R. McLean, Ctr. for Exceptional Computing (United States)

In today's highly mobile, networked, and interconnected internet world, the flow and volume of information is overwhelming and continuously increasing. Therefore, it is believed that the next frontier in technological evolution and development will rely in our ability to develop intelligent systems that can help us process, analyze, and make-sense of information autonomously just as a well-trained and educated human expert. In computational intelligence, neuromorphic computing promises to allow for the development of computing systems able to imitate natural neuro-biological processes that will form the foundation for intelligent system architectures. This is achieved by artificially re-creating the highly parallelized computing architecture of the mammalian brain. As an interdisciplinary technology inspired from biology, artificial neural systems have been successfully utilized in many applications, such as control systems, signal processing, pattern recognition, vision systems, and robotics etc. In addition, the emerging neuromorphic computing field can also exploit the characteristic behavior of novel material systems with advanced processing techniques to achieve very large scale integration with highly parallel neural architectures for the fabrication physical architectures. This talk will focus on the technological challenges that we are seeking to overcome to enable intelligent parallel neuromorphic computing systems.

8751-13, Session 3

Human guided machine learning for Real-Time identification and characterization of cyber attacks

Misty Blowers, Air Force Research Lab. (United States)

No Abstract Available.

8751-14, Session 4

A pipelined FPGA implementation of an encryption algorithm based on genetic algorithm.

Nonel S. Thirer, Holon Institute of Technology (Israel)

With the evolution of digital data storage and exchange, it is essential to protect the confidential information from every unauthorized access. High performance encryption algorithms were developed and implemented by software and hardware. Also many methods to attack the cipher text were developed. In the last years, the genetic algorithm has gained much interest in cryptanalysis of cipher texts and also in encryption ciphers.

This paper analyses the possibility to use the genetic algorithm as a multiple key sequence generator for an AES (Advanced Encryption Standard) cryptographic system, and also to use a three stages pipeline (with four main blocks: Input data, AES Core, Key generator, Output data) to provide a fast encryption and storage/transmission of a large amount of data.

Thus, the input data unit receives the initial data stream and provides fixed size data blocks (plaintexts) to the AES core. Every plaintext is encrypted by the AES core using a new key-sequence, provided by the GA based key generator. This key-generator is based on crossover and mutation only. The new chromosomes provide the new key-sequence and are also the parents for the next generation. The cipher text is provided to Output data block to storage or transmission. The FPGA implementation of this pipeline is analyzed, concerning advantages, extensions and limits. For a faster processing of a large amount of data (as images), a parallel processing is analyzed.

For decryption, the same GA based key generator must be used (with the same initial key). Brute force or GA based attacks are more difficult for large blocks of data, due to various keys for every cipher text.

8751-16, Session 4

A spider-web approach to the recovery of ad hoc cognitive radio networks of heterogeneous sensor nodes in energy-limited environments

William S. Hortos Jr., Associates in Communication Engineering Research and Technology (United States)

In ad hoc deployments of wireless sensor networks (WSNs), consisting of cognitive radios and heterogeneous sensor nodes in battlefield and similar environments characterized by autonomous, energy-limited operation, the network may incur the operational loss of a sufficient number of nodes to cause partitioning of the topology. The objective of this work is to develop a strategy for restoring network connectivity in response to widespread heterogeneous node outages due to sensor failures and energy depletion, through placement of additional relay nodes. The bio-inspired approach to WSN recovery is based on the behavior of spiders in repairing webs. The approach reestablishes link connectivity required by the mission using the least number of relays and cognitive awareness of available resources, while guaranteeing a certain degree of connectivity in the repaired topology. In contrast to methods that seek to form a minimum spanning tree among the partitioned sections of the damaged network, the proposed approach establishes a topology that resembles a spider web, in which the disjoint segments are positioned at the network periphery. The resulting topology displays greater connectivity than a minimum spanning tree and also achieves superior area coverage. Furthermore, the approach achieves balanced distribution of traffic among the deployed relay nodes. The recovery approach based on spider webs is extended, so that the degree of connectivity in the repaired topology is ensured to the next higher level. Both centralized and distributed versions of the bio-inspired spider-web approach are developed. Simulation results for a WSN, deployed in an energy-limited scenario, demonstrate the efficacy of the proposed resource-aware, spider-web recovery algorithm compared to that of an approach based on minimum spanning trees.

8751-17, Session 5

Vehicle tracking and analysis within a city

Yu Liang, Michael Henderson, Shane Fernandes, Central State Univ. (United States); Josh Sanderson, Wright State Univ. (United States); Darrell Barker, Air Force Research Lab. (United States)

Sensor-oriented vehicle tracking and analysis of a city (VTAC) plays an important role in transportation control, public facility management and national security. This project is dedicated to the development of a generic VTAC framework, which employs temporal and spatial dependent partial differential equations (PDE) to formulate the expected traffic flow, through which movement of the observed vehicles may be measured and analysis. The boundary conditions and parameters for the traffic flow are derived from the statistical analysis about historical transportation data; the physics domain is derived from the geographic information system. Using the artificial video data generated by Blender as benchmark data, the VTAC framework is validated by measuring and identifying those anomalous vehicles appeared in the video.

8751-18, Session 5

Exploring manifold learning using laser vibrometry data

Andrew M. Freeman, Air Force Research Lab. (United States); Scott J. Kangas, Jacobs Engineering Group Inc. (United States); Olga Mendoza-Schrock, Air Force Research Lab. (United States)

Understanding and organizing data is the first step toward exploiting

vibrometry sensor phenomenology for target classification. What signal features are good for distinguishing vehicles and other such targets and what measurements, or combination of measurements, can be used to classify the dataset by type? A particular technique, Diffusion Maps, has demonstrated the potential to extract features that intuitively make sense [1]. We want to develop an understanding of this tool by validating existing results using vibrometry data. If we could specifically measure the defining features for classification then the future question will then be to determine a subset of these features that can be measured remotely. This paper briefly describes the Diffusion Map technique, shows potential for dimension reduction for vibrometry data, and describes interesting problems to be further explored.

8751-19, Session 5

The effects of clothing on gender classification using LIDAR Data

Ryan R. McCoppin, Nathan Koester, Howard N. Rude, Louis A. Tamburino, Wright State Univ. (United States); Andrew M. Freeman, Air Force Research Lab. (United States); Mateen M. Rizki, Wright State Univ. (United States); Olga Mendoza-Schrock, Air Force Research Lab. (United States)

In this paper we describe preliminary efforts to extend previous gender classification experiments using feature histograms extracted from 3D point clouds of human subjects. The previous experiments used point clouds drawn from the Civilian American and European Surface Anthropometry Project (CAESAR anthropometric database provided by the Air Force Research Laboratory (AFRL) Human Effectiveness Directorate and SAE International). This database contains approximately 4,400 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. The recognition results with the tightly control CAESAR database reached levels of over 90% accuracy. A smaller secondary point cloud data set was generated at Wright State University to allow experimentation on clothed subjects that was not possible with the CAESAR data. We present the preliminary results for the transition of classification software using different combinations of training and tests sets taken from both the CAESAR and clothed subject data sets. As expected, the accuracy achieved with clothed subjects fell short of the earlier experiments using only the CAESAR data. Nevertheless, the new results provide new insights for more robust classification algorithms.

Conference 8752: Modeling and Simulation for Defense Systems and Applications VIII

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8752-1, Session 1

High-fidelity modeling and simulation for wideband receiver development

Chen Wu, Anne Young, Defence Research and Development Canada, Ottawa (Canada)

Research experience has shown that it is expensive to design, build and test a RF/microwave system that is comprised of various RF/microwave components. In order to mitigate the problem, High-Fidelity Modeling and Simulation (HFM&S) is a practical approach that includes high-fidelity behavioural model (HFBM) of the receiving system and scenarios embedded with different Concept of Operations (CONOPS). HFM&S is also an essential way to develop receiving system specifications that can be used for system validation and verification.

This paper presents the HFBM of a wideband digital receiver using Matlab/Simulink® and the RF Toolbox/RF Blockset®, and the use of the model to build a multi-channel receiving system that has a linear antenna array. The receiving system is installed on an UAV to intercept a ground-based emitter signal in a scenario that is built in Satellite Tool Kit®. Through the design and build of the UAV payload and its deployment in a scenario, this paper demonstrates the following:

• what is meant by HFBM of a system and how it can simulate real hardware;

• how signal integrity in the HFM&S can be and should be retained;

• why amplitude and phase are important for signal waveform level M&S;

• why the modern high performance computing technology should be used for signal waveform M&S; and

• why the development of a realistic scenario is an important part of HFM&S for application CONOPS development?

8752-2, Session 1

Integration of radio-frequency transmission and radar in general software for multimodal battlefield signal modeling

Kenneth K. Yamamoto, Nathan J. Reznicek, D. Keith Wilson, U.S. Army Engineer Research and Development Ctr. (United States)

Radio-frequency (RF) transmission and radar systems were integrated into a general framework for modeling and simulating battlefield signal propagation. Specifically, the U. S. Navy Electromagnetic Propagation Integrated Resource Environment (EMPIRE), which contains nearly twenty different realistic RF propagation models, was integrated into the Environmental Awareness for Sensor and Emitter Employment (EASEE) software, being developed by the U. S. Army ERDC. The integration utilizes an XML-based interface between EASEE and EMPIRE to set inputs for and run propagation models. To accommodate radars, fundamental improvements to the EASEE software architecture were made to support active-sensing scenarios by including forward and backward propagation of RF signals between radar and target. Models for reflecting targets were defined to apply a target-specific reflection coefficient (i.e., scattering cross section) to incident wavefields and to produce a radiation pattern depicting the directionality of signal reflections. The newly added RF modality increases EASEE's capabilities for simulating a wide variety of sensor modalities, which also include acoustic, seismic, electro-optical/infrared, and chemical/biological. EASEE is a transitioning software capability that performs operationally focused simulations for defense force protection and surveillance planning applications. EASEE predicts sensor performance and optimizes sensor selection and placement for target detection by characterizing complex terrain and weather effects on target signatures, signal propagation, and sensor systems. It has an expansive library of realistic physics models and statistical methodologies that account for uncertainties from random signal-generation and propagation mechanisms. A flexible object-oriented design approach allows for efficient integration and simulation of diverse signal modalities within EASEE.

8752-3, Session 1

Model-driven requirements engineering (MDRE) for real-time ultra-wide instantaneous bandwidth signal simulation

Daniel Y. Chang, Naval Air Warfare Ctr. Weapons Div. (United States)

While conducting a cutting-edge research in a specific domain, we realize that (1) requirements clarity and correctness are crucial to our success, (2) hardware is hard to change, most work is in software requirements development, coding and testing [ ], (3) requirements are constantly changing, so that configurability, reusability, scalability, adaptability, modularity and testability are important non-functional attributes, (4) if our research is successful, the results could be applied to other domains with similar problems. In this paper, we propose to use model-driven requirements engineering (MDRE) to model and guide our requirements/development, since models are easy to understand, execute, and modify. The domain for our research is Electronic Warfare (EW) real-time ultra-wide instantaneous bandwidth (IBW) signals simulation. The proposed four MDRE models are (1) ADC/FPGA/DAC architecture, (2) parallel data channels synchronization, (3) post-DEMUX (post-ADC) and pre-MUX (pre-DAC) bits re-mapping, and (4) Discrete Fourier Transform (DFT) filter bank. This research is unique since the instantaneous bandwidth we are dealing with is in gigahertz range instead of conventional megahertz.

8752-4, Session 2

NASA Operational Simulator (NOS) for V&V of complex systems

Scott Zemerick, TMC Technologies (United States); Justin Morris, NASA IV&V (United States)

The NASA Operational Simulator (NOS) is introduced as a generic software-only simulation architecture for NASA missions. NOS was developed by the NASA Independent Verification & Validation (IV&V) Independent Test Capability (ITC) Team to provide a complete software V&V environment. NOS is utilized by developers and (independent) testers to verify the functionality of a spacecraft's flight software from a system-wide perspective. Use of NOS on two NASA spacecraft are described: the Global Precipitation Measurement spacecraft and the James Webb Space Telescope. While NOS has primarily been utilized on NASA missions, its generic architecture can be easily applied across domains to support V&V of complex systems.

NOS is capable of executing the spacecraft's unmodified flight software executable on readily deployed environments such as laptops and thumbdrives. NOS consists of reusable hardware models, simulators, and custom-developed middleware that provides simulated MIL-STD-1553 and SpaceWire busses. A key feature is its dynamic error injection capabilities via intuitive GUIs and open APIs. The error injection is critical for performing V&V of the flight software; hardware faults can be simulated and off-nominal tests can be executed without additional effort. NOS is easily integrated with ground systems and other components to support complete mission analysis.

Typically, engineers are limited to a minimal number of hardware test-strings with little availability. NOS reduces this risk because it supports unlimited deployment. Engineers can quickly test concepts before hardware tests are executed. In addition to creating complete system simulators, NOS can also serve as a stop-gap solution for when hardware is unavailable.

8752-5, Session 2

Validating an artificial intelligence human proximity operations system with test cases

Justin R. Huber, Jeremy Straub, The Univ. of North Dakota (United States)

An artificial intelligence-controlled robot (AICR) operating in close proximity to humans poses numerous risks to these humans. These risks range from keeping people and processes safe in the context of the AICR's situation-specific decision making to ensuring a safe response to unplanned situations or environments. Validating the performance of an AICR, which must operate in a real-world environment, is an ill posed problem due to the complexity that is introduced by the erratic (non-computer) actors. In order to prove the AICR's usefulness, test cases must be generated to simulate the actions of these actors, so the AICR can be shown to perform properly in the environments where it will be operated. This paper looks at validating an AICR's safe performance in the context of a common human activity, moving through a crowded corridor, using test cases. This test is a two-dimensional simplification relevant to autonomous UAV navigation in the national airspace.

An AI use case producer (UCP) is be used to generate test cases for AICR validation. It employs a pseudo-random operation script generation technique for the simulated actors. The question of how many use cases are necessary to show that the AICR is able to operate successfully is discussed. The benefits and drawbacks of using the AI UCP are considered and the difference in testing throughput from using the AI UCP versus human test case generation is characterized. The challenge of validating AICR safety, given a nearly infinite set of possible circumstances that it may encounter, is also explored.

8752-6, Session 2

A five states survivability model for missions with ground-to-air threats

Tina Erlandsson, Saab AB (Sweden); Lars Niklasson, Univ. of Skövde (Sweden)

Fighter aircraft flying in hostile territory are exposed to the risk of getting hit by enemy fire from ground-based air defense systems. A model describing the survivability for a route, i.e., the probability that aircraft can fly the route unharmed, would be a useful component in support systems for planning suitable routes to fly as well as evaluating flown routes. The survivability model presented here is based on a continuous Markov model with five states; Undetected, Detected, Tracked, Engaged and Hit. The enemy is described with sensor areas and weapon areas and the transition intensities in the Markov model depend on whether or not the aircraft is inside any of these areas. For example, the aircraft can only get tracked when inside a sensor area and can only get hit when inside a weapon area. The five states model enables the separation of the risk of getting detected and the risk of getting hit and the user can chose to focus on one or both or these risks depending on the importance of the mission. Furthermore, the fact that the enemy's sensor systems can exchange information is taken into account, implying that the risk of getting tracked is increased if another sensor system has previously detected the aircraft. The paper also includes a discussion regarding which factors that impact the transition intensities. Simulations of illustrative scenarios are presented for highlighting the properties of the model and areas for further development of the model are suggested.

8752-8, Session 3

Method for simulating free space optical data links for personnel applications

Kiron Mateti, Naval Surface Warfare Ctr. Crane Div. (United States); Brandon R Clarke, Ean J Seals, Gregory J Petty, Hoang Q Tran, Courtney L Boykin, Gail M Nicholson, Joshua D Borneman, Naval Surface Warfare Center Crane Electro Optic Technology Division (United States)

Free Space Optical (FSO) wireless data links are a proven and ready technology for non-RF communications. This technology could be used to feed high definition video data from a scope to soldier or a platoon for advanced situational awareness. A major design challenge for FSO links in personnel applications is ensuring line of sight (LoS) between transmitter and receiver during crucial moments in a mission. Laser based communications have very high bandwidth but very narrow Field-of-View (FOV). LED based systems could provide wider FOV, yet need specifications on the FOV and proper placement of transmitter and receiver. Currently, no study exists on the FOV requirements or placement of these systems for personnel applications . In this work, we capture the movements of a warfighter in a typical application where an FSO data link would be used. We track head and gun movements using image processing techniques. We present a method to simulate transmitter and receiver on the warfighter helmet and gun scope and analyze LoS and FOV. Using this method allows optimization of FSO data link placement and provides requirements for future FSO technology.

8752-9, Session 4

Super-resolution mosaics from airborne video using robust gradient regularization and optimization algorithm

Aldo Camargo, Ingenia Technology Ltd. (Peru); Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Qiang He, Mississippi Valley State Univ. (United States); Fidel Jara, National University of Engineering (Peru)

Unmanned Aircraft Systems (UAS) have been used in many military and civil applications, particularly surveillance. Lastly, there are industries: farms, oil, mines, etc., that are interested on this technology. One of the best ways to use the capacity of a UAS imaging system is by constructing a mosaic or panorama of the recorded video. However, the data analysis of UAS videos is frequently limited by motion blur; the frame-to-frame movement induced by aircraft roll, wind gusts, and less than ideal atmospheric conditions; and the noise inherent within the image sensors. Therefore, using super-resolution mosaicking of low-resolution UAS surveillance video frames, becomes a critical requirement for UAS video processing and important for further effective image understanding. This paper presents a novel algorithm for the construction of super-resolution mosaicking. The algorithm is based on the Conjugate Gradient (CG) method and Geman -McClure prior function for the regularization of the ill-conditioned problem.

8752-10, Session 4

Review scalable high performing solutions using GPUs

Thomas Reed, NVIDIA Corp. (United States)

We will review the following three case studies

1. DigitalGlobes use of GPUs to improve the latency of Orthorectification and Pan-Sharpening

2. Image processing algorithm chain - imrovement to SWAP

3. MotionDSP - GPUs impact the reattime aspect of viedoe processing

8752-11, Session 4

Advances in computational fluid dynamics solvers for modern computing environments

Daniel L. Hertenstein, John R. Humphrey Jr., Eric 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). While the capabilities of CFD solvers have continually increased and improved to support features such as moving bodies and adjoint-based mesh adaptation, the software architecture has not. This has led to poor scaling as core counts reach the tens of thousands. In the modern High Performance Computing (HPC) world, clusters with hundreds of thousands of cores are becoming the standard. In addition, accelerator devices such as NVIDIA GPUs and Intel Xeon Phi are being installed in the majority of new systems. It is important for CFD solvers to take advantage of the new hardware as the computations involved are well suited for the massively multicore architecture. In our work, we demonstrate the need and benefits of rearchitecting current CFD solvers and incorporating accelerators by example using AVUS, a CFD solver developed by the Air Force Research Labratory (AFRL) and the Volcanic Ash Advisory Center (VAAC). The effort has resulted in increased performance and scalability with openness to facilitate the use of alternative accelerators and without sacrificing accuracy. There are many well-known codes in the CFD space that can benefit from this work, such as FUN3D, OVERFLOW, and TetrUSS. Such codes are widely used in the commercial, government, and defense sectors.

8752-12, Session 5

Productive high-performance software for OpenCL devices

John M. Melonakos, AccelerEyes LLC (United States); Pavan Yalamanchili, Chris McClanahan, Umar Arshad, Michael Landes, Shivapriya Jamboti, Abhijit Joshi, Shehzan Mohammed, Kyle Spafford, Vishwanath Venugopalakrishnan, AccelerEyes (United States); James Malcolm, AccelerEyes LLC (United States)

Over the past 5 years, heterogeneous computing has gone from nice to must-have in technical computing. OpenCL represents the standard by which CPUs, GPUs, APUs, FPGAs, DSPs, and mobile devices are being programmed for speed. However, OpenCL is difficult to program and adoption is limited. Further, those that do adopt OpenCL find it difficult to easily achieve good performance and even more difficult to achieve good performance across chips from different vendors. Compilers are unable to automatically exploit the parallelism benefits in any meaningful way. These problems are solved by the high-performance ArrayFire software library that represent the best of both worlds, providing an easy-to-use interface of functions while simultaneously delivering top-notch speeds.

8752-13, Session 5

Scalable models for programming modern HPC systems

Kyle E Spagnoli, John R. Humphrey Jr., Paul A. Fox, Eric J. Kelmelis, EM Photonics, Inc. (United States)

Modern high performance computing (HPC) systems consisting of traditional multi-core processors augmented with massively parallel co-processors are rapidly becoming commonplace in today's computing landscape. Presently three of the top ten supercomputers in the world are implemented with this hybrid architecture. Effectively utilizing these systems has been an area of research and most of the solutions proposed are only relevant to a single codebase, computing technique, or hardware platform. As such, the rate of adoption of these hybrid architectures into real world HPC applications has been slow. The principal challenge lies in the fact that co-processor architectures imposes an additional level of programmer concern. Issues such as managing distributed memory, platform specific kernel tunings, hardware initialization, and load balancing must be re-evaluated upon the arrival of each new generation of hardware. In our work, we present modern programming methods in which a program is represented as an interconnected graph of hardware independent tasks. From this graph, we create an efficient execution plan that dispatches the work appropriately to an available computing element capable of running the task. This model offers the benefits of high utilization, seamless scalability to larger systems, and a simple solution to utilize new (or future) hardware devices. This approach is applicable to a number of common HPC problems such as linear algebra, image processing, climate simulation, and computational fluid dynamics.

8752-14, Session 5

Performance impact of dynamic parallelism on different clustering algorithms

Jeffrey T. DiMarco, EM Photonics, Inc. (United States); Michela Taufer, Univ. of Delaware (United States)

CUDA is NVIDIA's parallel computing platform and programming model that is constantly pushing the boundaries of computational parallelism. The newest version, CUDA 5, introduces dynamic parallelism, which allows GPU threads to create new threads and adapt to its data. This effectively eliminates the superfluous back and forth communication between the GPU and CPU through nested kernel computations. An Eclipse edition of Nsight has also been released alongside CUDA 5 for more efficient development, debugging, and profiling on Linux. In this paper, we aim to quantify the performance gains of dynamic parallelism versus the previous implementations of CUDA and the CPU. We will take advantage of the features that Nsight Eclipse Edition provides to profile and compare the performance of CUDA 4.0 to CUDA 5.0 with and without dynamical parallelism. The change in performance will be measured using two well-known clustering algorithms that are data dependent: k-means clustering and hierarchical clustering. K-means has a sequential data dependency wherein iterations occur in a linear fashion, while hierarchical clustering has a tree-like dependency that produces split tasks. Analyzing the performance of these data dependent algorithms across multiple platforms will give us a better understanding of the benefits or drawbacks to CUDA 5's new dynamic parallelism feature.

8752-15, Session 5

Applying big data techniques to heterogeneous military data

John R. Humphrey Jr., Kyle E. Spagnoli, Eric J. Kelmelis, EM Photonics, Inc. (United States)

In the last decade, the computing industry has made major advances in the ability to store and, more importantly, to search massive data sets. A huge emphasis has been placed on consumer applications, such as web search, image tagging, and song recognition, but there is an opportunity now to apply these tools to military applications. The military has deployed countless sensor types that collect data of many types, and there is a desire to be able to search and analyze this data across sensor types. For instance, a soldier in the field equipped with a smart phone can take a picture of a vehicle, and within moments receive an identification and operational readout of that vehicle. Meanwhile, that picture is entered into a database and geo-tagged for later data-mining efforts to analyze things such as enemy troop movements. To effectively build such a system relies on powerful new platforms such as Hadoop and Cassandra, with data- and use-case-centric indexing schemes that allow for rapidly accessing appropriate data from what is potentially a petabyte or more. In this talk, we discuss our approach to bridging the gap between freely available commercial tools targeted at consumer applications and the needs of the military.

8752-16, Session 6

Digital command and control (C2) in electromagnetic battlespace

Ekrem Kurt, Turkish Air Force Academy (Turkey)

Military operations are executed in an increasingly complex electromagnetic environment. Over the last decade, All nations focused on improving their signals intelligence capabilities which has significantly improved intelligence support to EW. Today, there are many evolving facets of electromagnetic battlespace that include not only Electronic Attack (EA) but also improved situational awareness via information sharing and optimal positioning of Electronic Support (ES) systems, whether it is on a ship, a ground vehicle or an aircraft, for example. The aim is to use EW resources more intelligently in the battlespace and, by extension, improve their effectiveness. Another benefit is to provide tactical commanders with a timelier and less ambiguous picture of the electromagnetic battlespace.

In this study, it will be explained that if the targets using electromagnetic spectrum, can be dynamically detected and a linkage between 5th generation missile systems and platforms are obtained, command and control in EM Battlespace can be done more efficiently. It is planned to establish a joint management system which is able to obtain real-time data of the electromagnetic spectrum and be able to evaluate planned and achieved electronic atttacks. As we live in a network related life, it is needed to put out electronic capabilities at strategic and operative levels in order to seek for requirements at the same time. For this reason, EW capabilities must be fully integrated with joint command and control systems to enable information sharing, and to provide an accurate common operational picture (COP) of EW operations.

8752-17, Session 6

Determining the flare dispensing program effectiveness against conical-scan and spin-scan reticle systems via Gaussian mixture models

Mehmet C. Sahingil, Murat S. Aslan, TÜBITAK UEKAE (Turkey)

The reticle systems which are considered as the classical approach for determining the angular position of radiating targets in infrared band are widely used in early generation surface-to-air and air-to-air infrared guided missile seekers. One of the cost-effective ways of protecting aircrafts against these missiles is to dispense flare decoys from the counter-measure dispensing system (CMDS) integrated into the aircraft platform. Although this counter-measuring technique seems very simple, if not optimized carefully, it may not be effective for protecting the aircraft. Flares should be dispensed in accordance with a specific dispensing program which determines the number of flares to be dispensed from each dispenser of the CMDS and timing sequence of dispensing. Optimizing the parameters of the dispensing program is not trivial. It requires a good understanding of the operating principle of the threat seeker, operational capabilities of own platform and engagement scenario between them.

In the present paper, we propose a complete simulation-based procedure to form an effectiveness boundary of flare dispensing programs against the spin-scan and conical-scan reticle seekers. The region of effectiveness is determined via Gaussian mixture models. The raw data is collected via extensive number of simulations using a MATLAB-coded simulator which models reticle-based seeker, aircraft radiation, aircraft motion, aircraft CMDS system, flare motion and flare radiation.

8752-19, Session 6

GPU-enabled projectile guidance for impact area constraints

Jonathan Rogers, Texas A&M Univ. (United States)

Guided projectile engagement scenarios often involve impact area constraints, in which it may be less desirable to incur miss distance on one side of a target or within a specified boundary near the target area. Current projectile guidance schemes such as impact point predictors cannot handle these constraints within the guidance loop, and as a result will produce dispersion patterns that are insensitive to these constraints. In this paper, a new projectile guidance law is proposed that leverages real-time Monte Carlo impact point prediction to continually evaluate the probability of violating impact area constraints. The desired impact point is then adjusted accordingly. Real-time Monte Carlo simulation is enabled within the feedback loop through use of graphics processing units (GPU's), which provide a large number of parallel pipelines through which a dispersion pattern can routinely be predicted. The result is a guidance law that can achieve minimum miss distance while avoiding impact area constraints. First, the new guidance law is described and formulated as a nonlinear optimization problem which is solved in real-time through massively-parallel Monte Carlo simulation. Then, an example simulation is shown in which impact area constraints are enforced, and results are compared with a standard impact point predictor scheme. Finally, dispersion simulations are described which demonstrate the ability of the GPU-enabled guidance scheme to avoid an arbitrary set of impact area constraints, generating an impact probability density function that optimally trades miss distance within the restricted impact area. The proposed guidance scheme has applications beyond smart weapons to include missiles, UAV's, and other autonomous systems.

8752-20, Session 6

Characterization of infrared imaging performance within a general statistical framework for environmental impacts on battlefield signals and sensing

D. Keith Wilson, U.S. Army Engineer Research and Development Ctr. (United States); Christopher T. Borden, Elizabeth S. Bettencourt, Atmospheric and Environmental Research, Inc. (United States); Kenneth K. Yamamoto, U.S. Army Engineer Research and Development Ctr. (United States)

Environmental Awareness for Sensor and Emitter Employment (EASEE) is a software framework for modeling the impacts of terrain and weather on a diverse range of battlefield sensing systems. The goal is to provide software tools that realistically capture complex environmental effects impacting sensor performance, yet are simple enough for use by soldiers with little specialized training. This paper describes incorporation of infrared (IR) modeling into EASEE, and the subsequent challenges of supporting imaging sensors within a framework that had previously evolved primarily for non-imaging signal types, such as acoustic, seismic, and RF. The framework requires modules for signature generation, propagation, and signal processing to be uncoupled and interchangeable. The approach involves characterizing statistical sensor performance metrics, such as probability of detection, rather than simulating actual images. Some key enhancements needed to support imaging sensors were: (1) geometric models for targets, (2) packaging of multiple attributes representing target image properties (radiance, projected area, and spatial spectrum), (3) explicitly distinguishing between signals for the background, target of interest, and nuisance targets , and (4) calculation of apparent temperature differences (as opposed to incoherent energy summation). Target signatures are generated using MuSES (Multi-Service Electro-optic Signature), whereas the IR background properties are generated using FASST (Fast All-Season Soil STrength) and numerical weather prediction models. Propagation is handled primarily with MODTRAN (MODerate resolution atmospheric TRANsmission),

although simpler models such as a line-of-sight calculation can also be employed. Both the Target Task Performance (TTP) metric and Johnson Criteria sensor performance algorithms are implemented for computing detection.

8752-21, Session PTues

Design and Implementation of Dynamic Hybrid Honeypot Network

Peili Qiao, Harbin Univ. of Science and Technology (China)

The method of constructing a dynamic and self-adaptive virtual network is suggested to puzzle adversaries, delay and divert attacks, exhaust attacker resources, and collect the attacking information. The concepts of Honeypot and the Honeyd, which is the frame of virtual Honeypot are introduced. The techniques of network scanning including active fingerprint recognition are analyzed. Dynamic virtual network system is designed and implemented. A virtual network similar to real network topology is built according to the collected messages from real environments in this system. By doing this, the system can perplex the attackers and can further analyze and research the attacks. Test to this system proves that this design can successfully simulate the real network environment and can be used in network security analysis.

8753-1, Session 1

Multi-platform RF emitter localization using extremum seeking control

Huthaifa A. Al Issa, Raul Ordonez, Univ. of Dayton (United States)

In recent years there has been growing interest in Ad-hoc and Wireless Sensor Networks (WSNs) for a variety of indoor applications. Thus, recent developments in communications and RF technology have enabled system concept formulations and designs for low-cost radar systems using state-of-the-art software radio modules.

Position-Adaptive radar concepts have been formulated and investigated at the AFRL within the past few years. Adopting a position-adaptive approach to the design of distributed radar systems shows potential for the development of future radar systems. These radar systems will function under new and challenging environments that contain large clutter discretes and require co-functionality within multi-signal RF environments.

Position-Adaptive Direction Finding (PADF) technique is based on the formulation and investigation of Path Loss Exponent (PLE) based metrics that are measured and estimated across multiple platforms in order to robotically/intelligently adapt the location of each platform. In other words, each individual node adapts its position based on sensing values, dependent upon the medium, and converges towards the target. By using the relationship between RSS values and the associated distance between sender and receiver, the target's position can be approximated. RSS data is approximated into distance values based on PLE values, and estimates the position of the target using a Least Square Estimation (LSE) method.

PADF has been tested on a number of different configurations in the laboratory via the design and implementation of four IRIS wireless sensor nodes as receivers and one hidden sensor as a transmitter during the localization phase.

In this this paper, we present the experimental performance analysis on the application aspect.

We apply Extremum Seeking Control (ESC) schemes by using the swarm seeking problem, where the goal is to design a control law for each individual sensor that can minimize the error metric by adapting the sensor positions in real-time based on cross-path loss exponents estimates between sensors, thereby minimizing the unknown estimation error. As a result we achieved source seeking and collision avoidance of the entire group of the sensor positions.

8753-2, Session 1

Quality-of-service comparison of a protocol for an active RFID network with sensing and a cross-layer protocol for a wireless sensor network

William S. Hortos Jr., Associates in Communication Engineering Research and Technology (United States)

The quality-of-service (QoS) performance of a protocol for the partition of a fully integrated wireless sensor network(WSN) into an RFID subnet of active tags and readers and a subnet of multi-sensor nodes, viewed together as a hybrid RFID/sensor network, is compared to the QoS performance of the optimized cross-layer protocol through modeling and simulation. Interactions among autonomously nodes of a WSN focus on cooperative processing of data from multiple types of sensors to satisfy common mission objectives. The subsystem of radio transceivers in a WSN can be viewed as a subnet of active RFID tags and readers integrated with sensors, multiprocessors, storage, and limited energy devices at nodes. Fused results from multiple types of raw sensor inputs to the WSN are analogous to information flows in a mobile ad hoc network (MANET) labeled "multimedia." The QoS metrics for the fused results in the WSN can be associated with the QoS metrics for multimedia in a MANET, e.g., throughput, delay, jitter, packet error rate, etc. These metrics are typically specified at the highest, or application, layer of the network protocol stack to ensure that QoS requirements for the combined sensor data are satisfied. Application-layer metrics, in turn, depend on the performance of the lower protocol layers: presentation, session, transport, network, medium access control (MAC), and physical. The dependence of the QoS metrics on the lowest five protocol layers are the basis for a comprehensive approach to QoS optimization in a general WSN with multiple sensor types at each node. The lower protocol layers can be associated with the RFID subnet, while higher layers are associated with functions of the multiple sensors, multiprocessors, storage, and energy sources at nodes. Motivations for the study are a consideration of interference at RFID readers, system portability to locations with different wireless standards, and the periodic retrofit of RF modules.

8753-3, Session 1

Optical communication line-of-sight analysis for dismounted warfighters

Jiayi Geng, Gail Nicholson, Naval Surface Warfare Ctr. Crane Div. (United States)

Optical communication between a dismounted Warfighter and his weapon-mounted scope would provide increased capability. Since optical communication requires line-of-sight, typical movements of a Warfighter during different military missions and their effect on line-of-sight were researched. Video analysis shows technological feasibility for this application and provides the basis for a future testing standard.

8753-4, Session 1

Performance evaluation of CCI on the forward CDMA channel

Salim Alsharif, Mohammad 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. Microzoning is the technique, where the cells are further divided into smaller zones. The advantage of this technique is that the cochannel interference in the cellular system is reduced because the cell maintains a particular coverage radius. The objective of this paper is to analyze the performance of cochannel interference on the forward channels of the proposed microzone based CDMA cellular systems operating with perfect power control in an effort to reduce the cochannel interference. Simulation results showed that the proposed technique can effectively minimize cochannel interference and the proposed architecture can be used for practical applications.

8753-5, Session 1

Pulse based sensor networking using mechanical waves through metal substrates

Stephan Lorenz, Michigan State Univ. (United States) and College of Electrical and Computer Engineering (United States); Bo Dong, Qiong Huo, William J. Tomlinson Jr., Subir Biswas, Michigan State Univ. (United States)

This paper presents a novel wireless sensor networking technique using ultrasonic signal as the carrier wave for binary data exchange. Using the properties of lamb wave propagation through metal substrates, the proposed network structure can be used for runtime transport of structural fault information to ultrasound access points. Primary applications of the proposed sensor networking technique will include conveying fault information on an aircraft wing or on a bridge to an ultrasonic access point using ultrasonic wave through the structure itself (i.e. wing or bridge). Once a fault event has been detected, a mechanical pulse is forwarded to the access node using shortest path multi-hop ultrasonic pulse routing. In order to maintain a routing table, nodes use a novel one hop distance estimation, which is based on the properties of lamb wave propagation. The advantages of mechanical waves over traditional radio transmission using pulses are the following: First, unlike radio frequency, surface acoustic waves are not detectable outside the medium, which increases the inherent security for sensitive environments in respect to tapping. Second, event detection can be represented by the injection of a single mechanical pulse, whereas radio messages usually take several bits. Therefore, sending a pulse reduces the energy consumption. The contributions of this paper are: 1) Development of a transceiver for transmitting/receiving ultrasound pulses with a pulse loss rate below 2?10-5 and false positive rate with an upper bound of 2?10-4. 2) A novel one hop distance estimation based on the properties of lamb wave propagation with an accuracy of above 90%. 3) Implementation of a wireless sensor network using mechanical wave propagation for event detection on a 2024 aluminum alloy plate, commonly used for aircraft skin construction

8753-6, Session 2

An investigation of Crest factor and power amplifier back-off requirements For non-OFDM multicarrier modulations

John W. Nieto, Harris Corp. (United States)

This paper will investigate a proposed high data rate High Frequency (HF) system which employs non-OFDM multi-carrier modulation. Up to 16 carriers are selected based on spectrum utilization in a 200 kHz bandwidth. Of interest in are the crest factor of this approach (as compared to a single-carrier modulation) and power amplifier effects on the transmitted bandwidth.

8753-7, Session 2

Differential OFDM peak-to-average reduction techniques

Fred C. Kellerman, Harris Corp. (United States)

Orthogonal Frequency Division Multiplexing (OFDM) is a novel technique often chosen because it allows for a less complex receiver design. Simple techniques allow OFDM to mitigate multipath without a complex equalizer. For practical systems however its resultant high peak to average power ratio (PAPR) characteristic places a great burden on the dynamic range of radio power amplifiers and receive circuitry. There already exists a large body of work describing various techniques for PAPR reduction. However techniques applied in the frequency domain that implement some form of data re-ordering are usually proprietary meaning that both the receiver and transmitter must follow the same unique protocol. Alternatively time domain techniques often employ clipping to reduce PAPR at the expense of signal integrity. The focus of this research is centered on techniques that will attempt to reduce PAPR while retaining backwards compatibility for Differential OFDM systems.

8753-8, Session 2

Turbo MMSE equalizer for spread OFDM signal detection

Ali A. Elghariani, Michael D. Zoltowski, Purdue Univ. (United States)

Spread Orthogonal Frequency Division Multiplexing (OFDM) has been introduced to improve the diversity performance of the original OFDM in the frequency selective fading channel. In spread OFDM system, every data symbol is modulated by all OFDM subcarriers. Linear equalizer such as MMSE is used in spread OFDM signal detection, which has low complexity compared to the optimal equalizers such as Maximum Likelihood (ML) [1].

In this paper, soft-in soft-out MMSE equalizer is used in the turbo equalization setup to improve the BER performance of spread OFDM system. In this setup the MMSE equalizer and the channel decoder will exchange soft information in an iterative fashion until the convergence is achieved. Though the MMSE turbo equalization has been introduced before for several Inter Symbol Interference (ISI) systems [2], it has different setup with spread OFDM system and its performance may vary with different spreading matrices. The performance will be investigated with both full spread and partial spread OFDM scenarios. The decoding algorithms that are used in this turbo implementation are convolutional and LDPC decoding. MATLAB simulation results will be presented to show the performance improvements and comparisons.

8753-9, Session 2

Noncoherent unitary space-time codes for wireless MIMO communications

Xinjia Chen, Ernest L. Walker, Southern Univ. and A&M College (United States)

In some scenarios of wireless communications, due to the fast change of channel information, it is very difficult to estimate the channel parameters in real time. This difficulty can be overcome by non-coherent communication techniques. In this paper, we propose a new class of unitary space-time codes for non-coherent wireless MIMO communications, aimed at improving the bit error rate performance and data speed of communication systems. We demonstrate that this class of unitary space-time codes can be efficiently decoded using sphere decoder algorithms. A numerical approach is proposed for the optimization of signal constellation.

Such coding techniques can be applied to the data transmission of wireless sensor systems.

8753-11, Session 3

Quasi-coherent performance of convolutional-coded continuous phase modulation

James A. Norris, John W. Nieto, Harris Corp. (United States)

Continuous Phase Modulation (CPM) schemes are advantageous for low-power radios. The constant envelope transmit signal is more efficient for both linear and non-linear amplifier architectures. A standard, coherent CPM receiver can take advantage of modulation memory and is more complex than a coherent Phase Shift Keyed receiver. But the CPM signal can be demodulated non-coherently and still take advantage of the trellis structure inherent in the modulation. With this complexity reduction, the CPM receiver is comparable in performance to a Phase Shift Keyed radio with the power utilization of a Frequency Shift-Keyed design. In this paper, we discuss the addition of the convolutional coded CPM performance enhancements as applied to quasi-coherent demodulation. The differences in complexity will be analyzed and the overall performance enhancements of several different modulation schemes will be illustrated.

8753-12, Session 3

PSK31 implementation in an FPGA

William M. Batts Jr., Carlos O. Alva, Harris Corp. (United States)

Most digital systems today include an FPGA device for computational support and to provide interfaces to peripheral devices. Typically, digital designs include a control processor, a DSP or both. Communications functions such as modems that operate over the air often require resources expanding all three devices (FPGA for data processing, DSP for signal processing and microprocessor for control). It is often desirable to integrate such communications function reusing the existing HW while obtaining performance, at a low power cost. In this paper, the feasibility of implementing the PSK31 modem SW modules in RTL and as a SOC (system on chip) component is studied. The performance of the open-standard SW based PSK31 digital modem is compared to an FPGA implementation under Gaussian and ITU-MLD channels. Statistical analysis is applied to both results to find their confidence intervals and establish a baseline. Performance is measured in terms of power per word transmitted and encoding/decoding times at matched Eb/N0 conditions. Furthermore, addition of more robust communication techniques will be studied and the cost of such improvements will be measured in terms of power and processing times.

8753-13, Session 3

Power and spectrally efficient communications: a comparison of linear and nonlinear modulation schemes

Colin Brown, Phil Vigneron, Communications Research Ctr. Canada (Canada)

This paper compares linear and non-linear modulation schemes for both bandlimited and power limited scenarios. In particular, we discuss the various trade-offs in terms of spectral efficiency, signal to noise ratio requirements and transmission range when selecting a candidate modulation scheme. Examples of the trade-offs are shown for maximising transmission range in frequency flat fading channels.

8753-14, Session 3

Estimating channel capacity and power transfer efficiency of a multilayer acoustic-electric channel

Soumya Chakraborty, Kyle R. Wilt, Gary J. Saulnier, Henry A. Scarton, Rensselaer Polytechnic Institute (United States); Pankaj K. Das, Univ. of California, San Diego (United States)

Recent research has shown that acoustic waves can be used to transmit data and power through metallic barriers. In this paper, we extend this work to consider the case where the channel consists of multiple layers of different materials. In particular, we are considering a steel-water-steel type of interface, i.e. a thin layer of water column sandwiched between two steel walls. A piezoelectric transducer is mounted on the dry side of a steel wall and is used to generate acoustic waves that propagate through the steel wall, water column, and second steel wall. A transducer attached on the dry side of the receiving end steel wall converts the acoustic waves back to an electrical signal. Our channel is acoustic-electric in nature and is modeled as cascade of layers and interfaces in MATLAB. Each layer (single material) and interface is interpreted as transmission line in the acoustic domain. To maximize the capacity and reduce interference, data transmission is performed using orthogonal frequency division multiplexing (OFDM). The width of water column is varied and its effect on the channel characteristics and capacity is shown. Results show that a channel formed by two 1/2 inch thick steel walls and a 5 cm water column is capable of supporting data rates of tens of megabits/sec and of transferring power with more than 30 percent efficiency. A prototype system is currently being implemented to verify the simulation results. This technology could be helpful for sensing and monitoring purposes in defense, industrial and commercial systems.

8753-15, Session 4

Low-complexity algorithms for spatio-temporal directional spectrum sensing with applications in cognitive radio

Arjuna Madanayake, Chamith Wijenayake, Uma Potluri, Judith Abeysekara, Dale Mugler, The Univ. of Akron (United States)

Cognitive radio (CR) provides enhanced access to the radio spectrum by identifying primary and secondary users (PUs and SUs) and then engineering opportunistic communication links for SUs for better utilization of bandwidth. Spectrum sensing is a signal-processing step in CR networks, where available RF channels (white spaces) are identified for SU exploitation.

Typically, the spectrum sensing is done in the time-frequency domain, by identifying spectral signatures using techniques such as energy detection and cyclo-stationary feature detection. This research takes into account both spatial and temporal spectra leading to multi-dimensional (MD) spectral white spaces. We exploit spectral properties of the received signals from an array of antennas using MD signal processing for achieving spectral sensing in the spatio-temporal frequency domain. MD white-space detection takes in to account the direction and location information of the PUs and SUs in the CR environment and creates opportunistic links to SUs.

MD digital filtering techniques having low complexity compared to conventional delay-sum and phased-array beamforming algorithms is investigated, leading to low-complexity energy detection algorithms with applications in both spatial and temporal white space detection. The MD algorithms employ digital beam filters having infinite impulse response (IIR) for detection of PU/SU location and directions of RF transmission. Low complexity digital filters are proposed for highly tunable energy detectors for spatio-temporal sensing. Also described is an algorithm that delivers the magnitude-FFT at greatly lower multiplier complexity compared to conventional-FFTs, with RF spectral sensing applications in low-power hand-held SU devices. Block diagrams, simulations, and results will be discussed.

8753-16, Session 4

Precise RFID localization in impaired environment through sparse signal recovery

Yimin D. Zhang, Saurav Subedi, Moeness G. Amin, Villanova Univ. (United States)

Radio frequency identification (RFID) is a rapidly developing wireless communication technology for electronically identifying, locating, and tracking products, assets, and personnel. RFID has become one of the important means to construct real-time locating systems (RTLS) that track and identify the location of objects in real time using simple, inexpensive tags and readers. The applicability and usefulness of RTLS techniques depend on their achievable accuracy. In multilateration-based localization techniques, the achievable accuracy heavily relies on the precision of the range estimates between a reader and the tags. Such range information can be obtained by using the received signal strength indication (RSSI) and/or the phase difference of arrival (PDOA). In both cases, however, the accuracy is significantly compromised when the operation environment is impaired. In particular, multipath propagation affects the measurement accuracy of both RSSI and phase information. In addition, because RFID systems typically operate in short distances, RSSI and phase measurements are also coupled with the reader and tag

antenna patterns, making accurate RFID localization very complicated and challenging. In this paper, we develop a new method to localize RFID tags or readers by exploiting sparse signal recovery techniques. The proposed method allows the channel environment and antenna patterns to be taken into account and be properly compensated at a low computational cost. As such, the proposed technique yields superior performance in challenging operation environments with the abovementioned impairments.

8753-17, Session 4

Target Position Localization in a Passive Radar System Through Convex Optimization

Batu Chalise, Yimin D. Zhang, Moeness G. Amin, Villanova Univ. (United States); Braham Himed, Air Force Research Laboratory (United States)

In contrast to conventional active radar systems which typically operate in a monostatic mode with a wide signal bandwidth, passive radar systems (PRS) use an extremely narrow signal bandwidth, and the signal levels are usually very weak. These features make the task of accurate estimation of the target positions difficult in PRS. In this paper, we consider target localization in PRS using the bistatic time-of-arrival (TOA) information measured at multiple synthetic array locations, where the positions of these synthetic array locations are subject to random errors. The maximum likelihood formulation of the target localization problem is considered for cases where receive array locations are perfectly and imperfectly known. The formulated optimization problems are nonconvex. An efficient convex approximation based on semidefinite relaxation and iterative refinement is proposed for solving the nonconvex problems. Simulation results demonstrate that the proposed method is robust against imperfections in the receiver array positions. It is also shown that the mean square position error performance of the proposed method is close to the Cramer-Rao lower bound.

8753-18, Session 4

Collaborative beamfocusing radio (COBRA)

Jeremy P. Rode, Mark Hsu, David Smith, Anis Husain, Ziva Corp. (United States)

This paper presents simulations and experimental results obtained on a novel technique called Collaborative Beamfocusing Radio (COBRA) which exploits RF channel reciprocity using time-reversal (TR) to coherently align an ad-hoc distributed array of N radios to automatically achieve diffraction-limited beamfocusing to an intended receiver (IR) with signal gains of N2 without complex algorithms or necessity to align or sweep the antennas. COBRA simultaneously beamfocuses and compensates for multipath, even in non-line-of-sight environments producing peak signal gains (> 10 dB).

TR operates by sending a channel sounding from the IR to the transmitter. The sounding is recorded by the transmitter, reversed in time, and then used as the transmit pulse shaping filter. RF channel reciprocity ensures this TR filter is the optimal spatio-temporal matched filter to the channel. After transmitting the data shaped with the TR filter, the IR receives pulses consisting of the CIR's autocorrelation; having a central peak consisting of the coherent sum of the total energy in the LOS plus all of the multipath echoes.

To enable TR to align transmitters into an ad-hoc distributed array, a time alignment algorithm is used that avoids causality violations and in-band-full-duplex operation exploiting reciprocal buffering techniques. By synchronizing CIR capture and TR retransmission across multiple radios, the reciprocity necessary to achieve coherent alignment at ~GHz carriers is achieved using only standard quartz-oscillators. TR aligns the delays associated with the channel and multipath, and the COBRA time alignment need only to maintain relative coherency between the CIR capture and TR retransmission.

8753-19, Session 4

Estimation of the seismic disaster-stricken area based on wireless communication data

Xiaoyong Zhang, Xiaofeng Xie, Baokun Ning, Gang Sun, National Earthquake Response Support Service (China)

The use of mobile telecommunication systems in worldwide society has now reached almost epidemic proportions. The communication base stations are the fundamental components of the mobile communication systems and are distributed everywhere. After the earthquake, some of the communication base stations may be damaged or destroyed. This kind of damage badly impacts the mobile communications in a great extent, but it provides an opportunity to locate the seismic disaster-stricken area and to estimate the extent of the damage. In this study, the wireless communication data obtained after the earthquake are introduced to assess the earthquake disaster rappidly. Firstly, the wireless communication data including the real-time signaling data and the base station data are used to analyze the behavior and the relationship of the mobile phones and the base stations. Based the analysis results, five signaling parameters are selected and the Apriori algorithm is used to judge the damaged status of the stations. All the base stations within the affected area of the earthquake are cluster analyzed using the K-means method by the damaged status and are divided into several categories according the damage level. Each category of stations will produce a range of earthquake damage grade in the spatial domain within the affected area. Finally, the seismic disaster-stricken areas are located, and the extent of the damage is estimated. Tested in the case of Wenchuan earthquake, happened on May 12, 2008 in Sichuan Province of China, the paper's method produced reliable results. The case also showed that the wireless communication data is very fast and useful source of information from the disaster attached areas, especially when there is no way to get the field investigation information.

8753-20, Session 5

Self-Organized Pulse Switching for Binary Sensing and Actuation

Qiong Huo, Bo Dong, Subir Biswas, Michigan State Univ. (United States)

This paper presents a novel energy-efficient and robust distributed self-organized pulse switching architecture with a sensor-cell based event localization for wireless sensor and actuator network applications. The key idea of this pulse switching architecture is to abstract a single pulse, as opposed to multi-bit packets, as the information exchange mechanism. Unlike multi-bit packet communication, the proposed pulse switching architecture is based on pulse communications where a node either transmits a pulse or keeps silent at every time unit. Specifically, an event can be coded as a single pulse in a specific time unit with respect to the global clock. Then the pulse is transported multi-hop while preserving the event's localization information in the form of temporal pulse position representing its originating cell, destination cell and next-hop cell. The proposed distributed pulse switching is shown to be energy-efficient compared to traditional packet switching especially for binary event sensing and actuation applications. Binary event sensing and actuation with conventional packet transport can be prohibitively energy-inefficient due to the communication, processing, and buffering overheads of the large number of bits within a packet's data, header, and preambles. This paper presents a joint MAC and Routing architecture for self-organized distributed pulse switching with the presence of errors and faults. Through simulation experiments, it is shown that pulse switching can be an effective distributed means for event based networking in wireless sensor and actuator networks, which can potentially replace the packet transport when the information to be transported is binary in nature.

8753-21, Session 5

Fast Fourier sampling for ultra-wide band digital receiver applications

Chen Wu, Sreeraman Rajan, Defence Research and Development Canada, Ottawa (Canada)

Application of compressive sensing to receiver design is still in its infancy. There are advantages to using compressive sensing approach for designing a receiver: the analog to digital conversion process is simpler; the power requirement for the receiver is reduced as the analog to digital conversion process is happening at a slower rate; the cost of the receiver is reduced as the components do not have tighter specification. However, we believe that such advantages do not come for free. It is not clear at this stage the disadvantages associated with compressive sensing. This paper will investigate the advantage and disadvantage of using compressive sensing while designing a receiver; specifically it will focus on the extraction of spectral information from the compressively sensed data.

Fast Fourier transform (FFT) is the most widely used signal processing method in modern digital RF/microwave receiver design, since it can be effectively implemented in digital signal processing (DSP) devices, such as the field programmable gate arrays. Based on current DSP technology only a small number of sampled data points, for example, less than 1024 points, can be easily processed by DSP devices; thus limiting the frequency resolution for analysis purposes. The frequency resolution will be degraded, when the digital receiver is designed to have ultra-wide instantaneous frequency band. In order to cover a wider instantaneous frequency bandwidth with fixed frequency resolution, one may have to increase number of FFT points and may not be implementable in DSP devices. In the middle of last decade, the Fast Fourier Sampling (FFS), also called the Sparse Fast Fourier Transform (SFFT), was developed to efficiently acquire spectral information from small number of sampled data. This paper explores the application of FFS/SFFT method to ultra wideband RF/microwave digital receiver design. The paper focuses on fast identification of the sparsely distributed carrier frequencies within an ultra-wide frequency band using fewer data samples than that for normal FFT.

8753-22, Session 5

Combination of spatial diversity and parallel decision feedback equalizer in a single-input multiple-output underwater acoustic communication system operating at very high frequencies

Violeta Skoro Kaskarovska, Pierre-Philippe Beaujean, Florida Atlantic Univ. (United States)

Single Input Multiple Output (SIMO) acoustic communication system using an adaptive spatial diversity combined with parallel Decision Feedback Equalizer (DFE) is presented in this work. The SIMO system operates at high frequencies with high data rate over a limited range (less than 200 m) in very shallow waters. The SIMO system consists of a single source transmitting Binary Phase Shift Keying (BPSK) messages modulated at 25 kHz with carrier frequency 300 kHz received by multiple receivers. In each receiver, the received symbols are equalized and used to perform diversity combining. This is considered diversity combining at lower level and results are used as feedback parameters for diversity combining performed at higher, DFE level. Maximal Ratio Combining (MRC) is performed at each level. Diversity combining at DFE level generates new improved messages at each receiver that can be combined further to achieve better results in the next iteration of diversity combining. The adaptive process of diversity is repeated until the best possible result is achieved or a predefined error criterion is met. Bit Error Rate (BER) and Signal-to-Noise and Interference Ratio (SNIR) are used as performance metrics of the acoustic channel. Experimental results using SIMO system with three, four or five receivers and pre-processed real recorded data demonstrate ability to improve the performance of the acoustic channel in challenging environments. Using received messages with non-zero BER, adaptive spatial diversity can achieve BER of 0% and increased SNIR of 3 dB with number of iterations depending on the number of receivers used.

8753-24, Session 5

Regularization in radio tomographic imaging

Ramakrishnan Sundaram, Gannon Univ. (United States); Richard Martin, Air Force Institute of Technology (United States); Christopher Anderson, U.S. Naval Academy (United States)

This paper demonstrates methods to select and apply regularization to the linear least-squares model formulation of the radio tomographic imaging (RTI) problem. Typically, the RTI inverse problem of image reconstruction is ill-conditioned due to the extremely small singular values of the weight matrix which relates the link signal strengths to the voxel locations of the obstruction. Regularization is included to offset the non-invertible nature of the weight matrix by adding a regularization term such as the matrix approximation of derivatives in each dimension based on the difference operator. This operation yields a smooth least-squares solution for the measured data by suppressing the high energy or noise terms in the derivative of the image. Traditionally, a scalar weighting factor of the regularization matrix is identified by trial and error (adhoc) to yield the best fit of the solution to the data without either excessive smoothing or ringing oscillations at the boundaries of the obstruction. This paper proposes new scalar and vector regularization methods that are automatically computed based on the weight matrix. Evidence of the effectiveness of these methods compared to the preset scalar regularization method is presented for stationary and moving obstructions in an RTI wireless sensor network. The variation of the mean square reconstruction error as a function of the scalar regularization is calculated for known obstructions in the network. The vector regularization procedure based on selective updates to the singular values of the weight matrix attains the lowest mean square error.

8753-25, Session 5

Ubiquitous data modeling and analysis for ambulance services enhancement

Jalel Akaichi, ISG (Tunisia)

Ubiquitous data, captured by mobile devices and positioning technologies as sets of time-stamped positions, doesn't usually carry semantics. This, obviously, harden its storage as well as its analysis. In this paper, we raise, in a general context, the challenges of modeling, storing and analyzing ubiquitous or trajectory data, and, in particular, a case study related to ambulance services. We propose a conceptual model based on UML notation extended with stereotypes expressing explicitly the semantic of trajectory-oriented concepts. To valid our conceptual approach, we implement the ambulance trajectory data warehouse and we perform OLAP operations for analysis purposes.

Tuesday - Wednesday 30–1 May 2013

Part of Proceedings of SPIE Vol. 8754 Open Architecture/Open Business Model Net-Centric Systems and Defense Transformation 2013

8754-1, Session 1

Naval open systems architecture *(Invited Paper)*

Nick Guertin, U.S. Navy (United States)

No Abstract Available.

8754-3, Session 1

Networked sensors: insights into ISR and force protection *(Invited Paper)*

Thomas Conway, PM/NV-RSTA (United States)

No Abstract Available.

8754-4, Session 1

The UAS control segment architecture: an overview *(Invited Paper)*

Richard Ernst, Office of the Secretary of Defense (United States); Parag Batavia, Neya Systems LLC (United States)

No Abstract Available.

8754-5, Session 1

RF-FPGA and its impact on open architecture arrays *(Invited Paper)*

William Chappell, Defense Advanced Research Projects Agency (United States)

No Abstract Available.

8754-6, Session 1

A model for open architecture mission control systems *(Invited Paper)*

Tim Pavlick, IBM Corp. (United States)

No Abstract Available.

8754-7, Session 1

Program executive office littoral combat ships (PEO LCS) science and technology overview *(Invited Paper)*

Megan Cramer, U.S. Navy (United States)

No Abstract Available.

8754-9, Session 2

Architecting a dynamic cyber defense through hardening privilege, identity, and access management

Bassam S. Farroha, U.S. Dept. of Defense (United States)

The new paradigm of secure Information sharing is a fundamental enabler in facilitating better business and security practices, where exchange of information has moved to a more automated approach. All new capability developments should aim to architect dynamic systems with smart decision models that monitor and control authorized data while propagating between security domains to reach the authenticated and authorized users, while prohibiting unauthorized access according to prevailing policy. The Department of Defense (DoD) and Federal Agencies have established an information strategy for their respective communities that implement the national level information sharing strategy which utilizes a comprehensive Identity and Access Management (IDAM) capability. The new business and mission environments capitalize on the utilization of virtual environments to achieve IT efficiencies and relay on a solid security capability to protect sensitive information.

8754-10, Session 2

Evaluating encrypted Boolean functions on encrypted bits: Secure decision-making on the black side

Rajesh Krishnan, Cosocket LLC (United States); Ravi Sundaram, Northeastern Univ. (United States)

We present a novel approach for secure evaluation of encrypted Boolean functions on encrypted bits. Building upon Barrington's work to transform circuits to group programs and the Feige-Killian-Naor cryptographic protocol, our novel Fixed Structure Group Program construction for secure evaluation eliminates the need for an expensive Universal Circuit to hide the function. Elements on the Black side weave together and multiply two coordinated streams of random sequences of elements from an unsolvable group; the Boolean decision is recovered while preserving the confidentiality of the decision function and the input bits. The operation is fast and can be further sped up using parallel computation. Our approach can handle expressions with NC1 complexity, which is the class of Acyclic Boolean Circuits with polynomial width and logarithmic depth in the size of the input. This efficiently parallelizable class includes non-monotone Boolean expressions of equality, inequality/range, Hamming distance, Boolean matrix multiplication, and k-of-m threshold matching operations. The combined benefits of scaling and expressivity of our approach enables secure decision-making on the Black side. Envisioned applications include confidential publish/subscribe systems (with empirically validated performance), secure content-oriented internetworks, confidential forwarding and firewalling rules, and cross-domain guards.

8754-11, Session 3

Modular, open, scalable architectures with applications to C4ISR systems *(Keynote Presentation)*

Bobby R. Junker, Office of Naval Research (United States)

No Abstract Available.

8754-12, Session 3

The GDAIS journey in OA/OBM *(Keynote Presentation)*

Carlo Zaffanella, General Dynamics Advanced Information Systems (United States)

No Abstract Available.

8754-13, Session 3

Small business perspectives on the open business model *(Keynote Presentation)*

Howard Reichel, In-Depth Engineering Corp. (United States)

No Abstract Available.

8755-1, Session 1

Image encryption in the wavelet domain

Long Bao, Yicong Zhou, C. L. Philip Chen, Univ. of Macau (Macao, China)

With the wide use of information technologies, individuals and organizations frequently utilize the Internet and wireless networks for communications. However, the Internet and networks have an intrinsic and essential problem with respect to communication security due to networks being open to publics including attackers. Thus, classified and vital information in a form of images, videos or documents should be encrypted to against attacks before being transmitted.

Traditional encryption methods such as the Data Encryption Standard (DES) [1] and Advanced Encryption Standard (AES) [2] do not have good performance for the image information with redundancy [3]. Hence, a number of algorithms specially for encrypting image information have been developed. Examples include chaos-based image encryption algorithms [4–7] and many others [8–10]. They usually encrypt images by transferring them into the noise-like images. However, this noise-like characteristic is an apparent visual sign indicating the presence of an encrypted image, which may catch more attention to attackers [11].

Motivated by the data hiding technologies, this paper proposes a novel concept of image encryption by "hiding" an encrypted image into a cover image. The resulting encrypted image is visually the same as the cover image, overcoming the above-mentioned problem. To demonstrate feasibility of this concept, this paper introduces a new image encryption algorithm based on the wavelet decomposition.

The proposed algorithm first uses a chaos-based image encryption algorithm to encrypt the original image. A cover image is decomposed into four wavelet sub-bands. The algorithm then replaces the high frequency sub-band at the diagonal direction with the encrypted image. The final encrypted image is obtained by combining the processed sub-bands using the inverse wavelet transform. The image visually looks the same as the cover image. For the image decryption, we simple decompose the encrypted image into wavelet sub-bands and extract the protected image from the diagonal sub-band. By using corresponding chaos-based decryption process, the original image is then reconstructed. Computer simulations are provided to demonstrate the excellent encryption performance of the proposed concept and algorithm.

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8755-2, Session 1

Biometric feature embedding using robust steganography technique

Rasber D. Rashid, Sabah A. Jassim, Harin Sellahewa, The Univ. of Buckingham (United Kingdom)

This paper is concerned with robust steganographic techniques to hide and communicate biometric data in mobile media objects like images, over open networks. More specifically, the aim is to embed binarised features extracted using discrete wavelet transforms and local binary patterns of face images as a secret message in an image. The need for such techniques can arise in law enforcement, forensics, counter terrorism, internet/mobile banking and border control. What differentiates this problem from normal information hiding techniques is the added requirement that there should be minimal effect on face recognition accuracy.

We propose an LSB-Witness embedding technique in which the secret message is already present in the LSB plane but instead of changing the cover image LSB values, the second LSB plane will be changed to stand as a witness/informer to the receiver during message recovery. Although this approach may affect the stego quality, it is eliminating the weakness of traditional LSB schemes that is exploited by steganalysis techniques for LSB, such as PoV and RS steganalysis, to detect the existence of secrete message.

Preliminary experimental results show that the proposed method is robust against PoV and RS attacks compared to other variants of LSB. We shall also discuss variants of this approach and determine capacity requirements for embedding face biometric feature vectors while maintain accuracy of face recognition.

8755-3, Session 1

Performance assessments of Android-powered military applications operating on tactical handheld devices

Brian A. Weiss, Lisa Fronczek, Emile Morse, National Institute of Standards and Technology (United States); Zeid Kootbally, Univ. of Maryland, College Park (United States); Brian Antonishek, Craig I. Schlenoff, National Institute of Standards and Technology (United States)

Transformative Apps (TRANSAPPS) is a DARPA-funded program whose goal is to develop a range of militarily-relevant software applications ("apps") to enhance the operational-effectiveness of military personnel on (and off) the battlefield. TRANSAPPS is developing a military apps marketplace to facilitate rapid development of applications to address user needs by connecting engaged communities of end-users with development groups. The National Institute of Standards and Technology's (NIST) role in the TRANSAPPS program is to design and implement evaluation procedures to assess the performance of: 1) the various software applications, 2) software-hardware interactions, and 3) the supporting online application marketplace. Specifically, NIST is responsible for evaluating 50+ tactically-relevant applications on numerous Android-powered platforms that includes functional regression testing and quantitative performance testing. This paper discusses the evaluation methodologies employed to assess the performance of four key program elements: 1) handheld-based applications and their integration with various hardware platforms, 2) handheld device security,

3) client-based applications and 4) network technologies operating on both the handheld and client systems along with their integration into the application marketplace. Handheld-based applications are assessed using a combination of utility and usability-based checklists and quantitative performance tests. Handheld device security is explored from the perspectives of the authorized curious user and the unauthorized malicious user. Client-based applications are assessed to replicate current overseas operations and to assess connected operations envisioned for later use. Finally, networked applications are assessed on handhelds to establish baselines of performance for when connectivity will be common usage.

8755-4, Session 1

No-reference quality assessment of H.264/AVC encoded video based on natural scene features

Kongfeng Zhu, Univ. Konstanz (Germany) and Univ. of Dayton (United States); Vijayan K. Asari, Univ. of Dayton (United States); Dietmar Saupe, Univ. Konstanz (Germany)

H.264/AVC coded video quality is crucial for evaluating the performance of consumer-level video camcorders and mobile phones. In this paper, a no-reference video quality metric is proposed to blindly predict the quality of videos compressed by H.264/AVC.

We assume that natural scenes possess certain features which are distorted by video compression. The distortion is estimated by extracting the distorted features of natural scenes in compressed video, such that the quality is predicted without a reference.

The algorithm uses a frame-based approach in which the distortion of each frame is measured first, and then their mean is considered as the distortion of the video. For each frame, the Discrete Cosine Transform (DCT) map is generated by applying 4X4 DCT on all the 4X4 image subblocks. For each DCT map, five features are extracted from the 15 AC coefficients (kurtosis, homogeneous area, edge energy, blockiness, and histogram distance between high and low frequency components). A multilayer neural network with 10 hidden layer nodes is used to pool all the features into one single value as the overall distortion.

We trained our algorithm and did leave-one-out tests on the LIVE Video Database with 40 H.264/AVC coded videos of 10-second length each. The correlation coefficient (CC) between the predicted video quality computed by the proposed algorithm and the mean opinion score of human subjects was above 0.9. The proposed method outperformed the full-reference SSIM (structure similarity) index since its declared performance is CC=0.864. We got a better result even though it is no reference.

8755-5, Session 1

Adjunctive numerical relations in multimedia signal covers

James C. Collins, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

This paper introduces a new redundant number system, the adjunctive numerical representation (ANR), which offers improvements over other well known redundant number systems such as the Fibonacci, Lucas, and the Prime number systems when used in multimedia data hiding applications. It will be shown that this new redundant number system has potential applications in digital communications, signal, and image processing. After describing the derivation of the ANR system, the paper will offer two illustrative applications for this new redundant coding system. First an enhanced bit-plane decomposition of image formatted files with data embedding (steganography and watermarking). Secondly, an example of an expanded bit-line decomposition of audio formatted files with data embedding and index-based retrieval capability will be described. The computer simulations of this new ANR system will detail the statistical stability required for effective data encoding techniques and demonstrate the improvements in the embedding capacity in multimedia carriers.

8755-6, Session 1

Mean field game theoretic approach for security in mobile ad-hoc networks

Yanwei Wang, Carleton Univ. (Canada); Helen Y. Tang, Defence Research and Development Canada, Ottawa (Canada); Fei R. Yu, Minyi Huang, Carleton Univ. (Canada)

Game theory can provide a useful tool to study the security problem in mobile ah hoc networks (MANETs). Most of existing works on applying game theories to security only consider two players in the security game model: an attacker and a defender. While this assumption may be valid for a network with centralized administration, it is not realistic in MANETs, where centralized administration is not available. Consequently, each individual node in a MANET should be treated separately in the security game model.

In this paper, using recent advances in mean field game theory, we propose a novel game theoretic approach for security in MANETs. The mean field game theory provides a powerful mathematical tool for problems with a large number of players. To the best of our knowledge, using mean field game theoretic approach for security in MANETs has not been considered in existing works. The contributions of this work are as follows. (1) We propose a dynamic mean field game theoretic approach to enable an individual node in MANETs to make strategic security defence decisions without centralized administration. (2) Since security defence mechanisms consume precious system resources (e.g., energy), the proposed scheme considers not only the security requirement of MANETs but also the system resources. (3) Each node only needs to know its own state information and the aggregate effect of the other nodes in the MANET. Therefore, the proposed scheme is a fully distributed scheme. Simulation results will be presented to illustrate the effectiveness of the proposed scheme.

8755-7, Session 1

Efficient high-capacity steganography techniques

Alan A. Abdulla, Harin Sellahewa, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

Performance indicators characterizing modern steganographic techniques include capacity (i.e. the quantity of data that can be hidden in the cover medium), stego quality (i.e. artifacts visibility), and strength or robustness (intended as the resistance against active attacks aimed to destroy the secret message). Fibonacci based embedding techniques have been researched and proposed in the literature to achieve efficient steganography technique in terms of capacity with respect to stego quality. In this paper, we investigate innovative ideas that extend Fibonacci-like steganography by bit-plane(s) mapping instead of bit-plane(s) replacement. Our proposed algorithms increase embedding capacity using bit-plane mapping that embeds two bits of the secret message in three bits of a pixel of the cover, at the expense of a slight loss in stego quality. While existing Fibonacci embedding algorithms do not use certain intensities of the cover for embedding due to the limitation imposed by the Zekondorf theorem, our proposal solve this problem and make all intensity values candidates for embedding. Both Fibonacci and binary based representations of the secret message as well as the cover image have been tested and the results demonstrate that the proposed techniques double the embedding capacity when compared to existing Fibonacci methods.

8755-8, Session 1

A novel method of testing image randomness with applications to image shuffling and encryption

Yue Wu, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States); Joseph P. Noonan, Tufts Univ. (United States)

This paper addresses the question of testing the degree of randomness within an image, which is essential to evaluate the security performance of image processing tasks like shuffling and encryption. Although some existing algorithms are developed for testing the degree of image randomness, most of them are subjective or heuristic. In this paper, we will present an objective method to evaluate the degree of image randomness by using the norm-2 distance between two pixels.

In the first place, we mathematically model a so-called "perfectly shuffled image" with ideal statistical properties of independently identically distributed pixels.

We select the norm-2 distance between two distinctive pixels within a perfectly shuffled image as our test statistic, because the norm-2 distance is known to be the most appropriate for image data. Based on the theoretical model perfectly shuffled image, we successfully derive the theoretical distribution of the test statistic and also its theoretical mean m and variance s^2.

To test the image randomness, we then compare two non-overlapped n-pixel (n>30) sequences in a perfectly shuffled image and characterize the difference between these two sequences as the average of the norm-2 distance of corresponding pixels in two sequences. As a result, this average norm-2 distance follows the Gaussian distribution of mean m and variance s^2/n, because of the central limit theorem. This knowledge allows us to construct a Z-test to test whether a given image is indistinguishable from a perfectly shuffled image.

To better evaluate the image randomness, we discuss many aspects of the implementation, including parameter selections, stabilization of the our evaluation and minimize the Type-I error of the proposed method by using robust statistics, and a fast implementation.

Our simulation results show that the proposed method is robust, effective and efficient for testing the randomness of a image. The proposed method can be also used as the first step in determine whether or not an image shuffling or encryption algorithm is suitable for cryptographical applications.

8755-9, Session 2

Smartphone identification using digital images *(Invited Paper)*

Harin Sellahewa, The Univ. of Buckingham (United Kingdom)

No Abstract Available.

8755-10, Session 2

Location-assured, multifactor authentication on smartphones via LTE communication

Torben Kuseler, Ihsan A. Lami, The Univ. of Buckingham (United Kingdom)

With the added security provided by LTE and IPv6, geographical location has become an important factor for authentication to enhance the security of remote client authentication during mCommerce applications using Smartphones. Tight combination of geographical location with classic authentication factors like PINs/Biometrics in a real-time, remote verification scheme over the LTE layer connection assures the authenticator about the client itself (via PIN/biometric) as well as the client's current location, thus defines the important aspects of "who", "when", and "where" of the authentication attempt without eaves dropping or man on the middle attacks. To securely integrate location as an authentication factor into the remote authentication scheme, client's location must be verified independently, i.e. the authenticator should not solely rely on the location determined on and reported by the client's Smartphone. The latest wireless data communication technology for mobile phones (4G LTE, Long-Term Evolution), recently being rolled out in various networks, can be employed to enhance this location-factor requirement of independent location verification. The integrated LTE Control Plane LBS allows efficient, continuous location tracking of the mobile phone that is performed during normal operation of the LTE-based communication between client and network operator resulting in the authenticator being able to verify the client's claimed location more securely than it was possible with GSM or UMTS. Trials and experiments show the security improvements of the LTE based location verification.

8755-11, Session 2

Security enhancement for mobile ad hoc networks routing with OLSRv2

Zhexiong Wei, Carleton Univ. (Canada); Helen Y. Tang, Defence Research and Development Canada, Ottawa (Canada); Fei R. Yu, Carleton Univ. (Canada); Maoyu Wang, Communications Research Ctr. Canada (Canada)

Mobile Ad Hoc Networks (MANETs) have been identified as a key communication technology in tactical environments and emergency response operations because of its flexibility and many other advantageous features. However, the features of MANETs, including dynamic membership, topology, and open wireless medium, may lead MANETs suffering from many security vulnerabilities. Secure routing in MANETs has emerged as an important MANET research area.

In tactical environments, malicious nodes can drop or modify packets that are received from other nodes. These misbehaviours may seriously affect the availability of services in the network. In this paper, we propose a scheme that enhances the security of Optimal Link State Routing version 2 (OLSRv2) in MANETs based on trust.

Misbehaviors such as dropping or modifying packets can be detected in our scheme through trust calculation. In the proposed scheme, more accurate trust can be obtained by considering different types of packets and other important factors such as buffers of queues and states of wireless connections, which may cause dropping packets in friendly nodes. Additionally, a punishment factor is introduced in order to make the trust evaluation more realistic.

Simulation results have been presented to demonstrate the effectiveness of our scheme, which improves secure throughput and packet delivery ratio considerably, with slightly increased average end-to-end delay. We will extend the scheme to a general framework which can be deployed to other routing protocols in the future work.

8755-13, Session 2

Multiple-image encryption based on optical coherence multiplexing technique

Badr-Eddine Benkelfat, TELECOM & Management SudParis (France); Sonia Elwardi, Mourad Zghal, Univ. of Carthage (Tunisia); Ayman Alfalou, ISEN Brest (France)

We present a novel application of the optical coherence multiplex technique for multiple image encryptions. The proposed optical encryption technique uses a 2D adapted light coherence modulation scheme and two encryption keys. The first one is a biometric real image and the second one is a random coherence length coding i.e a special birefringent plate. Our technique allows an original multiplexing technique of multiple images through a light beam. For that, our novel encryption method is based on an all optical real time multichannel signal

addition and subtraction operations. This technique, which uses the path difference multiplexing technique (also called coherence multiplexing technique), permits a parallel and a simultaneously single and multiple image arithmetic operations. It's based on coherence modulation of light which utilizes the coherence properties of broadband sources for encoding a target image with an optical path-difference larger than the coherence length of the source.

The robustness of the new encryption method was tested against brute force, Known-plaintext attacks. To measure the performance of our system, we used two criteria: MSE (Mean Square Error) criterion, and the correlation. This latter consists in correlating the fake image (decrypted with false keys). This is to show that falsely decrypted image has no resemblance to the target image. To perform this correlation criterion, we chose to use the POF correlation filter for its resistance against random noise.

8755-45, Session 2

Robust image coding *(Invited Paper)*

Erlan H. Feria, College of Staten Island (United States)

A fundamental issue in image coding is how robust the coder performance can be while in the presence of images whose pixel correlation properties change greatly. A review is presented of the large vertical/horizontal pixel correlation differences that are found between standard images of the JPEG suit case and synthetic aperture radar (SAR) images, as well as to how standard image coders often fail to provide a robust high performance solution to these significant pixel correlation differences. The discussion then turns to the review of a nascent subbands-based minimum mean square error (MMSE) predictive-transform (PT) source coding formulation that in an inherent manner successfully addresses this robustness issue while simultaneously achieving excellence in both image-compression as well as computational-burden performance. Finally a straight forward change of a stability parameter in the source-model that is inside the MMSE PT source-coder is shown to naturally lead to outstanding joint source/channel coding solutions while subjected to taxing channel disturbances.

8755-16, Session 3

Progress in multi-channel image fusion for face image matching

Stephen P. DelMarco, BAE Systems (United States)

Fusion techniques have proven to be very useful for many signal and image processing applications including image recognition, image registration, and biometric matching. Along with standard fusion techniques, hypercomplex image processing techniques have been developed recently. These techniques represent a form of image fusion in which several image components are combined to form a multi-channel image. The multi-channel imagery may be processed using hypercomplex transforms, such as the hypercomplex Fourier transform, for image matching and registration. In this paper we investigate performance of multi-channel image fusion for face image matching. We use 3-D color face imagery and investigate fusion of various combinations of grayscale intensity, color, and range information. We conduct a theoretical investigation to identify conditions under which matchers using image channel fusion provide superior matching performance relative to matchers fusing single channel image matching results. We present numerical performance results in the form of Receiver Operating Characteristics curves quantifying matching performance for verification hypothesis testing problems.

8755-17, Session 3

Face detection at a distance with AdaBoost filtering and color-shape information

Seokwon Yeom, Dongsu Lee, Daegu Univ. (Korea, Republic of)

Face detection at a distance is very challenging since images are often degraded by blur and noise as well as low resolution. This paper discusses a face detection method with the AdaBoost detector and a false alarm reduction scheme based on color and shape information. False alarms generated by the Adaboost algorithm are eliminated through skin-color testing and variable edge mask filtering. The skin-color test involves the validity of the average RGB components in the candidate windows. After the skin color test, the size of the edge mask is determined by the ellipse which is estimated from the binary cluster region. The binary cluster region is generated by the color test of the individual pixel. The shape of the candidate face regions is investigated by the variable edge mask filtering. In the experiments, this false alarm reduction scheme is shown to be very effective for the low resolution images captured in the long distance.

8755-18, Session 3

Feature quality-based multimodal unconstrained eye recognition

Zhi Zhou, Eliza Y. Du, Indiana Univ.-Purdue Univ. Indianapolis (United States); Edward J. Delp III, Purdue Univ. (United States)

Iris recognition has been tested to a most accurate biometrics using high resolution near infrared images. However, it does not work well under visible wavelengths. Sclera recognition has shown to achieve reasonable recognition accuracy under visible wavelengths. Combining iris and sclera recognition together can achieve better recognition accuracy. However, image quality can significantly affect the recognition accuracy. Moreover, under unconstrained situation, the acquire eye images may not be front. In this research, we proposed a feature quality-based multimodal unconstrained eye recognition method that combine the strengths of iris recognition and sclera recognition for human identification and can work with frontal and off-angle eye images. The research results show that the proposed method is very promising.

8755-26, Session 3

A new feature selection method for OCT retinal data analysis

Sumit Chakravarty, New York Institute of Technology (United States)

A new feature selection method for OCT retinal data analysis Curse of dimensionality often hinders the process of data mining. The data collected and analyzed generally contains huge number of dimensions or attributes and it may be the case that not all of the attributes are necessary for the data mining task to be performed on the data. Traditionally data dimensionality reduction techniques like Principal Component Analysis or Linear Discriminant analysis have been used to address this problem. But, these methods move the original data to a transformed space. However, the need might be to remain in the original attribute space and identify the key attributes for data analysis. This need has given rise to the research area of feature subset selection. In this paper we have used solid angle measure to tackle the problem of dimension reduction. Optical Coherence Tomography (OCT) is a frequently used and established medical imaging technique. It is widely used, among other application, to obtain high-resolution images of the retina and the anterior segment of the eye. Solid angle measure is used to characterize and select features obtained from OCT retinal images. The application of solid angle in feature selection, as proposed in this paper, is a unique approach to OCT image data mining. The experimental results with real life datasets presented in this paper will demonstrate the effectiveness of the proposed method

8755-19, Session 4

Edge-preserving image restoration

Bo Jiang, National Institute of Aerospace (United States)

Linear filtering methods often lead to the suppression of significant edge features during noise reduction. Since the presence of edges is perceptually related to sharpness and, hence, contrast, these approaches impact image quality significantly.

In this paper, we develop an edge-preserving noise reduction algorithm based on edge analysis and connectivity analysis to protect boundaries sharp and keep piecewise smoothing during filtering. The most common way of dealing with additive white Gaussian noise is to apply a Gaussian filter to attenuate noise. But an important consideration is the scale of the Gaussian filter: small scales let more noise and edges through, while larger scales suppress both noise and edges. To address this problem, multi-resolution edge analysis using a combination of Gaussian filters with different scales is applied to the edge analysis process.

Then, the connectivity analysis is applied to classify edges or noise pixels. The idea of connectivity analysis relies on the characteristics of noise and features. Specifically, noise does not have regional connectivity and also has random orientation. Using the idea of regional connectivity, pixels on edges are classified as “noise” are replaced by an average of their neighbors, hence reducing the impact of noise at that location and preserving the overall edge structure of the original image. During smoothing, the intra-region smoothing should occur preferentially over inter-region smoothing. Therefore, only those pixels lying at the same region as the center pixel are used to compute the average value of the neighborhood. Otherwise, after smoothing, the pixels closing the boundaries would have mixed information from both intra-region and inter-region pixels.

Experimental results generated from a series of images with different SNR support that this method is effective in noise reduction and edge preservation, even for very noisy condition.

8755-20, Session 4

Image enhancement technology for stereo videos

Yimin Qiu, School of Computer Science and Technology (China); Jinshan Tang, Michigan Technological Univ. (United States)

In the past, stereo vision technology has obtained great development and stereo videos also came to the market. As normal videos, the quality of the images needs to be enhanced for different applications and different viewers. In this paper, we propose a wavelet-based approach to enhance the quality of the original images for stereoscopic system. The proposed approach exploits wavelet transform to decompose the original image into wavelet domain and image enhancement is performed in wavelet domain. The image is enhanced by modification of the high-frequency coefficients. Experimental results show that the proposed approach outperforms conventional approaches.

8755-21, Session 4

High-capacity embedding with indexed data recovery using adjunctive numerical relations in multimedia signal covers

Sos S. Agaian, The Univ. of Texas at San Antonio (United States); James C. Collins, Air Force Information Operations Ctr. (United States)

We introduce a technique for covertly embedding data throughout an audio file using redundant number system decomposition across non-standard digital bit-lines. This bit-line implementation integrates an index recoverable embedded algorithm with an extended bit level representation that achieves a high capacity data channel within a audio multimedia file. It will be shown this new steganography method has minimal aural distortive affects while preserving both first and second order cover statistics, making it less susceptible to most steganalysis attacks. Our research approach involves reviewing the common numerical methods used in common binary-based algorithms. We then describe basic concepts and challenges when attempting to implement complex embedding algorithms that are based on redundant number systems. Finally, we introduce a novel class of numerical based multiple bit-line decomposition systems, which we define as Adjunctive Numerical Representations. The system is primarily described using basic PCM techniques in uncompressed audio files however extended applications for alternate multimedia is addressed. This new embedding system will not only provide the statistical stability required for effective steganography but will also give us an improvement in the embedding capacity in this class of multimedia carrier files. This novelty of our approach is demonstrated by an ability to embed high capacity covert data while simultaneously providing a means for rapid, indexed data recovery.

8755-22, Session 4

Sub-word Based Arabic Handwriting Analysis for Writer Identification

Makki Maliki, Naseer Al-Jawad, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

Analysing a text or part of it is the key to the handwriting identification. The paper hypothesis is based on extracting and identifying the writer’s habits. These habits are embedded in special parts of handwriting text. In Arabic each word consists of one or more sub-word(s). The end of each sub-word is considered to be a connect stroke. As a result the sub-words are considered to be very important parts which reflect the writer habits and it can lead for writer identifications.

The experimental results show that using a group of sub-words could be used to identify the writer with a successful rate between 70.6% and 94.1%, when top1 is used, and it can go up to 100% when top5 is used based on K nearest neighbour. However previous work, using a complete word, shows successful rate of at most 90% in top 10

8755-23, Session 4

ZEA-TDMA: design and system level implementation of a TDMA protocol for anonymous wireless networks

Debasmit Banerjee, Bo Dong, Subir Biswas, Michigan State Univ. (United States)

Wireless sensor network used in military applications may be deployed in hostile environments, where privacy and security is of primary concern. This can lead to the formation of a trust-based sub-network among mutually-trusting nodes. However, designing a TDMA MAC protocol is very challenging in situations where such multiple sub-networks coexist, since TDMA protocols require node identity information for slot assignments. This paper introduces a novel distributed TDMA MAC protocol, ZEA-TDMA (Zero Exposure Anonymous TDMA), for anonymous wireless networks. ZEA-TDMA achieves slot allocation with strict anonymity constraints, i.e. without nodes having to exchange any identity revealing information. By using just the relative time of arrival of packets and a novel technique of wireless collision-detection and resolution for fixed packet-sizes, ZEA-TDMA is able to achieve MAC slot-allocation which is described as follows. Initially, a newly joined node listens to its one-hop neighborhood channel usage and creates a slot allocation table based on its own relative time, and finally, selects a slot that is collision free within its one-hop neighborhood. The selected slot can however cause hidden collisions with a two-hop neighbor of the node. These collisions are resolved by a common neighbor of the colliding nodes, which first detects the collision, and then resolve them using an interrupt packet. ZEA-TDMA provides the following features: a) it is a TDMA protocol ideally suited for highly secure or strictly anonymous environments b) it can be used in heterogeneous environments where devices use different packet structures c) it does not require network time-synchronization, and d) it is insensitive to channel errors. We have implemented ZEA-TDMA on the MICA2 hardware platform running TinyOS and evaluated the protocol functionality and performance on a MICA2 testbed.

8755-24, Session 5

Social network forensics: using commercial software in a university forensics lab environment

Pavel Halkin, Knut Kroeger, Reiner Creutzburg, Fachhochschule Brandenburg (Germany)

The aim of this article is to give a practical overview of forensic investigation of social network cases using certain commercial software packages in a university forensics lab environment.

Students have to learn the usefulness of forensic procedures to ensure evidence collection, evidence preservation, forensic analysis, and reporting.

It is demonstrated how to investigate important data from social network users.

Different scenarios of investigations are presented that are well-suited for forensics lab work in university.

In particular, we focus on the new version of Belkasoft Evidence Center and compare it with other well-known tools regarding functionality, usability and capabilities.

8755-25, Session 5

Gait recognition using spatio-temporal silhouette-based features

Azhin Sabir, Naseer Al-Jawad, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

Now a day Biometric systems are becoming progressively important in human recognition/identification. Human Gait Recognition becoming increasingly interesting in several applications; like security, medical, and robotics. Gait can be different from other biometrics because it can be unobtrusive and obtained from distance. This paper presents a new algorithm for human gait recognition based on Spatio-temporal body biometric features. The proposed algorithm extracts the Gait cycle by finding the local maxima of a width signal from a sequence of Silhouette images.

Gait Spatio-temporal signature is attained based on the distances between (feet, knees, hands, shoulders, height, and intersection point between legs). Moreover, the changes between any two consecutive frames of the silhouette for each leg has been detected separately, and represented by the least square function. These two features are then added to the feature vector.

Principal Component Analysis is applied followed by K-Nearest Neighbor with a certain threshold used for classification. The threshold is obtained by experiment from a set of data captured from the CASIA database. The preliminary experimental results show that our approach is providing more accurate and confident recognition rate compared to the existence approaches.

8755-27, Session 5

Adaptive error-correction codes for distortion face identification

Wafaa R. Hussein, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

The face is one of the most desired physiological biometrics traits for automatic person identification. Application of face recognition includes access control to sensitive information/locations law-enforcement and forensics and as a proof of identity to claim entitlement to services. This paper aims to investigate the use of error correction techniques for face recognition in uncontrolled environments (face distortion). We investigated error patterns in binary face feature vectors extracted from different image windows for different blurring conditions.Two kinds of blurring(Gaussian and Degradation) were applied. By estimating statistical parameters for the intra- and inter-class distributions of Hamming distances in each window, we encode with appropriate ECC's and each subband depending on these distributions in distortion condition. The proposed approach is tested for binarised wavelet templates using : Extended Yale-B face database. We shall demonstrate that using different combinations of BCH-based ECC's for different blocks/windows and different recording conditions leads to different accuracy rates, and that using ECC's results in significantly improved recognition results.

8755-46, Session 5

Superresolution-based face recognition: Do we need training image set? *(Invited Paper)*

Nadia Al-Hassan, Harin Sellahewa, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

This paper is concerned with face recognition under uncontrolled condition, e.g. at a distance surveillance scenarios, and post-rioting forensic, whereby captured face images are severely degraded/blurred and of low resolution. This is a tough challenge due to many factors including difficulties in determining a model for image degradation that encompasses a range of realistic capturing conditions. We present the results of our investigations into recently developed Compressive Sensing (CS) theory to develop scalable face recognition schemes using a variety of over-complete dictionaries that construct super-resolved face images from any input low-resolution degraded face image. We shall demonstrate that deterministic as well as non-deterministic dictionaries that do not involve the use of face image information but satisfy some form of the Restricted Isometry Property (RIP) used for CS can achieve face recognition accuracy levels as good a, if not better than, those achieved by dictionaries, proposed in the literature, that are learnt from face image databases using elaborate procedures. We shall elaborate on how this approach helps in crime fighting and terrorism.

8755-14, Session PTues

Linger thermo theory, Part I: on the novel dynamics dual of the stationary ectropy/entropy latency information theory

Erlan H. Feria, College of Staten Island (United States)

Latency Information Theory (LIT) is the nascent universal guidance theory for efficient system analysis and designs. LIT has roots in a structural and physical latency-certainty/information-uncertainty (SPLI) duality. The SPLI duality was first identified in 1978 in linear quadratic gaussian (LQG) 'continuous' control and then applied to 'quantized' control (Feria, Graduate-Center/CUNY Ph.D., 1981). Since 2004 it is being successfully applied to radar, statistical-physics, cosmology, biological lifespan problems, etc. In the LIT system analysis, the following four information-system types are identified and their stationary entropy/

ectropy determined: 1) sources, whose bit-rate has as lower bound the source-entropy H; 2) retainers, whose surface-area per volume rate has as lower bound the retainer-entropy N; 3) processors, whose binary-operator-rate has as lower bound the processor-ectropy K; and 4) movers, whose delay-rate has as lower bound the mover-ectropy A. After the LIT analysis is completed either lossless or lossy low-rate-coders are designed to replace undesirable high-rate-systems. In this paper a Linger Thermo Theory (LTT) is revealed as the dynamics dual of stationary entropy/ectropy LIT. LTT is different from LIT in two basic respects, firstly, the four information-system types are assumed to occupy the same physical space and, secondly, physical microstates become the source outcomes in H's definition. For close systems it is found that K, N and A monotonically increase as H increases following thermodynamics' second law. Thus LTT inherently surfaces as the dynamics dual of stationary entropy/ectropy LIT. In a companion paper a LTT derived lifespan equation is used to determine a life insurance premium.

8755-28, Session PTues

Comparison of LSB steganography in Encrypted YCbCr and RGB image planes

Muhammad U. Ghani, The Univ. of Oklahoma (United States)

LSB steganography is implemented with Cryptography using YCbCr and RGB image planes. In this study Steganography method is used to cover secret image using RGB image pixels as its cover media. The secret information is hidden into one of the RGB pixel plane. The Steganographic image is encrypted into three image planes of RGB and is sent over to the receiving channel. For comparison purposes, the same cover image is converted to the YCbCr and the secret image is hidden in the Y plane of the YCbCr pixel plane. The stego image is combined with the CbCr planes and then converted to the RGB pixel plane. For both the RGB images the image quality is measured by some image quality parameters. The image quality parameters used in this study were mean square error, peak signal to noise ratio, normalized cross co-relation, structural content, average difference and maximum difference. The image quality and security is better for the YCbCr image plane as compared to the RGB image plane. The level of security is enhanced by performing cryptography first on the secret image and then using LSB steganography. Stealing of the secret image from the Stego image is made very hard for an unauthorized person.

8755-29, Session PTues

Security solution against denial of service attacks in BESIP system

Filip Rezac, Miroslav Voznak, Jakub Safarik, Pavol Partila, Karel Tomala, Technical Univ. of Ostrava (Czech Republic)

Many large institutions operate small offices with tens or hundreds of employees. A common requirement is the full integration of these departments in the organization's environment (examples are libraries and branch offices). With our proposed solution BESIP, the integration can be achieved easily with the use of IP telephony and supporting network infrastructure. The device is designed as a price acceptable solution that supports SIP (Session Initiation Protocol) IP telephony and also services such as secure communication using SRTP and TLS, monitoring of call quality, tools for detection and elimination attacks, billing and clear configuration via a web interface.

The system consists IP telephony software and a part of BESIP is also module responsible for the safety. Today one of the most common attack against these types of network elements is Denial of Service - DoS. It is because of high efficiency and relatively simple feasibility. It was, therefore, necessary to develop methods for security, which can be used not only as part of our system, but also as a general solution for IP Telephony.

The article refers about the scheme of the BESIP system in more details, the vulnerability of VoIP softswitches to DoS attacks and methods for servers protection are also mentioned. Based on practical testing, the paper summarizes the knowledge and describes the most effective methods that are successful against DoS attacks not only in IP telephony, but a wide range of network services. These methods were used to provide a good basis for our defense algorithm that in its implementation combines ideas and practices for providing adequate protection against the threats mentioned herein.

8755-30, Session PTues

Linger thermo theory, Part II: on the application of linger thermo theory to determining life insurance premiums

Erlan H. Feria, College of Staten Island (United States)

In this paper a computer implemented algorithm is given for determining a life insurance premium. The premium is based on a theoretical adult lifespan (T) calculated from: T = dT(M/dM)^2 where M is the adult's mass, dM is the mass of the consumed food per day (e.g., 0.4 kg for a 2000 kcal diet) and dT is the duration of one day. This equation inherently surfaced from a nascent Linger Thermo Theory (LTT) that unifies Thermodynamics and Lingerdynamics, its recently revealed time-dual (Feria, "Latency information theory: Novel lingerdynamics ectropies are revealed as time duals of thermodynamics entropies.", IEEE Int. Conf. on Systems, Man and Cybernetics, October 12, 2011, Anchorage, Alaska). Since T is proportional to the ratio of the individual's mass to the consumed food per day squared, i.e., (M/dM)^2, it predicts that higher weight (obese) individuals can have the same lifespan as lower weight ones when both have the same M/dM ratio. Most importantly, this property has the virtue of being in full agreement with a recent National Institute of Aging (NIA) study published online August 29, 2012 in the journal Nature, which surprised and shocked the researchers when they found that higher weight (obese) rhesus monkeys had a similar life expectancy as lower weight ones (Kolata, "Severe Diet doesn't Prolong Life, as Least in Monkeys", The N. Y. Times, August 29, 2012). It is thus expected that the proposed LTT method should improve on traditional calculations and actuarial tables that often presume that obese individuals have lower life-expectancies.

8755-31, Session PTues

IP telephony-based danger alert communication system and its implementation

Filip Rezac, Jakub Safarik, Miroslav Voznak, Karel Tomala, Pavol Partila, Technical Univ. of Ostrava (Czech Republic)

The paper deals with development of a web application allowing to deliver pre-recorded voice messages by using SIP generator. The developed application is a part of complex system, which has been evolved in Dpt. of Telecommunications, Technical University of Ostrava for last three years.

Our intent is focused on disaster management, the message, which should be delivered within specified time span, is typed in the application and text-to-speech module ensures its transformation to a speech format, after that a particular scenario or warned area is selected and a target group is automatically unloaded. For this purpose, we have defined XML format for delivery of phone numbers which are located in the target area and these numbers are obtained from mobile BTS's (Base transmission stations). The benefit of such communication compared to others is the fact that it uses a phone call and, therefore, it is possible to get feedback who accepted the message and to improve efficiency of alert system. Finally, the list of unanswered calls is exported and these users can be informed via SMS.

The whole system will be based in the data centre of a telecommunications operator and will be accessible to the crisis centre's staff. A staff member logs into the system created by us, loads the pre-

recorded alert and other parameters and sends the request. In the paper, the core of the danger alert system is described including algorithms of the voice message delivery. We also presents preliminary model of the crisis situations and calculate the approximate time to inform all people who are in the field.

8755-32, Session PTues

Breaking down the barriers of using strong authentication and encryption in resource constrained embedded systems

Ron Knobler, Peter Scheffel, Scott Jackson, McQ, Inc. (United States); Kris Gaj, Jens-Peter Kaps, George Mason Univ. (United States)

Various embedded systems, such as unattended ground sensors (UGS), are deployed in dangerous areas, where they are subject to compromise. Since numerous systems contain a network of devices that communicate with each other (often times with COTS radios), an adversary is able to intercept messages between system devices, which jeopardizes sensitive information transmitted by the system (e.g. location of system devices). Secret key algorithms such as AES are a very common means to encrypt all system messages to a sufficient security level, for which lightweight implementations exist for even very resource constrained devices. However, all system devices must use the appropriate key to encrypt and decrypt messages from each other. Traditional public key algorithms (PKAs), such as RSA and Elliptic Curve Cryptography (ECC), provide a sufficiently secure means to provide authentication and a means to exchange keys. However, these traditional PKAs are not suitable for very resource constrained embedded systems or systems which contain low reliability communication links (e.g. mesh networks), especially as the size of the network increases. Therefore, most UGS and other embedded systems resort to pre-placed keys (PPKs) or other naïve schemes which greatly reduce the security and effectiveness of the overall cryptographic approach. McQ has teamed with CERG at GMU to develop an approach using revolutionary cryptographic techniques that provides both authentication and encryption, but on resource constrained embedded devices, without the burden of large amounts of key distribution or storage.

8755-33, Session PTues

Solving data-at-rest for the storage and retrieval of files in ad hoc networks

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Based on current trends for both military and commercial applications, the use of mobile devices (e.g. smart phones and tablets) is greatly increasing. Several military applications consist of secure peer-to-peer file sharing without a centralized authority. For these military applications, if one or more of these mobile devices are lost or compromised, sensitive files can be compromised by adversaries, since COTS devices and operating systems are used. Complete system files cannot be stored on a device, since after compromising a device, an adversary can attack the data-at-rest, and eventually obtain the original file. Also after a device is compromised, the existing peer-to-peer system devices must still be able to access all system files.

McQ has teamed with the Cryptographic Engineering Research Group at George Mason University to develop a custom distributed file sharing system to provide a complete solution to the data-at-rest problem for resource constrained embedded systems and mobile devices. This innovative approach scales very well to a large number of network devices, without a single point of failure. We have implemented the approach on representative mobile devices as well as developed an extensive system simulator to benchmark expected system performance based on detailed modeling of the network/radio characteristics, CONOPS, and secure distributed file system functionality. The simulator is highly customizable for the purpose of determining expected system performance for other network topologies and CONOPS.

8755-34, Session PTues

Automatic analysis of attack data from distributed honeypot network

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There are many ways of getting real data about malicious activity in a network. One of them relies on masquerading monitoring servers as a production one. These servers are called honeypots and data about attacks on them brings us valuable information about actual attacks and techniques used by hackers. The article describes distributed topology of honeypots, which was developed with a strong orientation on monitoring of IP telephony traffic. IP telephony servers can be easily exposed to various types of attacks, and without protection, this situation can lead to loss of money and other unpleasant consequences. Using a distributed topology with honeypots placed in different geological locations and networks provides more valuable and independent results. With automatic system of gathering information from all honeypots, it is possible to work with all information on one centralized point. Communication between honeypots and centralized data store use secure SSH tunnels and server communicates only with authorized honeypots. The centralized server also automatically analyses data from each honeypot. Results of this analysis and also other statistical data about malicious activity are simply accessible through a built-in web server. All statistical and analysis reports serve as information basis for an algorithm which classifies different types of used VoIP attacks. The web interface then brings a tool for quick comparison and evaluation of actual attacks in all monitored networks. The article describes both, the honeypots nodes in distributed architecture, which monitor suspicious activity, and also methods and algorithms used on the server side for analysis of gathered data.

8755-35, Session PTues

Passive radiation detection using optically active CMOS sensors

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Recently, there have been a number of small-scale and hobbyist successes in employing commodity CMOS-based camera sensors for radiation detection. For example, several smartphone applications initially developed for use in areas near the Fukushima nuclear disaster are capable of detecting radiation using a cell phone camera, provided opaque tape is placed over the lens. In all current useful implementations, it is required that the sensor not be exposed to visible light. We seek to build a system that does not have this restriction. While building such a system would require sophisticated signal processing, it would nevertheless provide great benefits. In addition to fulfilling their primary function of image capture, cameras would also be able to detect unknown radiation sources even when the danger is considered to be low or non-existent. By experimentally profiling the image artefacts generated by alpha and beta particle impacts, algorithms are developed to identify the unique features of radiation exposure, while discarding optical interaction and thermal noise effects. Preliminary results focus on achieving this goal in a laboratory setting, without regard to integration time or computational complexity. However, future work will seek to address these additional issues.

8755-36, Session PTues

Three Dimensional Alpha Weighted Quadratic Filter Based Image Color Contrast Enhancement

Chen Gao, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

In this paper, we introduce a new spatial domain color contrast enhancement algorithm based on the three dimensional alpha weighted quadratic filter (AWQF). The goal of this work is to utilize the characteristics of the nonlinear filter to enhance image contrast while recovering the color information. For images with less than desirable illumination, a modified Naka-Rushton function is proposed to adjust the underexposed or overexposed intensities in the image. We also present a new image contrast measure called the Root Mean Enhancement (RME) to model Root Mean Square (RMS) contrast in image sub-blocks. A color RME contrast measure CRME is also proposed based on the PCA decomposition and the grayscale RME. The new measures help choose the optimal operating parameters for enhancement algorithms. We demonstrate the effectiveness of the proposed methods on varieties of images. Experimental results show that the proposed algorithms can enhance the image contrast and color quite efficiently and effectively. Comparisons with existing state of the art algorithms will be also presented.

8755-37, Session PTues

Mobile object retrieval in server-based image databases

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The increasing number of mobile phones equipped with powerful cameras leads to huge collections of user-generated images. To utilize the information of the images on site, image retrieval systems are becoming more and more popular to search for similar objects in an own image database. As the computational performance and the memory capacity of mobile devices are constantly increasing, this search can often be performed on the device itself. This is feasible, for example, if the images are represented with global image features or if the search is done using EXIF or textual metadata. However, for larger image databases, if multiple users are meant to contribute to a growing image database or if powerful content-based image retrieval methods with local features are required, a server-based image retrieval back-end is needed. In this work, we present a content-based image retrieval system with a client server architecture working with local features. On the server side, the scalability to large image databases is addressed with the popular bag-of-word model with state-of-the-art extensions to circumvent the loss of accuracy caused by the quantization step. The client end of the system focuses on a lightweight user interface presenting the most similar images of the database highlighting the visual information which is common with the query image. Additionally, new images can be added to the database making it a powerful and interactive tool for mobile content-based image retrieval.

8755-38, Session PTues

Linger thermo theory, Part III: on the application of the nascent linger thermo theory to cosmology

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Cosmological studies and observations starting in the late 1920's strongly indicate that our universe was created in an explosion of maximally dense mass-energy more than 13.7 billion years ago. Since then its volume has been continuously expanding, with an acceleration of this growth also confirmed recently. Many theoretical models have been advanced for the universe's spatial evolution, inclusive of some that are adverse to a continuous expansion. Yet, theoretical models aren't available where an expanding universe inherently surfaces from thermodynamics' laws which are believed to drive the universe's evolution (Atkins, Four Laws that Drive the Universe, Oxford, 2007). In this paper, a novel Linger Thermo Theory (Feria, "Latency Information Theory: Novel Lingerdynamics Ectropies are Revealed as Time Duals of Thermodynamics Entropies.", IEEE Int. Conf. on Systems, Man and Cybernetics, October 12, 2011, Anchorage, Alaska) leads us to a novel retainer-entropy enhanced thermodynamics achieving this goal. Linger Thermo Theory is the dynamics dual of the also novel stationary ectropy/entropy Latency Information Theory.

8755-39, Session PTues

Automated license plate with barcode recognition system

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License Plate Recognition (LPR) is an image-processing tools used to identify vehicles by their license plates. LPR system is a key to many traffic related applications such as road traffic monitoring, borders control, parking lots access control, unauthorized vehicles entering private areas monitoring, electronic payment systems (toll payment, parking fee payment), freeway arterial management systems and traffic surveillance. These tasks become more complicated when dealing with license plate images taken in various inclined angles, environment, color, climate (heavy rain…) or plate images with noise. Because this problem is usually used in real-time systems, it requires not only accuracy but also fast processing. The problem of automatic LPR recognition has been studied since 1980s. There are several of systems used so far for recognition of number plates such as BAM (Bi-directional Associative Memories) neural network character recognition, pattern matching etc. However, most of them worked under restricted conditions, such as fixed illumination, limited vehicle speed, designated routes, and stationary backgrounds. In this study, as few constraints as possible on the working environment are considered.

Recently one-dimensional barcodes have been promoted as a machine readable license plate. Each label contains a unique serial number coded in black and white bars that was a key into a database containing detailed information. Practically, the author is not familiar with license plate with barcode character recognition systems. In this paper, new algorithms for color vehicle license plate with barcode and without barcode identification are proposed. The presented method can be divided in three image processing phases: the phase of license plate and barcode segmentation, the phase of license plate processing and character recognition, and barcode recognition. The algorithm was tested with natural-scene gray-level vehicle images of different backgrounds and ambient illumination. The experiment performed by program based on aforementioned algorithms indicates that our LPR system based on color image processing is quite quick and accurate. Promising results have been obtained in the experiments with Israeli and Bulgarian license plates including images of poor quality. These results are also compared with other published LPR-systems

8755-40, Session PTues

Both thermal and visual image enhancements using fuzzy inference system

Mehdi Roopaei, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

In this paper, we propose a novel fuzzy contrast enhancement method based on the fuzzy set theory. Contrast enhancement techniques improve a characteristic or quality of an image, such that the resulting image is better than the original for a specific application or set of objectives. Fuzzy logic is a useful tool for handling the uncertainty in the images associated with vagueness and/or imprecision. The basic idea

of the proposed contrast enhancement method is to establish a simple fuzzy system based on the local information available to be used by a fuzzy inference system as a contrast intensifier. The experimental results demonstrate that the proposed algorithm is very effective in contrast enhancement both thermal and visual images as well as in preventing over- enhancement.

8755-41, Session PTues

Iterative color image enhancement and standardization

Clara M. Mosquera Lopez, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

In human vision, color images are perceptually richer than achromatic images. For instance, color and shape often convey important information for diagnosis in dermatology, evaluation of surface conditions in radar imaging, face detection and recognition, etc. Color is one of the most informative features of an image, and plays a central role in the development of image processing algorithms and computer vision systems. However, color may be randomly affected by several factors. Such factors include viewing geometry, differences among image acquisition protocols, capturing devices, lighting or other conditions. Consequently, performance of color-based classification systems is degraded when the color of the images is not standardized. Thus, color standardization is practically a necessary condition for developing accurate color-based automatic recognition systems. Standardization mainly consists of controlling the settings of a set of images such that their original device-dependent color space is transformed into some device-independent color space. Although various types of image standardization algorithms have been developed, there is a need for more precise methods that can provide sensitive and reproducible automatic image processing systems.

The goal of this paper is to present tools for simultaneous color image enhancement and standardization. In this paper, we introduce a new iterative algorithm that match the color statistics of an original image to the distribution of reference images. Reference images are considered to have a desirable color distribution for a specific application. The proposed method proceeds in two stages at each iteration: source image retrieval and color adjustment. First, a color similarity measurement is used to select an appropriated target from an image dataset by comparing the color dynamic range of the images. Second, we convert the images from the RGB model to a decorrelated color space before performing color transference operations. Next, the color statistics of the target image are transferred to the original image by using a pixel-based color mapping. Finally, a wavelet-based algorithm is applied to the re-colored image to preserve the original edge information and to lower the noise. The new image enhancement and standardization tool has several advantages: it is computationally efficient and it has the potential of increasing substantially the accuracy of segmentation and classification systems based on color features. Computer simulations indicate that the iterative and gradual color matching procedure is able to standardize the appearance of color images according to a desirable color distribution and reduce the amount of artifacts appearing in the resulting image. Applications of the developed tools include military applications, surveillance systems, tracking, and other fields where color constancy is a crucial issue. The developed method can also be adapted to any optical imaging device such as microscopes, endoscopes to improve the monitoring and diagnosis accuracy in several biomedical fields.

8755-42, Session PTues

Email forensics: a practical overview using certain commercial software tools

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The aim of the paper is to show the usefulness of modern forensic software tools for email investigation. In particular, we focus on the new version of Nuix and compare it with other well-known tools regarding functionality, usability and capabilities. It is shown how these software tools work and how capable they are in examining complex email scenarios.

8755-44, Session PTues

Using Java technology to connect to remote tactical radios

Lisa M. Scott, Michael Younger, U.S. Army Research Lab. (United States)

With the technical advancements and commonality of the World Wide Web, there are possibilities to build web-based user interfaces (WUI) that have the capability to monitor military assets from anywhere in the world. This paper presents a design for using Java as a programming language to build a web-based interface to connect, monitor and display the state of tactical radios remotely. This software system would consist of a module to send commands and collect data from one to all tactical radio(s) and a module for receiving, storing and displaying the results in a web browser. Technologies to be used include but limited to a web server, JavaScript, a lightweight database, Google Gson (GSON) and Java Script Object Notation (JSON). With the mobile device popularity and growing with high-speeds, the Android platform being open-sourced, the expansion of the interface to manipulate the radios using an Android platform will be considered. This paper will provide an overview for designing the graphical interface and software architecture to request, collect, store and display the radio data.

8756-2, Session 1

Scalable sensor management for automated fusion and tactical reconnaissance

Thomas J. Walls, Michael L. Wilson, U.S. Naval Research Lab. (United States); Darin Partridge, Jonathan R. Haws, Mark Jensen, Troy Johnson, Brad Petersen, Scott A. Anderson, Space Dynamics Lab. (United States)

The capabilities of tactical intelligence, surveillance, and reconnaissance (ISR) payloads are expanding from single sensor imagers to integrated systems of systems architectures. Increasingly, these systems of systems include multiple sensing modalities that can act as force multipliers for the intelligence analyst. We describe here a Sensor Management System (SMS) designed to provide a flexible central coordination component capable of managing multiple collaborative sensor systems onboard an aircraft or unmanned autonomous vehicle (UAV). Its purpose is to increase sensor-to-sensor cooperation and collaboration and to aid in the manned-unmanned teaming of autonomous and user-controlled sensors.

The SMS architecture is designed to be sensor and data agnostic and provide flexible networked access for both data providers and data consumers. It supports pre-planned and ad-hoc missions, with provisions for on-demand tasking and updates from users connected via data links. Management of sensors and user agents takes place over standard network protocols such that any number and combination of sensors and user agents, either on the local network or connected via data link, can register with the SMS at any time during the mission. The SMS provides control over sensor data collection to handle logging and routing of data products to subscribing user agents. It also supports the addition of algorithmic data processing agents for feature/target extraction and provides for subsequent cueing from one sensor to another. The SMS architecture was designed to scale from a small UAV carrying a limited number of payloads to an aircraft carrying a large number of payloads. The SMS system is STANAG 4575 compliant as a removable memory module (RMM) and can act as a vehicle specific module (VSM) to provide STANAG 4586 compliance (level-3 interoperability) to a non-compliant sensor system. The SMS architecture will be described and results from several flight tests will be shown.

8756-3, Session 1

Affordable non-traditional sources context exploitation to improve distributed fusion system robustness

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There is a need to affordably improve the robustness of distributed fusion systems by dynamic intelligent use of unforeseen non-traditional sources. Automated adaptive methods are needed to find relevant data, create models, characterize the quality, and apply such information to measure their conformity to fusion system products at all levels to include situation modeling and mission impact prediction. Based upon these measures the automated context exploitation management of new sources is needed to substantiate these results. Such “repurposed” data has the potential to expand upon the quantity, quality, availability, timeliness, and diversity of the baseline fusion system sources and therefore to improve endogenous entity state estimation accuracy and robustness at all levels of fusion. Techniques are described that automatically learn to characterize and search such repurposed data to enable operators to construct data model transformations into baseline High-Level Information Fusion (HLF) ontologies. To achieve this substantial new work is required to extend Joint Directors Lab (JDL) Level 4 Data Fusion model into a Data Fusion & Resource Management (DF&RM) technical architecture that effectively assesses and manages this expanded portfolio of external repurposed sources, objects, models, and algorithms to include data pattern discovery and context conformity assessment and management. The paper describes our context exploitation technical architecture, software development, and the demonstration of repurposed data context assessment using an IED insurgent workflow and an Intelligence Surveillance & Reconnaissance (ISR) fusion product.

8756-4, Session 1

Considerations for multiple hypothesis correlation on tactical platforms

Alan M. Thomas, Georgia Tech Research Institute (United States)

Tactical platforms benefit greatly from the fusion of tracks from multiple sources in terms of increased situation awareness. As a necessary precursor to this track fusion, track-to-track association, or correlation, must first be performed. The related measurement-to-track fusion problem has been well studied with multiple hypothesis tracking and multiple frame assignment methods showing the most success. The track-to-track problem differs from this one in that measurements themselves are not available but rather track state update reports from the measuring sensors. Multiple hypothesis, multiple frame correlation systems have previously been considered; however, their practical implementation under the constraints imposed by tactical platforms is daunting. The situation is further exacerbated by the inconvenient nature of reports from legacy sensor systems on bandwidth -limited communications networks. In this paper, consideration is given to the special difficulties encountered when attempting the correlation of tracks from legacy sensors on tactical aircraft. Those difficulties include the following: covariance information from reporting sensors is frequently absent or incomplete; system latencies can create temporal uncertainty in data; and computational processing is severely limited by hardware and architecture. Moreover, consideration is given to practical solutions for dealing with these problems in a multiple hypothesis correlator.

8756-5, Session 2

Efficiently applying uncertain implication rules to the transferable belief model

William J. Farrell III, Andrew M. Knapp, Lakota Technical Solutions, Inc. (United States)

Within the domain of multi-source classification fusion, automated algorithms typically rely on real-time parametric sensor data. That is, they generally do not incorporate subject matter expertise to fuse information from other knowledge (non-parametric) sources. This parametric approach often leads to ambiguous results that could be refined using subject matter expertise regarding relationships between the classification hypothesis space and hypothesis space of other knowledge sources. However, encoding relationships between these different domains is rarely considered due to lack of a computationally efficient way of propagating beliefs between different frames of discernment. We consider the case where subject matter expertise is encoded in the form of uncertain implication rules. This approach is met with several technical challenges: (1) computational scalability of fusing data with implication rules that relate different frames of discernment, (2) developing constraints on the implication rules to ensure logical results, and (3) accounting for uncertainty in the implication rules themselves. Based upon the approach introduced by Ristic and Smets, which addresses

the third challenge, we derive a computationally efficient simplification that allows implication rules to be used within the Transferable Belief Model (TBM) with polynomial computational complexity instead of power set complexity. This simplification is achieved by: (1) imposing two constraints on the implication rules and (2) restricting inference to singletons of the frames of discernment. The result enables subject matter expertise, defined by a set of uncertain implication rules, to be incorporated into multi-source classification algorithms using a computationally efficient TBM implementation.

8756-6, Session 2

A methodology for hard/soft information fusion in the condition monitoring of aircraft

Joseph T. Bernardo, Penn State (United States)

Condition-based maintenance (CBM) refers to the philosophy of performing maintenance when the need arises, based upon indicators of deterioration in the condition of the machinery. Traditionally, CBM involves equipping machinery with electronic sensors that continuously monitor components and collect data for analysis. The addition of the multisensory capability of human cognitive functions (i.e., sensemaking, problem detection, planning, adaptation, coordination, naturalistic decision making) to traditional CBM may create a fuller picture of machinery condition.

Cognitive systems engineering techniques provide an opportunity to utilize a dynamic resource—people acting as soft sensors. The literature is extensive on techniques to fuse data from electronic sensors, but little work exists on fusing data from humans with that from electronic sensors (i.e., hard/soft fusion). The purpose of my research is to explore, observe, investigate, analyze, and evaluate the fusion of pilot and maintainer knowledge, experiences, and sensory perceptions with digital maintenance resources. Hard/soft information fusion has the potential to increase problem detection capability, improve flight safety, and increase mission readiness.

This proposed project consists the creation of a methodology that is based upon the Living Laboratories framework, a research methodology that is built upon cognitive engineering principles. This study performs a critical assessment of concept, which will support development of activities to demonstrate hard/soft information fusion in operationally relevant scenarios of aircraft maintenance. It consists of fieldwork, knowledge elicitation to inform a simulation and a prototype.

8756-7, Session 2

Using classifier fusion to improve the performance of multiclass classification problems

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In multiclass classification problems, often the classifier is decomposed into a collection of binary classification problems, as opposed to jointly modeling all classes with a single classifier [1]. Various methods can be found in the literature for decomposing the multiclass problem into a collection of binary classifiers. Typical algorithms, and that are also studied here, include Each versus all remaining (EVAR) [1], Each versus all individually (EVAI) [2], and Output Correction Coding (OCC) [3]. With each of these methods a decision rule is formulated utilizing the various binary classifiers to determine the correct classification of an unknown data point. For example, with EVAR the binary classifier with maximum output is chosen. For EVAI, the correct class is chosen using a majority voting rule, and with OCC a comparison algorithm based minimum Hamming distance metric is used. In this paper, it is demonstrated that classification performance can be improved in each of these methods if the binary classifier outputs are trained using a discrete classifier based on uniform Dirichlet priors. Specifically, the BDRA [4] is used to not only train the appropriate binary classifier pairs, but it is also used to train on the discrete classifier outputs to formulate the correct classification decision of unknown data points. In this way, the BDRA fuses the binary classifier fusion outputs, while selecting the most relevant classifier pairs to improve the overall classifier decision space. Experimental results are shown with real data sets taken from the Keel Repository of classifier DataBases. In general, and for the data sets considered, it is shown that the new method's performance is superior to that of existing methods.

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8756-11, Session 3

Real-time tracking and fast retrieval of persons in multiple surveillance cameras of a shopping mall

Henri Bouma, TNO Defence, Security and Safety (Netherlands); Jan Baan, Technisch Physische Dienst-TNO (Netherlands); Sander Landsmeer, Chris Kruszynski, TNO Defence, Security and Safety (Netherlands); Gert Van Antwerpen, Technisch Physische Dienst-TNO (Netherlands); Judith Dijk, TNO Defence, Security and Safety (Netherlands)

The capability to track individuals in CCTV cameras is important for surveillance applications at e.g. train stations, airports and shopping centers. For the camera operators, however, it is laborious to track and trace people over multiple cameras. In this paper, we present a semi-autonomous system for real-time tracking and fast interactive retrieval of persons in video streams from multiple surveillance cameras in a shopping mall. We describe our system, which consists of pedestrian detection, track generation, space-time localization, appearance based re-identification and a graphical man-machine interface to fuse the information from multiple cameras. The system was tested in a shopping mall with eight cameras. These cameras have non-overlapping field-of-views and different lighting conditions. All video streams are processed in parallel on a distributed system and tracks and detections are continuously stored in a database. The operator can use these tracks and detections to quickly answer questions such as "where did a particular person come from?" or "where did he go to?". The interface enables live tracking in current streams and interactive searches in historic data. The results show that the system allows an operator to find the origin or destination of a person more efficiently.

8756-29, Session 3

Adaptive fusion algorithm for VIS and IR images driven by neural network

Bohumil Stoklasa, Jaroslav Rehacek, Zdenek Hradil, Palack? Univ. Olomouc (Czech Republic)

Because of today infrared technology, it is possible to acquire images of the scene in the visible band (VIS) and in the infrared band (IR). Than a composite image with higher information content for an observer should be computed. An ideal system should react to the input and change its internal fusion procedures to produce the best possible output. A number of studies in the field of fusion VIS and IR signals prove ability of adaptive systems outperform stationary fusion algorithms. Objective metrics for fusion process quality evaluation are mostly used in these comparisons. A description of adaptive system using change of internal fusion algorithm driven by input images statistics was published recently [1]. In this system, the connection between different inputs and preferred fusion algorithm is realized by a neural network. The aim of this study is use the same concept of an adaptive fusion system construction but including one algorithm with changeable parameters. A multiresolution algorithm was studied where number of decomposition levels and fusion rule for each level treat as parameters. Coarse-grained histogram versions of input images serve as metrics estimating the quality of the input images and driving the system parameters through the neural network. Supervised learning on a large dataset containing different types of inputs was used to set the neural network. In this study we compare a multiresolution algorithm with fix parameters and the adaptive approach. The adaptive system achieved better results according to objective measurement of the fusion process quality.

8756-13, Session 4

Multi-classifier decision level fusion for face classification in the harsh environments

Seokwon Yeom, Daegu Univ. (Korea, Republic of)

Face classification has wide applications in intelligent video surveillance, content retrieval, robot vision, and human-machine interface. Pose and expression changes and arbitrary illumination are typical problems for face recognition. When the face is captured at a distance, the image quality is often degraded by blurring and noise corruption. This paper investigates the efficacy of multi-classifier decision level fusion for face classification based on the photon-counting linear discriminant analysis with two different cost functions: Euclidean distance and negative normalized correlation. Decision level fusion comprises three stages: cost normalization, cost validation, and fusion rules. First, the costs are normalized into the same range with each other and then, the candidiate costs are selected during validation. Three fusion rules are employed: minimum, average, and majority-voting rules. In the experiments, out-of-focusing and motion blurs are rendered to simulate the effects of the long distance environments. It will be shown that the decision-level fusion scheme provides better results than the single classifier.

8756-14, Session 4

Intelligent decision making system using cloud models for monitoring farming operations

Abdulqadir I. Khoshnaw, Univ. of Kurdistan (Iraq)

Monitoring farming operations is an important task for an individual farmer and also for farming corporations on large scale. Monitoring crops, water resources, machines, and traffic of humans as well as animals on the farm is very important for making decisions by the farmer to manage farming operations especially if the terrain of the farm is rough. Some systems have been developed for monitoring farm operations using sensor networks, but most of these systems require human involvement in the monitoring. This research proposes an intelligent decision making system for monitoring farm operations. This system will make it easier to monitor different situations on the farm and make a decision about it with minimum human involvement especially if the farmer is not available. The decision making process adapted in this research is based on using cloud model theory for processing uncertainty in decision making. Cloud Model is a methodology to make decisions by modeling qualitative concepts and transform it into quantitative representation. This methodology adds a human like intelligence to the system where human brain makes decisions by processing quantitative concepts and not just numbers. The monitoring system is developed by employing a network of cameras on the farm to take images from different situations on the farm. These images will be processed by the system and decisions can be made based on processing these images using the cloud models. Currently the cloud models have been developed for some situations on a farm and the system is been integrated and tested.

8756-15, Session 4

Fusion of data from multiple sensors with model-based data analysis

Jeremy Straub, The Univ. of North Dakota (United States)

For many applications, the combination of data from multiple sources is required to reach a valid conclusion. Limited communications and processing capabilities (both computer and human) dictate that it is highly desirable to transmit, process and review information that has a greater likelihood of affecting the decision under consideration (or thesis, for a scientific experiment) before data that is less relevant. For unmanned craft (e.g., ground robots, UAVs, satellites and spacecraft), it is, thus, valuable to enable onboard autonomous analysis to determine what data is most relevant to a given scientific, surveillance or other goal. Previous work has demonstrated the ability to identify and prioritize discrepancies between collected and pre-existing (e.g., lower-resolution or predicted) data. This has been demonstrated with image, topographic and gravity model data. This paper focuses on combining the single-data-source analysis from these three datasets to produce a fusion-analysis that allows the value of the component data to be predicted, based on its value to supporting the thesis. This value is utilized as a metric to prioritize the data for transmission over a limited bandwidth connection (or to ensure that critical data, in a time-sensitive situation, is transmitted before less important data). An algorithm for combining this multi-source data is presented. The algorithm specifically focuses on combining the gravity, topographic and image data; however, its utility for other data types is extrapolated and discussed. The viability of this approach is evaluated in the context of persistent surveillance for Earth applications and near-Earth asteroid assessment applications.

8756-16, Session 4

Performance analysis of image fusion methods in transform domain

Yoonsuk Choi, Ershad Sharifahmadian, Shahram Latifi, Univ. of Nevada, Las Vegas (United States)

Image fusion involves merging two or more images in such a way as to retain the most desirable characteristics of each. There are various image fusion methods and they can be classified into three main categories: i) Spatial domain, ii) Transform domain, and iii) Statistical domain. We focus on the transform domain in this paper as spatial domain methods are primitive and statistical domain methods suffer from a significant increase of computational complexity. In the field of image fusion, performance comparison is a hot topic since the evaluation result gives valuable information which can be utilized in various applications, such as military, medical imaging, remote sensing, and so on. In this paper, we analyze and compare the performance of fusion methods based on four different transforms: i) wavelet transform, ii) curvelet transform, iii) contourlet transform, and iv) nonsubsampled contourlet transform. Fusion frameworks and algorithms for each of the four transforms are explained in detail, and two different sets of images are used in our experiments. Furthermore, performance evaluation criteria like entropy, similarity measure, piella metric and mutual information are used to quantitatively analyze the fusion results. The comparison results show that the nonsubsampled contourlet transform method performs better than the other three methods. We also inspect the effect of decomposition level during the fusion process by using different levels of decomposition. Results indicate that the decomposition level of 3 showed the best fusion performance, and decomposition levels beyond level-3 did not affect the fusion results.

8756-17, Session 4

An approach to DSM refinement with fusion of airborne lidar point cloud data and optical imagery

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The airborne Lidar system, which usually integrated with optical camera, is an efficient way of acquiring 3D geographic information and enjoys widely application in building DSM. However, when the airborne Lidar is used in urban area, where there are a large amount of tall buildings, the characteristic points of buildings are seldom measured and the measured points are frequently too sparse to create precise building models. In this paper, an approach to DSM refining DSM in urban area with fusion of airborne Lidar point cloud data and optical imagery is put forward. Firstly, the geometric relationship between the airborne Lidar point and the correspondent pixel on the image synchronously taken by optical camera is analyzed. The relative position and attitude parameters between the laser rangefinder and the camera are determined in the process of alignment and calibration. Secondly, the building roof edges on the optical image are extracted with Robert edge detection algorithm. By tracing the building roof edges, the contours of building roofs in vector format are acquired and the characteristic points of buildings are further extracted. Thirdly, all the Lidar measured points on the roof of specific building are separated from the point cloud data by judging the geometric relation between Lidar measured points and the building roof contour, which is represented by a polygon, according to their plane coordinates. Finally, the DSM refinement for buildings can be implemented. All pixels representing the building roof are given heights as same as that of nearer Lidar point inside the polygon. Ortho-photo map and virtual building models of urban area with higher quality can be reached with the refined DSM and optical images. Experiments show that the proposed calibration method is correct and effective.

8756-18, Session 5

A cognitive approach to vision for a mobile robot

David P. Benjamin, Pace Univ. (United States); Damian M. Lyons, Fordham Univ. (United States); Christopher Funk, Pace Univ. (United States)

We describe a cognitive vision system for a mobile robot, which works in a manner similar to the human vision system, using saccadic, vergence and pursuit movements to extract information from visual input.

At each step, the vision system selects a point in the visual input to fixate on. Distance, shape, texture and motion information are computed in a small region and used to build a mesh which is embedded within an overall 3D model of the robot's environment. Background knowledge is used to extend this structure as appropriate, e.g. if a patch of wall is seen, it is hypothesized to be part of a large wall and the entire wall is created in the virtual world. The difference between the input from the real camera and from the virtual camera is compared using local Gaussians, creating an error mask that indicates the main differences between them. This is then used to select the next fixation.

This approach permits us to use very expensive algorithms on small localities, generating very accurate models. It also is task-oriented, so the robot can use its goals to decide which parts of the environment need to be examined.

The software components of this architecture include PhysX for the 3D virtual world, OpenCV and the Point Cloud Library for visual processing, and the Soar cognitive architecture which controls the perceptual processing and robot planning. The hardware is a custom-built pan-tilt stereo color camera.

We describe experiments using both static and moving objects.

8756-19, Session 5

Persistent unmanned airborne network support for cooperative sensors

Ajay Verma, Ronald Fernandes, Knowledge Based Systems, Inc. (United States)

Highly-dynamic mobile-wireless sensor networks operating in a large region present unique challenges in end-to-end communication for sensor data sharing and data fusion, particularly caused by the time varying connectivity of high-velocity nodes combined with the unreliability of the wireless communication channel. Not much work is found in literature that can utilize the agent mobility in order to achieve the network connectivity requiring minimal use of transmission power. This paper uses the concepts of dynamic control theory that governs the movement of the sensor nodes in order to establish a well connected and distributed network while satisfying the mission dictated mission requirements and deployment constraints.

To establish an airborne communication network, a UAV or sensor agent must maintain a link(s) with other agents(s) and/or fixed base stations. A link between two UAVs sensors is deemed to be established when the linked UAVs are in line of sight as well as within the transmission range of each other. Ideally, all the UAVs as well as ground stations involved in operations must be fully connected. However, the continuous motion of UAVs poses a challenge to ensure full connectivity of the network. In this paper we explore the dynamic topological network configuration control enabling data sharing among various sensor agents under the mission related constraints in order to i) establish and maintain connectivity among sensors, and ii) to quickly recover from network connectivity disruptions.

8756-20, Session 5

Fusion of ranging data from robot teams operating in confined areas

Damian M. Lyons, Tsung-Ming Liu, Karma Shrestha, Fordham Univ. (United States)

We address the problem of fusing laser ranging data from multiple mobile robots that are surveying an area as part of a robot search and rescue or area surveillance mission. Reid and Braunl (2011) consider this kind of scenario where the robots are spread apart and are surveying a large area. However, we are specifically interested in the case where members of the robot team are working in close proximity to each other. The advantage of this teamwork is that it greatly speeds up the surveying process; the area can be quickly covered even when the robots use a random motion exploration approach. However, the disadvantage of the close proximity is that it is possible, and even likely, that the laser ranging data from one robot include many depth readings caused by another robot. We refer to this as mutual interference.

Using a team of Pioneer 3-AT robots with tilted laser sensors, we evaluate several techniques for fusing the laser ranging information so as to eliminate the mutual interference. There is an extensive literature on the mapping and localization aspect of this problem (e.g., Liu and Thrun (2003)), and recent work on mapping has included handling dynamic or transient map features (e.g., Wansiripitak and Murray (2009)). Our problem differs from the dynamic map problem in that we look at one kind of transient map feature, other robots, and we know that we wish to completely eliminate the feature.

We present and evaluate three different approaches to the map fusion problem: a robot-centric approach, based on estimating team member locations; a map-centric approach, based on inspecting local regions of the map, and a combination of both approaches. We show results for these approaches for several experiments for a two robot team operating in a confined indoor environment (4m x 4m).

1. Liu, Y., Thrun, S., Gaussian Multirobot SLAM, Advances in Neural INformation Processing Systems, NIPS 2003, Vancover Canada, 2003.

2. Robert Reid, Thomas Bräunl, Large-scale Multi-robot Mapping in

MAGIC 2010, IEEE Robotics, Automation and Mechatronics, Qingdao China. 2011.

3. S Wangsiripitak and D W Murray, Avoiding moving outliers in visual SLAM by tracking moving objects, Proc IEEE Int Conf on Robotics and Automation, Kobe, May 2009.

8756-21, Session 5

Combining metric episodes with semantic event concepts within the symbolic and sub-symbolic robotics intelligence control system (SS-RICS)

Troy D. Kelley, U.S. Army Research Lab. (United States)

This presentation will describe the ongoing development of a robotic control architecture that was inspired by computational cognitive architectures from the discipline of cognitive psychology. The Symbolic and Sub-Symbolic Robotics Intelligence Control System (SS-RICS) combines symbolic and sub-symbolic representations of knowledge into a unified control architecture. The new architecture leverages previous work in cognitive architectures, specifically the development of the Adaptive Character of Thought-Rational (ACT-R) and Soar. This presentation will detail current work on learning from episodes or events. The use of episodic memory as a learning mechanism has, until recently, been largely ignored by computational cognitive architectures. This presentation will detail work on metric level episodic memory streams and methods for translating episodes into abstract schemas. The presentation will also include research on learning through novelty and self generated feedback mechanisms for autonomous systems.

8756-22, Session 6

Primate-inspired vehicle navigation using optic flow and mental rotations

Ronald C. Arkin, Frank Dellaert, Natesh Suresh, Ryan Kerwin, Georgia Institute of Technology (United States)

Robot navigation already has many relatively efficient solutions: reactive control, simultaneous localization and mapping (SLAM), Rapidly-Exploring Random Trees (RRTs), etc. But many primates possess an additional inherent spatial reasoning capability: that of mental rotation. Our research addresses the question of what, if any, role mental rotations can play in enhancing existing robot navigational capabilities. To answer this question we explore the use of optical flow as a basis for extracting abstract representations of the world, comparing these representations with a goal state of similar format and then iteratively providing a control signal to a robot to allow it to move in a direction consistent with achieving that goal state. Specialized GPU architectures are used to provide fast and effective optical flow. We study a range of transformation methods to implement the mental rotation component of the architecture, including correlation and matching based on cognitive studies. The results to date are presented on our robotics platforms. We also include a discussion of how mental rotations may play a key role in understanding spatial advice giving, particularly from other members of the species, whether in map-based format, gestures, or other means of communication.

8756-23, Session 6

Multi-brain fusion and applications to intelligence analysis

Adrian Stoica, Yumi Iwashita, Curtis W. Padgett, Jet Propulsion Lab. (United States); Kyrre Glette, Univ. of Oslo (Norway); Riccardo Poli, Univ. of Essex (United Kingdom)

In rapid serial visual presentation (RSVP) images shown extremely rapidly can still be parsed by the visual system, and the detection of specific targets triggers specific EEG response. Research funded by DARPA's Neurotechnology for Intelligence Analysts program has proven speed-ups in sifting through satellite images when EEG signals of an intelligence analyst act as triggers. This paper extends the use of neurotechnology from individual analysts to collaborative teams; it presents concepts of collaborative brain computer interfaces and experiments indicating that the aggregation of information in EEGs collected from multiple users results in performance improvements compared to that of individual users.

8756-24, Session 6

Spatial cognition: robot target localization in open arenas based on rat studies

Alfredo Weitzenfeld, Univ. of South Florida Polytechnic (United States); Gonzalo Tejera, UDELAR (Uruguay); Alejandra Barrera, ITAM (Mexico); JeanMarc Fellous, University of Arizona (United States); Martin Llofriu, Univ. of South Florida (United States)

We describe our latest work in understanding spatial localization in open arenas based on rat studies and corresponding modeling with simulated and physical robots. The studies and experiments focus on goal-oriented navigation where both rats and robots exploit distal cues to localize and find a goal in an open environment. The task involves training of both rats and robots to find the shortest path to the goal from multiple starting points in the environment. The spatial cognition model is based on the rat's brain neurophysiology of the hippocampus extending previous work by analyzing granularity of localization in relation to a varying number and position of landmarks. The robot integrates internal and external information to create a topological map of the environment and to generate shortest routes to the goal through path integration. One of the critical challenges for the robot is to analyze the similarity of positions and distinguish among different locations using visual cues and previous paths followed to reach the current position. We describe the robotics architecture used to develop, simulate and experiment with physical robots.

8756-25, Session 6

Development of standard test methods for unmanned and manned industrial vehicles used near humans

Roger V. Bostelman, Richard J. Norcross, Joseph A. Falco, Jeremy A. Marvel, National Institute of Standards and Technology (United States)

The National Institute of Standards and Technology has been researching human-robot collaborative environments for automated guided vehicles. Safety of AGV's and manned vehicles with automated functions (e.g., forklifts that slow/stop automatically in hazardous situations) are the focus of the ANSI/ITSDF B56.5 safety standard. Recently, the NIST Mobile Autonomous Vehicle Obstacle Detection/Avoidance (MOVADA) Project began researching test methods for when humans enter or may enter the manned or unmanned vehicle path. The efforts supported the B56.5: 2012 version including changes that allow non-contact sensors to detect standard test pieces so long as they are within the path of the vehicle and beyond the stop zone of the vehicle. However, there remains an exception in the standard for when an obstacle suddenly appears within the vehicle stopping distance. Similarly, manned vehicles, such as forklifts, are allowed up to 20% non-visible regions where drivers may not see pedestrians enter the vehicle path. As such, liabilities could be at stake should these situations occur. These are real situations that occur frequently where for example, OSHA states that a person is killed every 3 days in a forklift accident and 80% of all accidents include pedestrians. Research, using unmanned and manned vehicles with integrated sensors, to be detailed in this paper includes development of test methods for when:

• standard test pieces and mannequins enter vehicle stop zones,

• non-line-of-site sensing is used to inform the vehicle of a pedestrian that may enter the vehicle path.

• forces on humans through development of a force measurement apparatus.

8756-26, Session 7

Information measures for multisensor systems

Christian P. Minor, Nova Research, Inc. (United States); Brian Stout, U.S. Navy (United States); Kevin R. Johnson, U.S. Naval Research Lab. (United States)

Spectral data capture a wealth of information in a wide variety of sensing modalities. While sharing a common multivariate structure, spectral data often exhibit characteristics that can be challenging to model using traditional statistical approaches. Recent research at the Naval Research Laboratory (NRL) has yielded probabilistic models for spectral data that enable the computation of information measures such as entropy and Kullback-Leibler divergence, with the goal of developing feature sets to increase the sensitivity and selectivity of multivariate chemical sensors. Results are presented for several types of spectral data in multisensor systems, as well as strategies for using information measures with other data sources.

8756-27, Session 7

Measuring knowledge: investigative research into the quantification of performance within a contextual multi-source PED fusion process

Larry A. Scarff, UTC Aerospace Systems (United States); Dustin Burke, Eric Jones, Aptima, Inc. (United States); Lynne G. Gilfillan, Rhumbline Consultants (United States); Stephanie Pratt, Aptima Inc. (United States); Cullen Jackson, Shawn Weil, Aptima, Inc. (United States); Stephen Fiore, Univ. of Central Florida (United States)

Historically, imaging system quality has been characterized using the National Image Interpretability Rating Scale (NIIRS); a subjective, task-based scale used to describe the overall utility of imagery. However, image quality metrics are no longer sufficient to quantify the information gain and subsequent knowledge formation provided by Processing, Exploitation, and Dissemination (PED) systems, which integrate data and information into a composite whole, providing enhanced confidence about larger questions of intelligence importance. While advanced PED systems will provide analysts with significantly greater contextual information, the quantification of the knowledge gain for these systems is not easily characterized.

We use the term “Knowledge-NIIRS” to represent the analogous approach toward characterizing PED fusion systems as was used in the past for imaging systems – even while recognizing that the process of measurement will be far more complex and challenging to develop. This paper describes our initial exploration toward an evaluation system for accurate interpretation and fusion of information into knowledge. Knowledge-NIIRS will ultimately serve to explicitly measure the value of contextual information gained through multi-source fusion, and its impact on the analyst’s ability to interpret and extract knowledge. Drawing upon naturalistic decision-making, cognitive engineering principles and information theoretic axioms, Knowledge-NIIRS embraces a more holistic approach to objectively measuring and quantifying the complex interpretation process.

The operational benefits of a Knowledge-NIIRS rating system include an enhanced understanding of the key contributors to knowledge improvement, which will lead to improved PED system designs, increased analyst productivity, and cost savings through maximization of the information value.

8756-28, Session 7

Enhancing situational awareness by means of visualization and information integration of sensor networks

Jussi Timonen, Jouko Vankka, Finnish Defence Forces (Finland)

This paper presents a solution for information integration and sharing architecture, which is able to receive data simultaneously from multiple different sensor networks. Creating a Common Operational Picture (COP) object along with the base map of the building plays a key role in the research. The object is combined with desired map sources and then shared to the mobile devices worn by soldiers in the field. The sensor networks we used focus on location techniques indoors, and a simple set of symbols is created to present the information, as an addition to NATO APP6B symbols.

A core element in this research is the MUSAS (Mobile Urban Situational Awareness System), a demonstration environment that implements central functionalities. Information integration of the system is handled by the Internet Connection Engine (Ice) middleware, as well as the server, which hosts COP information and maps. The entire system is closed, such that it does not need any external service, and the information transfer with the mobile devices is organized by a tactical 5 GHz WLAN solution. The demonstration environment is implemented using only commercial off-the-shelf (COTS) products.

We have presented a field experiment event in which the system was able to integrate and share real time information of a blue force tracking system, received signal strength indicator (RSSI) based intrusion detection system, and a robot using simultaneous location and mapping technology (SLAM), where all the inputs were based on real activities. The event was held in a training area on urban area warfare.

8757-2, Session 1

On localization attacks against cloud infrastructure

Wei Yu, Linqiang Ge, Mohammad Ali Sistani, Towson Univ. (United States); Rommie Hardy, Robert Reschly, U.S. Army Research Lab. (United States)

With cloud computing, users will not be aware of the location of computing server because service requests are conducted through the servers in remote data center. In this paper, we investigate a localization attack that allows the adversary to leverage CPU resources to localize the physical location of server used by victims. By embedding a covert signal into the CPU usage and correlating it with the response time from the targeted virtual machine, the adversary can find the location of target virtual machine. Through the combination of theoretical analysis and experiments, our data show that the investigated attack techniques can identify cloud infrastructure effectively.

8757-3, Session 1

ICS logging solution for network-based attacks using Gumistix technology

Jeremy Otis, Air Force Institute of Technology (United States)

Industrial control systems (ICS) monitor and control operations associated with the nation's critical infrastructure (e.g., electric power grid, oil and gas pipelines and water treatment facilities). These systems rely on technologies and architectures that were designed for system reliability and availability. Security associated with ICS was never an inherent concern, primarily due to the protections afforded by network isolation. However, a trend in ICS operations is to migrate to commercial networks via TCP/IP in order to leverage commodity benefits and cost savings. As a result, system vulnerabilities are now exposed to the online community. Indeed, recent research has demonstrated that many exposed ICS devices are being discovered using readily available applications (e.g., ShodanHQ search engine and Google-esque queries).

Due to the lack of security and logging capabilities for ICS, most knowledge about attacks are derived from real world incidents – after an attack has already been carried out and the damage has been done. This research provides a method for introducing sensors into the ICS environment that collect information about network-based attacks. The sensors are developed using an inexpensive, Gumstix platform that can be deployed and incorporated with production systems. Data obtained from the sensors provide insight into attack tactics (e.g., port scans, Nessus scans, Metasploit modules, and zero-day exploits) and characteristics (e.g., attack origin, frequency, and level of persistence). Findings enable security professionals to draw an accurate, real-time awareness of the threats against ICS devices and helps shift the security posture from reactionary to preventative.

8757-20, Session 1

Quantitative analysis of intrusion detection systems: snort and suricata

Joshua S. White, Jeanna Matthews, Thomas Fitzsimmons, Clarkson Univ. (United States)

Any modern organization that is serious about security deploys a network intrusion detection system (NIDS) to monitor network traffic for signs of malicious activity. The most widely deployed NIDS system is Snort, an open source system originally released in 1998. Snort is a single threaded system that uses a set of clear text rules to instruct a base engine how to react when particular traffic patterns are detected. In 2009, the US Department of Homeland Security and a consortium of private companies provided substantial grant funding to a newly created organization known as the Open Information Security Foundation (OISF), to build a multi-threaded alternative to Snort, called Suricata. Despite many similarities between Snort and Suricata, the OISF stated it was essential to replace the older single-threaded Snort engine with a multi-threaded system that could deliver higher performance and better scalability. Key Snort developers argued that Suricata's multi-threaded architecture would actually slow the detection process. Given these competing claims, an objective head-to-head comparison of the performance of Snort and Suricata is needed. In this paper, we present a comprehensive quantitative comparison of the two systems. We have developed a rigorous testing framework that examines the performance of both systems as we scale system resources. Our results show that a single instance of Suricata is able to deliver substantially higher performance than a corresponding single instance of Snort, but has problems scaling with a higher number of cores. We find that while Suricata needs tuning for a higher number of cores, it is still able to surpass Snort even at 1 core where we would have expected Snort to shine.

8757-7, Session 2

Industrial controls intrusion detection sensor

Robert M. Jaromin, Air Force Institute of Technology (United States); Barry E. Mullins, Jonathan W. Butts, Air Force Institute of Technology (United States)

Supervisory Control and Data Acquisition (SCADA) systems are large, highly-distributed networks that monitor and control industrial processes that often leverage Internet protocols and infrastructure to provide cost savings. Recently, it has been demonstrated that thousands of Programmable Logic Controllers (PLCs) and similar devices are exposed to the Internet and are unprotected [LEV11], regardless of risk. Despite the number of devices exposed, little is known about the PLC attack landscape due to a lack of sensing at the field device level. In traditional IT networks, cyber sensors, or honeypots are used to detect and study attack techniques in order to develop new preventative measures. Obtaining these benefits on SCADA systems has historically required dedicated, non-productive PLCs to be intentionally connected to the Internet as a sensor while a separate logging device records network activity targeting the PLC. This research focuses on developing SCADA sensors to emulate PLCs and record malicious activity using the powerful, yet inexpensive Gumstix platform to conduct exploratory research into the SCADA attack landscape. These dedicated devices provide an inexpensive, reconfigurable, and rapidly-deployable PLC emulation giving situational awareness into the SCADA attack environment, while eliminating the potential of damage to an expensive PLC. They can be embedded within industrial networks alongside production PLCs to detect device level attacks or deployed as part of a larger honeynet to attract attackers and study their techniques. This research objectively demonstrates the accuracy of the PLC emulator for critical functionality as well as measures its ability to accurately log attack activity.

[LEV11] E. P. Leverett. Quantitatively Assessing and Visualizing Industrial System Attack Surfaces. 2011.

8757-30, Session 2

Tools, tactics, and techniques advanced threat actors use to steal your technology, and new innovative sensing techniques you can use to identify them

Stephen Windsor, Ronald Shaffer, Maddrix, LLC (United States)

This presentation will show how advanced threat actors bypass today's cyber security "best practices" to identify, collect, and exfiltrate

advanced technology from victim networks. We will show examples from real attacks that resulted in significant data loss, and discuss countermeasures and risk mitigation techniques advanced threat actors use to avoid detection. We will follow-up by introducing a new and innovative technique called vector analysis that can rapidly detect advanced threat actors by identifying tradecraft and malware with non-traditional memory and disk-based artifacts. We will wrap up by presenting several vector analysis case studies from 2012-2013.

8757-8, Session 3

Framework for network-wide semantic event correlation

Robert Hall, Joshua Taylor, Assured Information Security (United States)

An increasing need for situational awareness within network-deployed Systems Under Test (SUT) has driven the desire for frameworks that facilitate system-wide data correlation and analysis. Massive event streams are generated from heterogeneous sensors which require tedious manual analysis.

We present a framework for sensor data integration and event correlation based on Linked Data/Semantic Web reasoning, complex event processing (CEP), and blackboard architectures. Sensor data are encoded as linked data models which are processed by CEP agents (which can incorporate both specialized reasoning processes, as well as general purpose Semantic Web reasoning techniques). Agents can publish inferences on shared blackboards and generate new semantic events that are fed back into the system.

We examine AIS Inc.'s Cyber Battlefield Training and Effectiveness Environment (CBTEE) project as a case study for use of the framework. CBTEE is a virtualized training platform that interprets the cyber-effects of operator actions within a cyber-environment. CBTEE also currently makes use of AIS Inc.'s Introvirt™, an introspective hypervisor, as its primary source of semantic events. Apache Camel™ is used for sensor integration within a Spring™ application context, which results in a dynamic topology for sensor data processing at runtime. Elements of this topology include integration of Apache ActiveMQ™ event broker and Esper™ complex event processing.

8757-9, Session 3

Efficient identity management and access control in cloud environment

Jonathan A. Gloster, The Van Dyke Technology Group, Inc. (United States)

As more enterprises are enticed to move data to a cloud environment to enhance data sharing and reduce operating costs by exploiting shared resources, concerns have risen over the ability to secure information within the cloud. Some believe this increased risk is based on the lack of trust associated with cloud implementations. Data or information is placed in the cloud and the information owner has little control on who gets access to the data because they do not control the environment. Over the past several years the Van Dyke Technology Group has analyzed several Identity and Access Management (IDAM) solutions to protect information in a distributed environment across multiple domains. Our research on this technology shows that classic access control mechanisms work best when there is a high degree of trust among the information domains sharing information and they have a common mission or business area (e.g. DoD Organizations, financial services firms). However in a cloud environment where data and information are distributed across diverse domains with no common mission or inherent trust, the IDAM model needs to be adjusted to allow decisions on access to be made not solely on trust among domains and users, but based more on risks of exposing the information content to unauthorized users. The results of this paper show that an incremental approach of transitioning data from legacy systems to cloud environments can maintain the integrity of classic IADM while taking advantage of the efficiencies of cloud technology

8757-10, Session 3

Software analysis in the semantic web

Joshua Taylor, Robert Hall, Assured Information Security (United States)

Under DARPA's Cyber-Genome program we have developed a suite of tools for Malware Analysis and Attribution through Genetic Information (MAAGI). The MAAGI tools facilitate automated large-scale analysis of malware. MAAGI contains several novel components designed specifically for this task. In this paper, we present one component in particular, Semantic Extractor.

Semantic Extractor (SemEx) consumes API call traces generated by the Cuckoo Sandbox to produce an encoding of that trace within a semantic graph. SemEx then applies function signature pattern matching rules to this trace in order to infer the existence of low level application behaviors. These low level behaviors provide semantic meaning and context for the corresponding system call, and an abstraction that additional rules and entailments can utilize.

Subject matter expert domain knowledge of high level application behavior is encoded as additional rules over the produced graph. These high level behaviors capture higher level program goals such as walking a directory or opening an outbound network connection. Downstream components use these higher level behaviors to infer the intentions and capabilities of the malware samples.

This paper covers the algorithms used in SemEx, as well as our approach for deriving behavioral rules and signatures. Additionally, we describe the next incremental steps toward the future development of related MAAGI components.

8757-12, Session 4

Remote Suspect Identification and the impact of demographic features on keystroke dynamics

Robert Dora, Patrick Schalk, John McCarthy, Scott Young, Assured Information Security (United States)

Assured Information Security (AIS), Inc. conducted a three-year keystroke dynamics research effort. The study optimized and applied four algorithms developed at Louisiana Tech University (LTU) towards a discreet keystroke dynamics sensor capable of authenticating users at login, continuously verifying their typing patterns, and identifying masquerading users with an overall equal error rate of 0.054. The keystroke sensor initially uses a Hidden Markov Model (HMM) algorithm for fixed-text authentication of the username and password. After logon, the sensor continuously and discreetly records and analyzes keystroke timings throughout the user's session by comparing key-pair timings against the signatures created during initial log-ons to verify the user's identity. Verification uses five signatures created for the Similarity algorithm, one for each timing feature – key press latency, key release latency, key interval time, and two key hold times (one for each key in the pair) – which are then fused together through a weighted majority voting algorithm. The average verification time for users is under twenty seconds of continuous typing. Users that fail verification are subject to identification, a process by which additional keystrokes are collected and then compared against the Similarity and naïve-Bayes signatures for every user in the database to determine the true identity of the current user. The study produced a massive keystroke dataset generated at LTU, in conjunction with AIS, Inc., that contains keystroke data for over 2,700 students, many of which participated in multiple data collections over a two-year period.

8757-14, Session 4

Dynamic malware analysis using IntroVirt: a modified hypervisor-based system

Joshua S. White, Richard Gloo, Stephen Pape, Adam Meily, Assured Information Security (United States)

By best estimates over 1000 new malware samples are released into the wild each day. To deal with this onslaught of automation is employed in by malware researchers. Dynamic analysis systems typically take the form of some sort of virtual machine monitoring capability. In response to this, malware authors have developed new techniques for detecting these environments and either change the malware accordingly or simply have it shutdown all-together. In this paper we present a new system for dynamic malware analysis which incorporates the use of IntoVirt an introspective hypervisor architecture and infrastructure that supports advanced techniques for stealth-malware-analysis [1]. This system allows for complete guest monitoring and interaction including manipulation and blocking of system calls. IntroVirt is capable of bypassing the virtual machine detection capabilities of even the most sophisticated malware by spoofing responses to system call responses. Additional fuzzing capabilities can also be employed to detect both malware vulnerabilities and polymorphism. With complete control of the system we show IntroVirt is a superior lightweight and extensible platform for malware analysis that surpasses the capabilities of the now ancient Anubis [2] platform.

8757-15, Session 5

The two stages hierarchical unsupervised learning system for complex dynamic ISR

Igor V. Ternovskiy, Air Force Research Lab. (United States); James Graham, U.S. Army Research Lab. (United States); Alan O'Connor, Air Force Research Lab. (United States)

The two stages hierarchical unsupervised learning system has been proposed for modeling complex dynamic surveillance and cyberspace systems. Using modification of the Dynamic Logic (DL) learning approach, we introduced three layers of learning concepts and input data: features, objects, and situations. Using the Bernoulli model, this approach models each situation as a collection of objects, and each object as a collection of features. Further complexity is added with the addition of clutter features and objects. During the learning process, at the lowest level, the binary features information (presence or absence) is provided only. The system attempts to determine in the same time probabilities of the situation and presence of corresponding objects from the detected features. The proposed approach demonstrated robust performance after seemingly short training. This paper discusses this hierarchical learning system in a broader context of different feedback mechanisms between layers and highlights challenges on the road to practical applications.

8757-17, Session 5

A multiresolution fractal additive scheme for blind watermarking of 3D point data

Mark D. Rahmes, Kathy Wilder, Kevin L. Fox, Harris Corp. (United States)

Three dimensional point data is expensive to collect and is therefore worth protecting with additional security technologies. Security can be boosted by applying steganographic techniques to protect data from various threats while enhancing tamper proofing measures. Adding cryptography greatly reduces the risks to geospatial systems as hackers must have a key. Attacks may be intended to disrupt normal functioning of the system. We present a fractal feature space for 3D point watermarking to make geospatial systems more secure. By exploiting the self similar nature of fractals, hidden information can be spatially embedded in point cloud data in an acceptable manner. Our method is a blind scheme in that it provides automatic retrieving of the watermark payload without needing the original cover data. Our method for finding similar patterns and encoding information in LiDAR point cloud data is accomplished through a look-up table as a code book. A watermark is merged into the point cloud data itself with low distortion. Fractals have long been used in imagery applications. Now with advances in computing technologies such as GPGPUs, fractal processing is now applicable for processing of big data. Our approach also applies to applications involving 3D meshes of objects such as in video games. This method is useful for collections from robotic, aerial, and ground-based vehicles. A watermarking technique such as described can be important for systems where point data is handled by numerous aerial collectors as well as by many analysts such as a National LiDAR Data Layer.

8757-18, Session 5

Simultaneous feature selection and clustering for intrusion alert correlation

Siyue Chen, Maxwell G. Dondo, Henry Leung, Univ. of Calgary (Canada)

As computer network security threats increase, most organizations implement multiple Network Intrusion Detection Systems (NIDS) to maximize detection and provide a comprehensive understanding of intrusion activities. However NIDS trigger a massive number of alerts on a daily basis. This can be overwhelming for computer network security analysts since it is a slow and tedious process to manually analyse each alert produced. Thus, automated and intelligent clustering is important to reveal the structural correlation of events by grouping alerts with common features. As the nature of computer network attacks, and therefore alerts, are not known in advance, unsupervised clustering is the best approach to achieve this goal. We propose a joint optimization framework for feature selection and clustering to aggregate similar alerts and to reduce the number of alerts that analysts have to handle individually.

More precisely, each identified feature is assigned with a binary value, which reflects the feature's saliency. This value is treated as a hidden variable and incorporated into a likelihood function for clustering. Since computing the optimal solution of the likelihood function directly is analytically intractable, we use the Expectation Maximisation (EM) algorithm to iteratively update the hidden variable and use it to maximize the expected likelihood. Our empirical results, using Defense Advanced Research Projects Agency (DARPA) 2000 dataset, show that the proposed method gives better results than the EM clustering without feature selection in terms of the clustering accuracy.

8757-21, Session 6

On detection of android malware

Wei Yu, Hanlin Zhang, Towson Univ. (United States); Rommie Hardy, Robert Reschly, Carol Ellis, U.S. Army Research Lab. (United States)

The popularity of mobile devices has greatly stimulated the spread of mobile malware and the detection of malware becomes a critical issue. To address this issue, we first conduct the survey threats of existing malware and the existing detection techniques (e.g., static analysis and dynamic analysis). We then evaluate the effectiveness of the existing commercial anti-virus tools using real-world malware samples. Our experimental data show that all these tools approach near 100 percent detection accuracy because the signatures of our malware samples are in the detection databases of antivirus software. After that, we also study the anomaly-based detection to capture the run-time behavior of malware and evaluate its effectiveness.

To address theses issues, we collect 200 malware samples and 200 benign samples and classify the samples into several categories. We install and run samples on Android devices. We develop a data

collection system that generates a system call log using Strace and then map useful system call information to numerical data for detection automatically. We use the system call sequence (n-grams of contiguous system call sequences of length n) as the detection feature and develop three techniques: (i) Statistical feature-based technique. We use statistical characteristics (e.g., mean and standard derivation) to capture the behavior of benign programs and malware; (ii) Machine learning-based technique. We use machine learning techniques (e.g., support vector machines) to teach classifiers to distinguish between malicious and benign actions; (iii) Information-theoretic based technique: We use the information theoretic measures (e.g., entropy) to capture the density of system call sequences. We implement all these techniques to investigate their effectiveness in terms of detection accuracy and overhead.

8757-23, Session 6

Complex scenes and situations visualization using hierarchical learning and recognition algorithm with dynamic 3D NeoAxis engine

Igor V. Ternovskiy, Air Force Research Lab. (United States); James Graham, U.S. Army Research Lab. (United States)

We applied the two stages hierarchical unsupervised learning system described earlier to model complex dynamic surveillance and cyber space monitoring systems using non-commercial version of NeoAxis visualization software. The hierarchical scene learning and recognition approach based on hierarchical Dynamic Logic was linked to 3D graphics engine for validation of learning and classification results and understanding human – autonomous system relationship. Scene recognition is performed by taking synthetically generated data and feeding it to a dynamic logic algorithm. The algorithm performs hierarchical recognition of the scene by first examining the features of the objects to determine which objects are present, and then then determines the scene based on the objects present. The paper presents a framework within which low level data linked to higher-level visualization can provide support to human operator and be evaluated in a detailed and systematic way.

8757-24, Session 6

Cognitive algorithms for cyber sensing and security

Leonid Perlovsky, Air Force Research Lab. (United States)

No Abstract Available.

8757-25, Session 7

Long-range costs of cyber-security research

Mohammed M. Olama, James Nutaro, Oak Ridge National Lab. (United States)

Government-funded research and development (R&D) plays an important role in accomplishing national and economic security. The majority of R&D funding for research in cyber-security is focused on latter stages of the software lifecycle such as maintenance and enhancements processes, rather than early stages such as design and development processes. Even recruiting for cyber-security focuses on end-of-life expertise. This trend increases the total software lifecycle costs in which over 75% is for maintenance and enhancements costs. However, the majority of faults are introduced early in the requirements, initial design and development processes. Detecting and fixing faults at initial stages improve the quality of software and, therefore, should result in reduction of the total lifecycle cost. Moreover, by fixing security problems at the last possible moment, fewer resources are available to make the product more useful, productive, or innovative. Worse, expenditures on expensive security measures mean less money for innovative concepts. Indeed, cyber-warfare as a weapon has been depicted as a race between finding faults in software and fixing those faults. If corrections are made at end of life, the attack always wins. Thus, early corrections change the game significantly.

In this paper, we illustrate using several studies conducted on real projects that proper budget allocation, i.e. assigning appropriate budget at early stages to prevent, detect and fix security problems at initial stages, should improve software security and quality, and therefore, reduce the total software lifecycle costs. The research topics addressed in this paper, however, are relevant not only to the federal government but also to the private sector and others who are interested in long range costs of cyber-security research.

8757-27, Session 7

Why cyber-forensic tools fail

Gary Hamilton, Assured Information Security (United States)

Incident responders rely on cyber forensic tools to detect and attribute intrusions, while adversaries employ anti-forensic techniques to thwart these efforts.

In general, cyber forensic tool developers take a reactive approach to anti-forensics, implementing countermeasures after a technique gains widespread popularity. This leads to forensic tools with inherent weaknesses that adversaries exploit to evade detection. This research exposed five key flaws in cyber forensic tools that anti-forensic practitioners exploit. Understanding these flaws will allow forensic tools developers to produce more comprehensive and secure technologies that minimize the anti-forensic threat.

The approach began with the identification of a significant cross-section of available cyber forensic and anti-forensic capabilities. Analysis of each capability exposed trends in each tool's functionality, which became the basis for cyber forensic and anti-forensic taxonomies. These taxonomies were used to categorize each capability based on these functional differentiators. Assessments then isolated successful anti-forensic techniques by comparing capabilities from each category of the anti-forensics taxonomy to tools from each category of the cyber forensic taxonomy. Further analysis of successful anti-forensic techniques exposed the underlying relationships that allowed it to succeed against a particular cyber forensic tool. As a result, the research identified five basic flaws found in cyber forensic tools. Future cyber forensic tool development that addresses these flaws will result in more robust capabilities that minimize the anti-forensic threat.

8758-7, Session 1

Data-to-decisions *(Keynote Presentation)*

John S. Eicke, Michael A. Kolodny, U.S. Army Research Lab. (United States)

No Abstract Available.

8758-9, Session 2

Adaptive context exploitation

Alan N Steinberg, Georgia Tech Research Institute (United States); Christopher L. Bowman, Data Fusion Corp. (United States)

A Phase 1 SBIR effort has been conducted to develop and demonstrate techniques for “repurposing” data. This effort was conducted under USAF contract FA8750-12-C-0163, Innovative Approaches to Situation Modeling, Threat Modeling and Threat Prediction.

Repurposing data, as we are using the term, involves the adaptive exploitation of data from sources beyond those determined at the time of system design. Such additional data may be contained in data stores that have become available to the system on-line, but which the baseline fusion system was not explicitly programmed to exploit. There is an interest in using such external information to enhance the performance of higher-level fusion in ISR systems that often must work with highly-ambiguous and noisy data in domains that are poorly modeled. The hope is to improve the accuracy and completeness of the ISR fusion product by appropriate exploitation of information that is normally external to the ISR system.

An ISR system is tasked to meet information needs, often specified in terms of user-specified Essential Elements of Information (EEIs). These EEI can be data elements concerning entities of interest at all fusion levels 0-4: their current, historical and predicted location, track, identity, classification, attributes, activities, and courses of actions; interactions and other relationships.

EEIs are formalized as sets of problem variables and a utility function on the accuracy of evaluating these variables. The input data used in solving an ISR problem may themselves be measurements of one or another EEI or information that may provide context for evaluating EEIs, in the form of estimates of variables that may be correlated in some way with one or more problem variables. We examine ways for an ISR system to exploit such direct and contextual information both from sources organic to and external to the ISR system.

We decompose this problem by means of the Data Fusion & Resource Management (DF&RM) Dual Node Network (DNN) technical architecture. Newly defined level 4 Resource Management processes plan and execute the search, evaluation and fusion of external data with organic ISR data. Newly-defined level 4 fusion processes determine the relevance and consistency of acquired external data with organic ISR information. Additional L.0-4 DF and RM functions are tasked to refine states estimates of L.0-3 entities (i.e. of entities existing independent of the system) and of L.4 entities (i.e. of system resources). The latter includes evaluating and refining the system’s predictive models that characterize the attributes and behaviors of L.0-3 entities and that characterize organic and external sensor/sources (accuracies, biases, etc.) and processes. In this way we – for the first time – integrate Data Mining into the DF&RM architecture, permitting a unified error model across sources, measurements and models, as well as fusion and management functions in information exploitation systems.

Design and prototype results will be presented, with plans for expanded development of adaptive context exploitation capability.

8758-10, Session 2

Concept of operations for collaboration and discovery from big data across enterprise data warehouses

Sreenivas R. Sukumar, Mohammed M. Olama, James Nutaro, Oak Ridge National Lab. (United States)

The next-generation analyst is facing the challenge of discovering actionable nuggets from terabytes/petabytes of data stored across enterprise data-warehouses. The solutions that enable such analysts have to resolve the dilemma on the concept of operations for how data sources have to be staged for analysis (i.e. how should one data source from an agency be conveniently posed in context to another data source from another agency?). In this paper, we study popular data staging practices such as the data-mart, federated-middleware, hub-and-spoke and all-in-one warehouse models. The study is along dimensions such as scalability, feasibility, convenience and cost with respect to the emerging “Big data” concerns of volume, velocity, variety and veracity. The results we present are from simulating analyst work-flows in each of the aforementioned models. The workflows in our experiments consider data extract, load and transform processes, application development timelines, operational factors such as availability/durability, complexity of the data schemas and meta-data issues thereof, network bandwidth constraints, data access latencies, query resource demands, etc. Based on the observations from simulation experiments, we are able to make recommendations for a business process flexible enterprise analytics roadmap. Our simulations highlight opportunities and risks in terms of infrastructure (data systems, connectivity, etc.) and policy (security, rules, etc.) as applied to real-world cross-agency data-sharing efforts.

8758-11, Session 2

GOOSE: Semantic search on internet connected sensors

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More and more sensors are getting Internet connected. This includes cameras on cell phones, CCTV cameras for traffic control as well as dedicated security and defense sensor systems. Human exploitation of all this sensor data for effective mission execution is due to the steadily increasing data volume impossible. Smart access to all sensor data acts as enabler for questions such as “Is there a person behind this building” or “Alert me when a vehicle approaches”.

The GOOSE concept has the ambition to provide the capability to search semantically for any relevant information within “all” (including imaging) sensor streams in the entire Internet of sensors. Similar to the capability provided by presently available Internet search engines which enable the retrieval of information on “all” pages on the internet. Similar to current Internet search engines any indexing services shall be utilized cross-domain. Main challenges for GOOSE are the Semantic Gap and Scalability.

The GOOSE architecture consists of five elements: (1) an online primitive extraction on each sensor stream; (2) an indexing and search mechanism for these primitives; (3) a ontology based semantic matching module; (4) a top-down hypothesis verification mechanism and (5) a controlling man-machine interface.

The paper will report on the initial GOOSE demonstrator, which

consists of the MES multimedia analysis platform and the CORTEX action recognition software, and provide an outlook into future GOOSE development.

8758-12, Session 2

A big data use perspective: CiteSeerX and friends

C. Lee Giles, The Pennsylvania State Univ. (United States)

Cyberinfrastructure or e-science has become crucial in many areas of science as managing and have access to big data often defines scientific progress. Open source systems have greatly facilitated design and implementation for supporting cyberinfrastructure and big data. We propose an open source integrated system, SeerSuite, for building an integrated search engine and digital library that focuses on all phases of scientific document information and knowledge extraction, such as citation extraction, automated indexing and ranking, chemical formulae search, table indexing, etc. The proposed open source architecture is a modular, extensible system built on successful OS projects such as Lucene/Solr and can be used in building enterprise search and cyberinfrastructure for the sciences and academia and managing big data. We highlight big data application domains with examples of specialized search engines they we have built for computer science, CiteSeerX, chemistry, ChemXSeer, archaeology, ArchSeer. acknowledgements, AckSeer, reference recommendation, RefSeer, collaboration recommendation, CollabSeer, and others, all using Solr/Lucene. Because such enterprise systems require unique information extraction approaches, several different machine learning methods, such as conditional random fields, support vector machines, mutual information based feature selection, sequence mining, etc. are critical for performance. We draw lessons for other e-science and cyberinfrastructure systems in terms of big data creation and use and system design and research issues.

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8758-26, Session 2

Some alternative strategies for dealing with big data *(Keynote Presentation)*

Moises Sudit, CUBRC Corp. (United States)

No Abstract Available.

8758-13, Session 3

Controlled English to facilitate human/machine analytical processing

David Braines, David Mott, Simon Laws, IBM United Kingdom Ltd. (United Kingdom); Geeth de Mel, IBM Thomas J. Watson Research Ctr. (United States) and U. S. Army Research Lab. (United States); Tien Pham, U.S. Army Research Lab. (United States)

Controlled English is a human-readable information representation format that is implemented using a restricted subset of the English language, but which is unambiguous and directly accessible by simple machine processes. We have been researching the capabilities of CE in a number of contexts, and exploring the degree to which a flexible and more human-friendly information representation format could aid the intelligence analyst in a multi-agent collaborative operational environment; especially in cases where the agents are a mixture of other human users and machine processes aimed at assisting the human users. CE itself is built upon a formal logic basis, but allows users to easily specify models for a domain of interest in a human-friendly language. In our research we have been developing an experimental component known as the "CE Store" in which CE information can be quickly and flexibly processed and shared between human and machine agents. The CE Store environment contains a number of specialized machine agents for common processing tasks and also supports execution of logical inference rules that can be defined in the same CE language. This paper outlines the basic architecture of this approach, discusses some of the example machine agents that have been developed, and provides some typical examples of the CE language and the way in which it has been used to support complex analytical tasks on synthetic data sources. We highlight the fusion of human and machine processing supported through the use of the CE language and CE Store environment, and show this environment with examples of highly dynamic extensions to the model(s) and integration between different user-defined models in a collaborative setting.

8758-14, Session 3

MIPS: A service-based aid for intelligence analysis

David Braines, John B. Ibbotson, Graham White, IBM United Kingdom Ltd. (United Kingdom)

The Management of Information Processing Services (MIPS) project set out with two main objectives; the notification to analysts of the arrival of relevant new information and the automatic processing of the new information. Within these objectives a number of significant challenges were addressed. To achieve the first objective, the development team had to demonstrate the capability for specific analysts to be "tipped-off" in real-time that textual reports and sensor-data have been received that are relevant to their analytical tasks, including the possibility that such reports have been made available by other nations. In the case of the second objective, the team had to demonstrate the capability for the infrastructure to automatically initiate processing of input data as it arrives, consistent with satisfying the analytical goals of teams of analysts, in as an efficient a manner as possible (including the case where data is made available by more than one nation).

Using the Information Fabric middleware developed as part of the International Technology Alliance (ITA) research program, the team created a service based information processing infrastructure to achieve the objectives and challenges set by the customer. The infrastructure allows either existing or specially written services to be integrated with each other as well as with other ITA technologies such as the Controlled English (CE) Store or the Gaian Database. This paper will identify the difficulties in designing and implementing the MIPS infrastructure together with describing its architecture and illustrating its use with a worked example use case.

8758-16, Session 3

Reusing information for high-level fusion: characterizing bias and uncertainty in human-generated intelligence

Dustin Burke, Alan Carlin, Paul Picciano, Georgiy Levchuk, Brian Riordan, Aptima, Inc. (United States)

To expedite the intelligence collection process, analysts reuse previously collected data. This poses the risk of analysis failure, because these data are biased in ways that the analyst may not know. Thus, these data may be incomplete, inconsistent or incorrect, have structural gaps and limitations, or simply be too old to accurately represent the current state of the world. Incorporating human-generated intelligence within the high-level fusion process enables the integration of hard (physical sensors) and soft information (human observations) to extend the ability of algorithms to associate and merge disparate pieces of information

for a more holistic situational awareness picture. However, in order for high-level fusion systems to manage the uncertainty in soft information, a process needs to be developed for characterizing the sources of error and bias specific to human-generated intelligence and assessing the quality of this data.

This paper outlines an approach Towards Integration of Data for unBiased Intelligence and Trust (TID-BIT) that implements a novel Hierarchical Bayesian Model for high-level situation modeling that allows the analyst to accurately reuse existing data collected for different intelligence requirements. TID-BIT constructs situational, semantic knowledge graphs that links the information extracted from unstructured sources to intelligence requirements and performs pattern matching over these attributed-network graphs for integrating information. By quantifying the reliability and credibility of human sources, TID-BIT enables the ability to estimate and account for uncertainty and bias that impact the high-level fusion process, resulting in improved situational awareness.

8758-17, Session 3

Reasoning with uncertain information and trust

Murat Sensoy, Univ. of Aberdeen (United Kingdom); Achille Fokoue, IBM Thomas J. Watson Research Ctr. (United States); Timothy J. Norman, Jeff Z. Pan, Univ. of Aberdeen (United Kingdom); Yuqing Tang, Carnegie Mellon Univ. (United States); Nir Oren, Univ. of Aberdeen (United Kingdom); Geeth de Mel, IBM Thomas J. Watson Research Ctr. (United States); Katia Sycara, Carnegie Mellon Univ. (United States); Lance Kaplan, U.S. Army Research Lab. (United States)

An important limitation of standard Description Logics is their inability to reason with uncertain and vague knowledge. Although probabilistic and fuzzy extensions of DLs exist, which provide an explicit representation of uncertainty, they do not provide an explicit means for reasoning about second order uncertainty. Dempster-Shafer theory of evidence (DST) overcomes this weakness and provides the means to explicitly represent fuse and reason about uncertain information. In this paper, we combine DL-Lite with DST to allow scalable reasoning over uncertain semantic knowledge bases. Furthermore, our formalism allows for the detection of conflicts between the fused information and domain constraints. Finally, we propose methods to resolve such conflicts through trust revision by exploiting evidence regarding the information sources. The effectiveness of the proposed approaches is shown through simulations under various settings.

8758-24, Session 3

A decision support system for fusion of soft- and hard-sensor information based on latent semantic analysis technique

Amir Shirkhodaie, Vinayak Elangovan, Mohammad S. Habibi, Amjad H. Alkilani, Tennessee State Univ. (United States)

Fusion of information from textual reports with data from energy-based sensors, collected from surveillance systems, is a real challenge and requires an appropriate technique facilitating their seamless integration and comprehension. When dealing with multi-facets information, a decision support system can be very instrumental in facilitating expert analysts explore and exploit available information in a timely fashion and achieve a better situational awareness. Evidently, efficiency and effectiveness of such approaches is vital for situations requiring rapid response for decisive emerging situations. In this paper, we have presented a decision support system based on Latent Semantic Analysis (LSA) technique for fusion of pertinent and cohesive soft/hard sensor information. The proposed decision support system operates over two information spaces: free-style textual information (e.g., military reports, emails, web pages, scientific/news reports, written documents) and structured semantically-annotated information generated by processing of hard sensor data presented in the format of a Transducer Markup Language (TML). The decision support system uses a latent semantic indexing approach to data mine relevant information supporting a query concept. The decision support system computes entropy of key words/phrases associated with searched textual information and uses this information as a basis for suggesting key future queries that could potentially assist in discovery of new knowledge about the searched concept. To test efficiency and effectiveness of the decision support system, we utilized corpus of textual documents containing both human annotated observations and semantically annotated hard sensor data. The latter information contains semantically annotated information representing attributes of physical targets and events as observed by the physical sensors (i.e., imaging cameras). The experimental results were tested against ground truths for verification and validation of performance of the decision support system. Our initial experimental results indicates that the decision support system can provide significant assistance in retrieving latent complex concepts that otherwise is difficult to comprehend from large corpus of textual information proficiently.

8758-1, Session 4

Crowded: a crowd-sourced perspective of events as they happen

Richard Brantingham, Aleem Hossain, Defence Science and Technology Lab. (United Kingdom)

'Crowded' is a web-based application that collates imagery of a particular location from a variety of media sources to provide an operator with real-time situational awareness.

Emergency services and other relevant agencies have detected or become aware of an event - a riot or an explosion, for instance - and its location. The ubiquity of mobile devices allows people to collect and upload media of the incident to the Internet, in real time. 'Crowded' manages the interactions with: Flickr; Instagram; YouTube; Twitter; and Transport for London traffic cameras, to retrieve imagery that is being uploaded at that point in time from that location. In doing so, it aims to provide human operators with near-instantaneous 'eyes-on' from a variety of different perspectives. Furthermore, where the original event detection is automated, 'Crowded' could be used to provide human feedback to improve detection algorithms and validate sources. 'Crowded' has been implemented as a series of alpha/beta-level integrated web-services. It aims to demonstrate how non-traditional, open sources can be used to provide a richer current intelligence picture than can be obtained from closed sources alone. It also demonstrates how open source technology and cloud-based services can be used in the modern intelligence and security environment to provide a multi-agency Common Operating Picture to help achieve a co-ordinated response.

8758-2, Session 4

Supporting tactical intelligence using collaborative environments and social networking

Arthur Wollocko, Michael Farry, Robert Stark, Charles River Analytics, Inc. (United States)

Modern military environments place an increased emphasis on the collection and analysis of intelligence at the tactical level. The deployment of analytical tools at the tactical level helps support the warfighter's need for rapid collection, analysis, and dissemination of intelligence. However, given the lack of experience and staffing at the tactical level, most of the available intelligence is not exploited.

Tactical environments are staffed by a new generation of intelligence analysts who are well-versed in modern collaboration environments and social networking. An opportunity exists to enhance tactical intelligence analysis by exploiting these personnel strengths, but is dependent on

appropriately designed information sharing technologies.

Existing social information sharing technologies enable users to publish information quickly, but do not unite or organize information in a manner that effectively supports intelligence analysis.

In this paper, we present an alternative approach to structuring and supporting tactical intelligence analysis that combines the benefits of existing concepts, and provide detail on a prototype system embodying that approach. Since this approach employs familiar collaboration support concepts from social media, it enables new-generation analysts to identify the decision-relevant data scattered among databases and the mental models of other personnel, increasing the timeliness of collaborative analysis. Also, the approach enables analysts to collaborate visually to associate heterogeneous and uncertain data within the intelligence analysis process, increasing the robustness of collaborative analyses.

Utilizing this familiar dynamic collaboration environment, we hope to achieve a significant reduction of time and skill required to glean actionable intelligence in these challenging operational environments.

8758-3, Session 4

Using the living laboratory framework as a basis for understanding next-generation analyst work

Michael D. McNeese, Vincent F Mancuso, Nathaniel J McNeese, Tristan C Endsley, Peter K Forster, The Pennsylvania State Univ. (United States)

The preparation of next generation analyst work will require alternative levels of understanding and new methodological departures from the way current work transpires. Current work practices typically do not provide a comprehensive approach that emphasize the roles of a) cognition, b) the emergent activity in a shared situated context, and c) collaborative teamwork. In turn, effective and efficient problem solving fails to take place and practice is often composed of piecemeal, techno-centric tools that isolate and stove pipe analysts while only providing rigid, limited levels of understanding of situation awareness. This coupled with the fact that many analyst activities are classified produces a challenging situation for the design of systems that support analyst cognition and teamwork. Through our work with cyber analysts, image analysts, and intelligence analysts we have realized that there is more required of researchers to study human-centered designs to provide for analyst's needs in a timely fashion.

This paper identifies and describes how The Living Laboratory Framework, as a means to develop a comprehensive and human-centric and problem-focused approach to next generation analyst work, design, and training. We explain how the framework is utilized for specific cases in various applied settings (e.g., crisis management analysis, image analysis, and cyber analysis) to demonstrate it's value and power in addressing an area of utmost importance to our country. Attributes of analyst work settings are delineated to suggest potential design affordances that could help specific and improve cognitive activities and awareness. Finally, the paper puts forth a research agenda for the use of the framework for future work that will move the analyst profession in a viable manner to address the concerns identified.

8758-4, Session 4

Exploiting client logs towards characterizing the user behavior on Web applications

Leandro G. Vasconcelos, National Institute for Space Research (Brazil); Rafael D. Coelho dos Santos, Instituto Nacional de Pesquisas Espaciais (Brazil); Laercio A. Baldochi Jr., Federal Univ. of Itajuba (Brazil)

Analysis of user interaction with computer systems can be used for several purposes, the most common being analysis of the effectiveness of the interfaces used for interaction (in order to adapt or enhance its usefulness) and analysis of intention and behavior of the users when interacting with these systems.

For web applications, often the analysis of user interaction is done using the web server logs collected for every document sent to the user in response to his/her request. In order to capture more detailed data on the users' interaction with sites, one could collect actions the user performs in the clients' side. An effective approach to this is the USABILICS system, which also allows the definition and analysis of tasks in web applications.

The fine granularity of logs collected by USABILICS allows a much more detailed log of users' interaction with a web application. These logs can be converted into graphs where vertices are users' actions and edges are paths made by the user to accomplish a task.

Graph analysis and visualization tools and techniques allow the analysis of actions taken in relation to an expected action path, or characterization of common (and uncommon) paths on the interaction with the application. This paper describes how to estimate users' behavior and characterize their intentions during interaction with a web application, presents the analysis and visualization tools on those graphs and shows some practical results with an educational site, commenting on the results and implications of the possibilities of using these techniques.

8758-5, Session 4

Exploring the dynamics of collective cognition using a computational model of cognitive dissonance

Paul R. Smart, Univ. of Southampton (United Kingdom); Katia Sycara, Carnegie Mellon Univ. (United States); Darren Richardson, Univ. of Southampton (United Kingdom)

The socially-distributed nature of cognitive processing in a variety of organizational settings means that there is increasing scientific interest in how the features of collaborative work environments affects the nature of collective cognition and the quality of collective cognitive outcomes. In military coalitions, for example, there is a need to understand how factors such as communication network topology, trust, cultural differences and the potential for miscommunication affects the ability of distributed teams to generate high quality plans, to formulate effective decisions and to develop shared situation awareness. In addition to understanding the relationship between collective cognitive performance and the features of collaborative work environments, there is also a need to understand how the technological and social organization of collaborative work environments interacts with psycho-cognitive processes operating at the level of individual human agents. For example, we need to develop a better understanding of how individual processing biases interact with the features of the larger socio-technical system in order to either help or hinder collective cognitive processing. In this paper, we present a computational model that is specifically designed to support experimental simulations into collective cognitive phenomena. We show how the model can be used to run simulations that explore the effects of a variety of factors on collective cognition. We also show how the model can be used to replicate the pattern of results seen in a number of experimental studies using human subjects. We suggest that the model can be used to support the development of sociotechnical systems that maximize the collective cognitive potential of distributed teams.

8758-6, Session 4

CE-SAM: a conversational interface for ISR mission support

Diego Pizzocaro, Christos Parizas, Alun Preece, Cardiff Univ. (United Kingdom); Dave Braines, David Mott, IBM United Kingdom Ltd. (United Kingdom); Jonathan Bakdash, U.S. Army Research Lab. (United States)

There is considerable interest in natural language conversational interfaces. These allow for complex user interactions with systems, such as fulfilling information requirements in dynamic environments, without requiring extensive training or a technical background (e.g. in formal query languages or schemas). To leverage the advantages of conversational interactions we propose CE-SAM (Controlled English Sensor Assignment to Missions), a system that guides users through refining and satisfying their information needs in the context of Intelligence, Surveillance, and Reconnaissance (ISR) operations. The rapidly-increasing availability of sensing assets and other information sources poses substantial challenges to effective ISR resource management. In a coalition context, the problem is even more complex, because assets may be 'owned' by different partners. We show how CE-SAM allows a user to refine and relate their ISR information needs to pre-existing concepts in an ISR knowledge base, via conversational interaction implemented on a tablet device. The knowledge base is represented using Controlled English (CE) - a form of controlled natural language that is both human-readable and machine processable (i.e. can be used to implement automated reasoning). Users interact with the CE-SAM conversational interface using natural language, which the system converts to CE for feeding-back to the user for confirmation (e.g. to reduce misunderstanding). We show that this process not only allows users to access the assets that can support their mission needs, but also assists them in extending the CE knowledge base with new concepts.

8758-18, Session PTues

Participatory telerobotics

Alexander D. Wissner-Gross, Harvard Univ. (United States) and Massachusetts Institute of Technology (United States) and Gemedy, Inc. (United States); Timothy M. Sullivan, Gemedy, Inc. (United States)

We present a novel "participatory telerobotics" system that generalizes the existing concept of participatory sensing to include real-time teleoperation and telepresence by treating humans with mobile devices as ad-hoc telerobots. In our approach, operators or analysts first choose a desired location for remote surveillance or activity from a live geographic map and are then automatically connected via a coordination server to the nearest available trusted human. That human's device is then activated and begins recording and streaming back to the operator a live audiovisual feed for telepresence, while allowing the operator in turn to request complex teleoperative motions or actions from the human. Supported action requests currently include walking, running, leaning, and turning, all with controllable magnitudes and directions. Compliance with requests is automatically measured and scored in real time by fusing information received from the device's onboard sensors, including its accelerometers, gyroscope, magnetometer, GPS receiver, and cameras. Streams of action requests are visually presented by each device to its human in the form of an augmented reality game that rewards prompt physical compliance while remaining tolerant of network latency. In experimental trials of our smartphone-based implementation, we found that high human compliance was achieved with minimal training. Because of its ability to interactively elicit physical knowledge and operations through ad-hoc collaboration, we anticipate that our participatory telerobotics system will have immediate applications for intelligence, surveillance, and reconnaissance.

8758-19, Session PTues

Conserving analyst attention units: use of multi-agent software and CEP methods to assist information analysis

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Although the capability of computer-based artificial intelligence techniques for decision-making and situational awareness has seen notable improvement over the last several decades, the current state-of-the-art still falls short of creating computer systems capable of autonomously making complex decisions and judgments in many domains where data is nuanced and accountability is high. However, there is a great deal of potential for hybrid systems in which software applications augment human capabilities by focusing the analyst's attention to relevant information elements based on both a priori knowledge of the analyst's goals and the processing/correlation of a series of data streams too numerous and heterogeneous for the analyst to digest without assistance.

Researchers at Penn State University are exploring ways in which an information framework influenced by Klein's RPD model, Endsley's model of situational awareness, Boyd's OODA loop, and the Joint Directors of Laboratories (JDL) data fusion process model can be implemented through a novel combination of Complex Event Processing (CEP) and Multi-Agent Software (MAS). Though designed primarily for stock market and financial applications, the high performance data-driven nature of CEP techniques provide a natural compliment to the proven capabilities of MAS systems for modeling naturalistic decision-making, performing process adjudication, and optimizing networked processing and cognition via the use of "mobile agents." This paper addresses the challenges and opportunities of such a framework for augmenting human observational capability as well as enabling the ability to perform collaborative context-aware reasoning in both human teams and hybrid human/ software agent teams.

8758-20, Session PTues

Representation of potential information gain to measure the price of anarchy on ISR activities

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One of the main technical challenges facing intelligence analysts today is determining, effectively, information gaps from huge amounts of collected data. Moreover, getting the right information to/from the right person (e.g., analyst, "warfighter on the edge") at the right time in a distributed environment has been elusive to our military forces. Synchronization of Intelligence, Surveillance, and Reconnaissance (ISR) activities to maximize the efficient utilization of limited resources (both in quantity and capabilities) has become critically important to increase the accuracy and timeliness of overall information gain. Given this reality, we are interested in quantifying the degradation of solution quality (i.e., information gain) as a centralized system synchronizing ISR activities (from information gap identification to information collection and dissemination) moves to a more decentralized framework. This evaluation extends the concept of price of anarchy, a measure of the inefficiency of a system when agents maximize decisions without coordination, by considering different levels of decentralization. Our initial research representing the potential information gain in geospatial and time discretized spaces is presented. This potential information gain map can represent a consolidation of Intelligence Preparation of the Battlefield products as input to automated ISR synchronization tools. Using the coordination of unmanned vehicles (UxVs) as an example, we developed a mathematical programming model for multi-perspective optimization in which each UxV develops its own flight plan to support mission objectives based only on its perspective of the environment (i.e., potential information gain map). Information is only exchanged when UxVs are part of the same communication network.

8758-21, Session PTues

Visualization and characterization of users in a citizen science project

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Recent technological advances allowed the creation and use of internet-based systems where many users can collaborate gathering and sharing information for specific or general purposes: social networks, e-commerce review systems, collaborative knowledge systems, etc. Since most of the data collected in these systems is user-generated, understanding of the motivations and general behavior of users is a very important issue.

Of particular interest are citizen science projects, where users without scientific training are asked for collaboration labeling and classifying information (either automatically by giving away idle computer time or manually by actually seeing data and providing information about it). Understanding behavior of users of those types of data collection systems may help increase the involvement of the users, categorize users accordingly to different parameters, facilitate their collaboration with the systems, design better user interfaces, and allow better planning and deployment of similar projects and systems.

Behavior of those users could be estimated through analysis of their collaboration track: registers of which user did what and when can be easily and unobtrusively collected in several different ways, the simplest being a log of activities.

In this paper we present some results on the visualization and characterization of almost 150.000 users with more than 80.000.000 collaborations with a citizen science project – Galaxy Zoo I, which asked users to classify galaxies' images. Basic visualization techniques are not applicable due to the number of users, so techniques to characterize users' behavior based on feature extraction and clustering are used.

8758-22, Session PTues

Beyond visualization of big data: a multistage data exploration approach using visualization, sonification, and storification

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As the sheer volume of data grows exponentially, it becomes increasingly difficult for existing visualization techniques to keep pace. The sonification field attempts to address this issue by enlisting our auditory senses to detect anomalies or complex events that are difficult to detect via visualization alone. Storification attempts to improve analyst understanding by converting data streams into organized narratives describing the data at a higher level of abstraction than the input stream that they area derived from.

While these techniques hold a great deal of promise, they also each have a unique set of challenges that must be overcome. Sonification techniques must represent a broad variety of distributed heterogeneous data and present it to the analyst/listener in a manner that doesn't require extended listening – as visual "snapshots" are useful but auditory sounds only exist over time. Storification still faces many human-computer interface (HCI) challenges as well as technical hurdles related to automatically generating a logical narrative from lower-level data streams.

This paper proposes a novel approach that utilizes a service oriented architecture (SOA)-based hybrid visualization/ sonification / storification framework to enable distributed human-in-the-loop processing of data in a manner that makes optimized usage of both visual and auditory processing pathways while also leveraging the value of narrative explication of data streams. It addresses the benefits and shortcomings of each processing modality and discusses information infrastructure and data representation concerns required with their utilization in a distributed environment. We present a generalizable approach with a broad range of applications including cyber security, medical informatics, facilitation of energy savings in "smart" buildings, and detection of natural and man-made disasters.

8758-23, Session PTues

Characterization of Gain-aware Routing in Delay Tolerant Networks

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A large number of emerging applications such as participatory sensing and content dissemination in social networks rely on efficient routing in Delay Tolerant Networks (DTNs). Majority of the existing DTN routing protocols attempt to minimize a single routing index such as message delay or forwarding count. However, for many DTN applications, such as distributing commercial content, targeting the best performance for one index and compromising the others is often insufficient. A more practical solution would be to strike a balance among multiple of these indices. Additionally, although multicast is a natural way of content dissemination for many applications, it is relatively less discussed in the mainstream DTN literature. In this paper, we focus on the problem of multicasting in DTN with an effort to balance the dissemination delay and message forwarding cost. We formulate the concept of an economic gain, which is the generated value due to content dissemination minus the forwarding cost, and present a benchmark mechanism for multicast routing which yields the best possible gain for any given network and mobility scenario. Using the ONE DTN network simulator , the behavior of the benchmark in achieving the maximum gain is evaluated considering different interest factors (i.e. the percentage of users interested in receiving a content), forwarding probability (the factor which aims to prevent blind forwarding) and mobility models. We also show the gap between the achieved gain in benchmark and a number of existing DTN routing protocols which also reveals the maximum possible gain that a gain-aware multicast routing protocol can achieve. Finally, we discuss the features of a potential gain-aware multicast routing protocol and the obstacles which prevent the existing protocols from achieving a higher gain, relative to the benchmark.

8758-25, Session PTues

Multimodal scenario analysis and visualization tool

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An analyst monitoring a specific situation today has a lot of information available to them. They would have several forms of imagery: airborne, satellite, video survellience, etc., covering differing spatial and spectral ranges spanning over varying time periods. This is all before any analysis is done on the data. While this should ultimately aid in the analysts task it can make it more complicated because of the sheer volume and the analysis involved. We at Rochester Institute of Technology have developed a prototype environment around a fictional scenario describing a specific intelligence question. This environment ingests data across a wide range of modalities, allows the analyst to interact with the data and perform analysis within the environment. This is all done with the ability to visualize the scenario according to date and time of the data capture in order to make predictions and understand observations as a function of time. The data used in this analysis was both real and simulated based on Midland Cogeneration Venture Power Plant. This plant supplies energy and steam (almost) exclusively to the Dow Chemical plant next door. We were able to characterize, on as dense a temporal sampling scale as available, the power output capacity of the power plant, which we assumed to be correlated to activity at the chemical plant. The simulations were produced by DIRSIG, the Digital Imaging and Remote Sensing laboratory's Synthetic Image Generator, a first principals physics based model.