Technical Abstract Summaries

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6538-01, Session 1

Internet security challenges for the future

P. K. Khosla, Carnegie Mellon Univ.

No abstract available

6538-02, Session 2

Secret communication by using data hiding in IPv6

M. Carli, A. De Castro, A. Neri, Univ. degli Studi di Roma Tre (Italy)

In this paper the use of Internet Protocol v.6 packets to convey hidden information is exploited. The possibility to hide information in commonly used data transport mechanisms allows one to send extra information in a transparent way in such a way that no one, apart from the intended recipient, is aware of the existence of the message. The hidden message does not affect the routing mechanism neither interferes with the security mechanisms implemented on IP based networks, as firewalls, intrusion detection systems, authentication tools.

The objective of this paper is twofold: first we demonstrate the possibility of hiding data by using header manipulation of IPv6 (Internet Protocol version 6 - RFC 2460), then, we apply this technique to the authentication mechanism between two nodes of an ad hoc wireless network. This work starts from (D. Kundur, K. Ahsan, “Pratical Data Hiding in TCP/IP”, ACM Workshop on Multimedia Security, 2002), in which the existence of the covert channels in IPv4 and data hiding possibilities are demonstrated.

From that analysis of IPv6, we have selected a field of the IPv6 packet header that is not optional and that, at the same time, it does not interfere with the normal routing operations. The details and the results will be reported in the final version of the paper.

In brief, we selected the 20-bits Flow Label field is used by a source node for labeling the packets of a stream. That is, the field value is 0 if the packet does not belong to a flow; if the packet is part of a flow between two users, than it assumes the same value for all the packets belonging to the stream. If a packet fragmentation occurs, the value of this field is the same for each fragment, and the Identification field is present in the Fragmentation Header. So we force the fragmentation of the flow.

As an example of practical application of the proposed scheme, we considered the shared key authentication procedure in an ad hoc network.

6538-03, Session 2

Innovative, wearable snap connector technology for improved device networking in electronic garments

K. Lee, E. Gans, T. P. Jannson, Physical Optics Corp.

This paper discusses a wearable snap connector technology that provides for the transfer of data and power throughout an electronic garment (e-garment). These connectors resemble a standard garment button and can be mated blindly with only one hand. Fully compatible with military clothing, their application allows for the networking of multiple electronic devices and an intuitive method for adding/removing existing components from the system. The attached flexible cabling also permits the rugged snap connectors to be fed throughout the standard webbing found in military garments permitting placement in any location within the uniform. Variations of the snap electronics/geometry allow for integration with USB 2.0 devices, RF antennas, and are capable of transferring high bandwidth data streams such as the 221 Mbps required for VGA video. With the trend towards providing military officers with numerous electronic devices (i.e., heads p display, GPS receiver, PDA), POC’s snap connector technology will greatly improve cable management resulting in a less cumbersome uniform. In addition, with electronic garments gaining widespread adoption in the commercial marketplace, POC’s technology is finding applications in areas such as sporting good manufacturers and video game technology.

6538-04, Session 2

Enterprise network intrusion detection and prevention system (ENIDPS)

C. M. Akujuobi, N. K. Ampah, Prairie View A&M Univ.

Securing Enterprise networks has so far been considered under two broad topics (i. e. Intrusion Detection Systems - IDS and Intrusion Prevention Systems - IPS). It has been proven that the right combination of selected algorithms/techniques under both topics always produces better security for a given network. This approach leads to using layers of physical, administrative, electronic, and encrypted system to protect valuable resources.

So far, there is no algorithm, which guarantees absolute protection for a given network from intruders. Intrusion Prevention Systems like IPSec, Firewall, Sender ID, Domain Keys Identified Mail (DKIM) etc. do not guarantee absolute security just like existing Intrusion Detection Systems. Our approach focuses on developing an IDS, which will detect all intruders that bypass the IPS and at the same time will be used in updating the IPS, since the IPS fail to prevent some intruders from entering a given network.

The new IDS will employ both signature-based detection and anomaly detection as its analysis strategy. It should therefore be able to detect known and unknown intruders or attacks and further isolate those sources of attack within the network. Both real-time IDS predictions and off-line IDS predictions will be applied under the analysis and response stages. The basic IDS architecture will also involve both centralized and distributed/heterogeneous architecture to ensure effective detection. Pro-active responses and corrective responses will also be employed here.

The new security system, which will be made up of both IDS and IPS, should be less expensive to implement compared to existing ones. Finally, limitations of existing security systems have to be eliminated with the introduction of the new security system.

6538-05, Session 2

Securing wireless sensor systems

M. Blaser, Certicom Inc. (Canada)

Data acquisition through wireless sensor systems enables remote monitoring and surveillance; tracking and tagging technologies for people, containers, vehicles and individual or aggregate assets; and physical security applications, providing data for diagnosis and response to alarms or events. These systems also provide mechanisms for communication, command, and control in systems designed for protection of infrastructure. The absence of wires opens possibilities for dynamic but also less secure networking environments, which are susceptible to sniffing, hacking, sabotage and operator error.

To secure networks and improve reliability, system and device designers employ strong authentication, key exchange, encryption and access control. This requires enabling provable identity in devices, using public-key cryptography. Public-key methods distribute security capabilities into individual devices, allowing the use of strong security policies across the network. These security policies define how devices are admitted to physical and logical networks, how they are allowed to move between networks and communicate at geographically separate locations, and how applications may interact.

We describe how authentication, key exchange and encryption can be efficiently designed into constrained sensor devices and how digital certificates provide a root of trust, facilitating decision-making for network access and authorization to participate in applications. In addition, we describe how these efficient security methods can meet stringent government requirements for military and homeland security applications, even in highly constrained devices, including the use of Suite B cryptographic algorithms.

6538-06, Session 2

An integrated wireless sensor network for tranporattion safety and security

M. A. Chowdhury, Clemson Univ.

Ensuring that the American highway transportation system remains a viable part of the nation's infrastructure is of paramount importance. Increasing population, growing numbers of vehicles, the threat of terrorism, and urban sprawl have impacted a highway system already overburdened and inadequately maintained. Given the anticipated increases in highway traffic, the problems in traffic infrastructure management and security will continue to grow. Therefore, it is critical to develop systems to manage this expected growth in the surface transportation system efficiently. The integrated sensor network presented in this paper distributes management and control of highway operations to manage growth and contribute to security by using state-of-the-art intelligent sensor technology for real-time traffic management and control. This integrated sensor network can work with any existing traffic sensors including the transmission-based optical sensor system developed by the first author of this paper. The research addressed three objectives for developing this integrated sensor network:

* The creation of distributed decision-making algorithms. Distributed decision making through collaboration between traffic sensors improve existing centralized response and control actions. Real-time traffic management can dramatically improve traffic safety and operations, and transportation security.

* Establishment and evaluation of a wireless network by exploiting the temporal and spatial structures of message exchanges. A wireless sensor network for traffic management will result from the communication structure requirements identified. Appropriate network protocols are incorporated to facilitate operations with enhanced efficiency and assured quality of service.

* Development of an integrated simulation platform. An experimental simulation test bed to demonstrate and evaluate the integrated sensor system is developed. The results generated from the simulation test bed are included in this paper.

This integrated wireless sensor network can transform surface transportation operations and improve security. The redundant distributed decision making for transportation infrastructure management will provide revolutionary protection against possible terrorist disruptions of transportation systems. This prototypical traffic regulation system, using a hierarchical wireless network architecture that does not currently exist, can replace the traditional model of traffic control characterized by wired connections or wireless base stations in which sensors send all measurements to control centers. The proposed system offers a collaborative model of wireless nodes that can independently measure traffic conditions on local segments and initiate robust control actions during any emergency events or security threats.

6538-07, Session 2

iScoutTM low-cost ad-hoc networked sensor enhancements

M. A. Winston, McQ, Inc.

McQ has developed a family of state of the art miniaturized low cost unattended ground sensors (UGS). The iScoutTM sensors are designed for indoor and outdoor intrusion detection and battle damage assessment. McQ has developed a very advanced second version of this sensor that is a very flexible platform capable of performing in a variety of applications. This latest version has enhanced processing, added memory, and improved sensor transducers. Sensors are equipped with mesh radios, GPS, and integrated seismic, acoustic, infrared, and magnetic transducers. Typical sensor sizes are similar to that of a deck of playing cards. Intended for high volume production, these are tactically useful sensors that can be manufactured in high volumes for a projected cost of less than $100 each. This paper will provide an overview of iScoutTM sensor systems, features, and performance.

6538-08, Session 3

Experiments on through-the-wall motion detection and ranging

P. Setlur, M. G. Amin, F. Ahmad, Villanova Univ.; P. D. Zemany, BAE Systems North America

Single frequency (Doppler) radars cannot be used in range estimation due to their range ambiguities. An additional frequency can be used to increase the maximum unambiguous range to accepted values for indoor range estimation of moving targets. The dual-frequency CW radar employs two different carrier frequencies and simultaneously measures the phase change with respect to time, for each of the two frequencies. It uses phase comparison of the transmitted and received CW signals to provide an estimate of the target range. It can function well in highly cluttered indoor scenes. The dual-frequency approach offers the benefit of reduced complexity, fast computation time, and real time target tracking. In this paper, we present experimental results showing the effectiveness of the proposed method for indoor range estimation. Targets undergoing different motions, such as constant Doppler, micro-Doppler, and accelerating profiles, behind concrete walls will be considered. The experiments include generating the Doppler signatures for human walking showing acceleration and deceleration patterns, and also the microDoppler signatures of typical indoor simple harmonic motions, such those associated with pendulums and fans.

6538-09, Session 3

Through-the-wall sensor systems based on hard x-ray imaging optics

T. P. Jannson, M. Gertsenshteyn, V. Grubsky, P. Amouzou, Physical Optics Corp.

In this paper, a new approach to X-ray non-intrusive inspection is discussed, based on hard X-ray imaging optics. A new X-ray lens, called lobster-eye-lens (LEL) is a transmission lens, based on reflection optics, with grazing-angle deflection of 0.2 degrees, with photon energy in the range of 40-100keV. The lens reflection optics is based on large high-quality X-ray mirrors, with r.m.s. lower than 1nm. The through-the-wall inspection capability of such a system can be applied for longer ranges (up to 100m in the air), and thick walls (over 1cm for wood, and over 2mm for metal). A number of CONOPS examples is discussed for homeland security applications.

6538-10, Session 3

THz identification of humans and concealed weapons for law enforcement, government, and commercial applications

A. U. Sokolnikov, Visual Solutions and Applications

Described is the principle of the THz sensing and its implementation based on a newly discovered possibility in a subvisible range to penetrate through various materials and to be absorbed by them to a various extent. The advantage of the proposed solution stems from a greater degree of mobility of the sensor and its ability to distinguish between different materials, the feature not attainable by the X-Ray apparatus. The identification may be also more "diplomatic" since it does not involve "seeing through". Presented are the description of the identification device as well as the objects of interest, and the prospects of the further development of the proposed principle/device.

6538-11, Session 3

Unique facility for law enforcement applicable CWD and TWS technologies test and evaluation

S. E. Borek, J. F. Seif, D. L. Stevens, D. E. Warren, Air Force Research Lab.

The Air Force Research Laboratory's Information Directorate (AFRL/IF) has established the Concealed

Weapons Detection/Through Wall Surveillance Test & Evaluation (CWD/TWS T&E) Facility to accomplish in-depth analysis of developed technologies applicable to these identified Law Enforcement (LE) operational and situational functional capabilities requirements. The technology prototypes in existence have been developed primarily through direct support from the Department of Justice (DOJ), National Institute of Justice (NIJ) Office of Science & Technology (OST). Additionally, Statements Of Need (SON) from US National and State LE agencies, along with market indicators, have driven other commercial institutions to research and investigate the feasibility of adapting their technology applications for utilization to address the CWD and/or TWS challenges.

This CWD/TWS T&E Facility is capable of performing T&E on all technologies that have been proposed to accomplish these functions. The current technology focuses are: for CWD, passive and acoustic operations; for TWS, active radio frequency (RF) and acoustic operations. However, this T&E facility can be easily adapted for analysis of other technology application prototypes.

The presentation and accompanying paper will highlight the unique capabilities of this facility. These being: T&E of CWD/TWS devices against NIJ specified requirements; Characterization of CWD/TWS devices performance; Characterization of the constructed walls for TWS; Representative test setups for CWD/TWS testing; Video recording of device testing; and the On-site fabrication group. The different devices available and scheduled for testing will be discussed, as well as the operational requirements against which each will be evaluated. Results from the T&E will be used to recommend how/when/where each device can be most effectively used.

6538-83, Session 3

Biometric identification using holographic radar imaging techniques

D. L. McMakin, D. M. Sheen, T. E. Hall, H. P. Foote, Pacific Northwest National Lab.

Pacific Northwest National Laboratory researchers have been at the forefront of developing innovative screening systems to enhance security and provide custom-fit clothing that utilize holographic radar imaging techniques. Award winning and first-of-a-kind cylindrical holographic imaging systems have been developed to screen people at security checkpoints for the detection of concealed, body worn, non-metallic threats such as plastic and liquid explosives, knifes and contraband. One embodiment of this cylindrical security scan is able to obtain full sized body measurements in near real time without the person under surveillance removing their outer garments. Radar signals readily penetrate clothing and reflect off the water in skin. This full body measurement system is used commercially for best fitting ready to wear clothing, which was the first "biometric" application for this technology. One compelling feature of this technology for biometric applications is that it can see effectively through disguises and body hair. This paper will discuss the holographic radar imaging technology for biometric applications and present numerous imaging results.

6538-12, Session 4

A real-time tracking system for monitoring shipments of hazardous materials

M. W. Humphrey, NorthWest Nuclear, LLC; P. C. Womble, J. Paschal, L. Hopper, Western Kentucky Univ.; D. Pinson, F. J. Schultz, NorthWest Nuclear, LLC

Due to the ever increasing use of radioactive materials in day-to-day living (e.g. the treatment of cancer patients, the irradiation of food for preservation, and the use of industrial radiography to check for defects in the welding of pipelines and buildings) there is a growing concern over the tracking and monitoring of these materials in transit prior to use as well as the waste produced by such use. The prevention of lost sealed radioactive materials is important in reducing the environmental and health risk posed by direct exposure, co-mingling in the metal recycling stream, use in contaminated consumer products, and use in terrorist activities.

Northwest Nuclear, LLC (NWN) and the Applied Physics Institute (API) at Western Kentucky University have developed a tracking technology (called PrecisionTraxTM) using active radio frequency identification (RFID) tags. The system can track and graphically display the location on maps, drawings or photographs of tagged items on any 802.11-compliant device (PDAs, laptops, computers, WiFi telephones). This location information would be vital for tracking the location of high level radiological sources while in transit. RFID technology would reduce the number of lost sources by tracking them from origination to destination. In 2005, Oak Ridge National Laboratory (ORNL) tested this technology by setting up monitoring stations along the prescribed route of shipments of radiological material between ORNL and Oak Ridge Associated Universities. We will discuss the results of this test along with the lessons learned while implementing the system within the network of a national laboratory.

6538-13, Session 4

Associated particle imaging

K. Warman, S. Thordarson, D. T. Kuo, D. G. Penn, M. Clements, Applied Signal Technology, Inc.

Detection of concealed explosives is a critical capability in a variety of applications including entry point screening, cargo inspection, and threat confirmation. The Associated Particle Imaging technique offers tremendous potential as a non-intrusive inspection method capable of providing through-barrier, three-dimensional target imaging, and material classification. The Associated Particle Imaging Explosive Detection System (APIEDS) was developed by Applied Signal Technology (AST) to meet the threat posed by concealed, vehicle borne explosives. Associated Particle Imaging technology is an active neutron probe technique that provides elemental compositions of materials, including explosives and other contraband, by means of gamma ray spectroscopy. A key advantage of this technology over traditional radiography is that access to both sides of a vehicle or container is not needed; all of the inspection equipment may be placed to one side of an object. Barrier materials may be metal, and as well as wood and drywall. Also, objects hidden inside or behind such barriers as pipes, boxes, drums, and boxes can be inspected without rotating either the detectors or the objects under investigation. The operational field of view is 60 degrees (full width) for the APIEDS system. System sensitivity allows for the detection of a cubic foot or more of the threat material.

6538-14, Session 4

Directional gamma-ray detection

K. Warman, J. Weckel, D. G. Penn, M. Clements, Applied Signal Technology, Inc.

The mishandling or intentional misuse of highly radioactive materials poses a public threat. There are scenarios where security, law enforcement, and safety agencies may need to locate such materials efficiently and rapidly in order to direct personnel. Threats not only come from terrorists attempting to weaponize such materials, but also from accidents or improper handling of medical or industrial materials. In one case, the negligent handling of medical materials (a 2 inch Cesium-137 source of activity 1400 Curies) in Goiania, Brazil lead to both fatalities and injuries after scavengers looking for scrap metal stole the material in September 1987. Traditionally, a search for such materials would rely on equipment such as Geiger counters that only indicate the intensity of gamma radiation and not the direction back to the source - prolonging the search. The K9-Gamma system developed by Applied Signal Technology provides line of sight direction to gamma ray sources in an operationally straightforward way. The system integrates a 360 degree panoramic camera with several gamma ray detectors. The display to the operator graphically indicates on the panoramic photograph where in the scene gamma radiation is coming from. The gamma ray direction finding is based on the Compton scattering between detectors, with a capability to show direction within 15 degrees. Achievable distance varies with the level of radioactivity of the source; a line of sight to sources such as the medical material in the Goianai incident could be determined in 1 minute at a distance of 1mile.

6538-15, Session 5

Aerostat acoustic payload for transient and helicopter detection

M. V. Scanlon, C. G. Reiff, L. Solomon, Army Research Lab.

The Army Research Laboratory (ARL) has conducted experiments using acoustic sensor arrays suspended below tethered aerostats to detect and localize transient signals from mortars, artillery and small arms fire. This persistant surveillance can have a powerful effect on the survivability and lethality of our soldiers. The airborne acoustic sensor array calculates an azimuth and elevation to the originating transient, and immediately cues a collocated imager to capture the remaining activity at the site of the acoustic transient. This single array's vector solution defines a ground-intersect region or grid coordinate for threat reporting. Unattended ground sensor (UGS) systems can augment aerostat arrays by providing additional solution vectors from several ground-based acoustic arrays to perform a 3D triangulation on a source location. The aerostat array's advantage over ground systems is that it is not as affected by diffraction and reflection from man-made structures, trees, or terrain, and has direct line-of-sight to most events. The same aerostat and UGS collaboration can track nearby helicopters in 3D for tether avoidance. Elevating the array gives an significantly longer range of detections under favorable MET conditions.

6538-16, Session 5

Electronic system for de-activation of clock-bombs with help of liquid nitrogen

A. Rahmani Nejad, Civil Aviation Organization (Iran)

Electronic system that is able to interrupt functionality of electronic clock and command circuit of clock activated bombs for unlimited time and deactivates any probable sensors like motion sensor, infra red sensor in some nanoseconds that it is possible to move the Bomb to any other place and then to be deactivated. In special case it is an alternate probable method to use liquid nitrogen to neutralize the chemicals and detonator in a neutralizing vessel. Electronic system for neutralizing bombs can be installed on a neutralizing container and it is connected by several wires to specific points of electronic part of bomb and This system is able to interrupt the functionality of bomb for unlimited time and gives Enough time to be neutralized by experts even in any other place (i.e. this system is capable to interrupt the functionality of probable sensors of bomb like motion sensor temperature sensor, infra red sensor or any kind of sensor that makes dangers to move the bomb or to change any of environmental conditions.)

This system consists of some subsystems as following:

1. A dummy clock

2. Some pseudo sensors that never change their state due to a change of sensed factor such as motion or temperature or any other actuating factor.

3. A variable power supply that can be set to have the exact electrical characteristics 0f batteries used in bomb.

This system is capable of substituting of any of dummy devices that never act in proper time. This substitution occurs just in some nanosecond by a very innovative method that no interruption of functionality for bomb occurs. One nanosecond i.e. 1/1000000000 of second is to short for bombs of any kind control systems to sense this interruption and to be activated.

This device is capable for deactivation of:

1. Deactivation of any bomb with mechanical clock and simple mechanical control system.

2. Deactivation of any bomb with electronic clock and complicated electronic control system.

3. Deactivation any kind of electrical or electronic sensors.

4. Deactivation of any kind of mechanical or chemical sensors that activation occurs when connection or disconnection occurs (from electronic point of view any short circuit or open circuit happens).

5. Deactivation of any electrical or electronic relay that may act as a part of ignition system or as a part of a sensor circuit.

Alternate special case method with this solution when the temperature reaches to-40 to -60 C the battery and any electronic device like charging capacitors will be deactivated and in less than minus 140 Celsius (or about 130 degree of Kelvin), detonator and chemical explosives will be neutralized.

6538-17, Session 5

A novel shoe scanner using an open-access quadrupole resonance sensor

C. W. Crowley, GE Infrastructure

Airport security and efficiency are both compromised by the process of requiring passengers to remove their shoe. A novel shoe scanner developed at the GE Security San Diego Center of Excellence uses Quadrupole Resonance (QR) to identify explosives hidden in shoes. The shoe scanner was developed with an open-access chassis and scanning chamber that allows passengers to stand in the system in a natural position during the scanning process. More traditional magnetic resonance systems are closed or partially closed and cannot be used for screening personnel because the scanning chambers confine the object in question. The shoe scanner's novelty lies in a particular chassis geometry that works in conjunction with an electrically connected QR coil geometry. The resulting scanning system achieves the same level of performance as a more confining system. The shoe scanner is small enough to allow integration with other sensors such as the GE Itemizer FXTM trace detection system. In fact, the first application of the novel shoe scanner is expected to be as a component in a multi-sensor verification and security system known as the Secure Registered Traveler (SRT) Kiosk. The SRT kiosk is designed to be used as part of the TSA's Registered Traveler Program.

6538-18, Session 5

De-activation of nuclear missiles by electromagnetic bomb-head missiles

A. Rahmani Nejad, Civil Aviation Organization (Iran)

This method is based on very efficient idea of using missiles carrying electromagnetic bomb head. These kind of missiles can explode when they are several kilometers far from the nuclear missiles in space or even they are several kilometers behind ballistic Nuclear missiles. The advantages of this method are:

1. destruction of nuclear missiles is accomplished without direct hit of two missiles then it is not very important to guide electromagnetic missiles to the nuclear missile hence accuracy will have minor effect

2. because in this method, nuclear missiles can be deactivated from even several tens of kilometers, then a time delay of some seconds will have minor effect

3. by this method nuclear missiles will not explode in space then there is no long range nuclear pollution.

4. launching a number of electromagnetic- head missiles toward the path of nuclear missiles will make a very reliable fire wall

5. because of very small head, such missiles will have very good maneuvering parameters.

6. such missiles will not have any pollution after acting

7. electromagnetic missiles will not have any secondary explosion that may make probable secondary explosion

8. electromagnetic-head missiles can be launched by patrol aircraft for very fast reaction.

9. by using this method nuclear missiles miss the correct path and ignition system, control system, and guidance systems will not be operational and no explosion in space will happen

10. this method will have minimum risk and minimum draw backs like pollution in space, explosion in space, accuracy, response time delay.

11. this method can be used for deactivating any kind of long- range missiles or

12. this method is very capable when a group of nuclear missiles, any kind of missiles or a group of army aircrafts are near to one another and tend to make possible attack, then by using only one or a few of electromagnetic missiles all will be deactivated.

6538-19, Session 5

Magnetic gradiometer for detection and localization of IEDs

Y. Dalichaouch, B. W. Whitecotton, S. Kuhn, Quantum Magnetics, Inc.; D. O. Walsh, Vista Clara, Inc.

Improvised explosive devices (IEDs) are typically made of artillery shells, which contain a significant amount of ferrous metal. As a result, they can be detected magnetically from a distance. The standoff range depends on the size and number of shells. In cluttered environments, these devices can be easily hidden in the natural environment in a number of ways typically along the roadside. To address this issue, GE Security is developing a passive magnetic gradiometer for standoff detection and localization of roadside IEDs. The sensor can be mounted on a vehicle or deployed on a robotic platform. This paper will present preliminary results for a vehicle-mounted system and discuss the sensor operation, noise sources and mitigation, and localization algorithm.

6538-21, Session 6

Real-time automated 3D sensing, imaging, and monitoring of dynamic microscopic biological events

B. Javidi, I. Moon, S. Yeom, Univ. of Connecticut; E. M. Carapezza, DARPA and DoD/DoJ Joint Program Committee Steering Group

No abstract available

6538-22, Session 7

Detection of chemical agents using a novel energy cell

J. Shewchun, Wayne State Univ.

The detection, classification and tracking of chemical agents being surreptitiously smuggled into public areas, such as airports, for destructive purposes is difficult to solve by unobtrusive means. We propose the use of a novel energy cell with gas/vapour sniffing capability. A variant of such devices are routinely used by police to detect alchohol emanating from the breath of suspected impaired vehicle drivers. We have advanced this technology with the development of an Pethanol Alkaline Energy Cell which is capable of reading gaseous emissions ultimately in the parts per billions range. Specific data will be presented.

6538-23, Session 7

Chemical, biological, and explosive vapor detection with microcantilever array sensors

J. D. Adams, R. Whitten, B. S. Rogers, Nevada Nanotech Systems, Inc.

Nevada Nanotech Systems, Inc (NNTS) is developing microcantilever-based Self-Sensing Array (SSA) technology to measure trace concentrations of explosives, toxic chemicals, and biological agent signatures. This technology is expected to provide the selectivity, durability, low cost, and low power needed for unattended sensor networks. The prototype system employs a variety of sensor coatings and the ability analyze electrical and thermal properties of vapor molecules on the cantilevers. This so-called Lab-on-a-Tip technology could lead to enhanced chemical identification capabilities of the trace detection platform. Results from recent system testing will be presented.

6538-24, Session 7

Chemical sensors based on functionalized microcantilever arrays

P. G. Datskos, N. V. Lavrik, Oak Ridge National Lab.; M. J. Sepaniak, P. Dutta, P. J. Chapman, The Univ. of Tennessee

Over the past three decades there have been spectacular developments in micro-electro-mechanical (MEMS) systems. As a result, an innovative family of chemical and biological sensors has emerged. While MEMS represents a diverse family of designs, devices with simple cantilever configurations are especially attractive as transducers for chemical and biological sensors. A microcantilever transducer converts changes in the Gibbs surface free energy into measurable mechanical responses. Specific binding sites present in chemically selective layers deposited on a cantilever provide affinity of targeted analytes to the sensor active area. Highly selective receptor layers can be designed using concepts of molecular and biomolecular recognition. In this work we discuss chemical sensors based on chemically modified cantilever arrays. We performed analyte species and concentration identification using an array of ten differentially functionalized microcantilevers coupled with a back-propagation artificial neural network (ANN) pattern recognition algorithm. The microcantilever array consisted of ten nanostructured silicon microcantilevers functionalized with polymeric, gas chromatography phases and macrocyclic receptors. The array response to analyte vapor was measured by an optical readout scheme and the responses were recorded for a selection of individual analytes as well as several binary mixtures. An ANN was designed and trained to recognize not only the individual analytes and binary mixtures, but also to determine the concentration of individual components in a mixture. The trained ANN correctly identified the test analytes we used (most with probabilities greater than 97%). The demonstrated unique aspects of the present work include the ability to detect chemicals in binary mixtures and provide both qualitative and quantitative information about the chemical environment.

6538-25, Session 7

A low-cost remote chemical sensor for E-UAV platforms

R. T. Zehr, S. K. Holland, G. Laufer, Univ. of Virginia

A low-cost sensor for the detection of hazardous chemicals was developed for deployment on expendable unmanned aerial vehicles (E-UAVs). The Totally Optical Vapor Analyzer (TOVA(tm)) sensor was designed for seamless and autonomous integration with a small E-UAV and was designed to detect chemical vapors in a nadir-viewing configuration from an altitude of 1000 ft while traveling at an air speed of 60 knots. The sensor is comprised of eight uncooled pyroelectric infrared detectors, each integrated with a different infrared bandpass filter, which provide low-resolution spectral scans of the atmosphere and ground features. Hazardous chemicals are detected and identified by their unique infrared absorption (or emission) signatures. A significant challenge to passive chemical detection in the 8-12 micron regime is scene variation resulting from the spectral emissivity characteristics of changing terrain features. Without additional information, such scene changes may be interpreted as a chemical detection. To reduce false alarms resulting from such scene variations, three color filtered (red, green, blue) photodiode detectors were integrated with the TOVA(tm) sensor. The photodiode detectors view the same scene as the infrared detectors and provide the additional scene information required to discriminate terrain variations from chemical detection events. A unique processing algorithm utilizes data from the infrared and visible detectors to identify background (or scene) changes, to detect and identify chemicals, and provide alarm levels based on the identified chemical and measured optical depth. The hybrid sensor has flown in test-flights on a Navy E-UAV and has demonstrated detection and identification of chemicals in laboratory and outdoor conditions.

6538-26, Session 7

Bio-aerosol optical sensor model development and initial validation

S. D. Campbell, MIT Lincoln Lab.

This paper describes the development and initial validation of a bioaerosol optical sensor model. The simulation model was used to help determine design parameters and estimate performance of a new low-cost optical sensor currently under development at MIT Lincoln Laboratory for detecting bioterrorism agents. In order to estimate sensor performance in detecting biowarfare simulants and rejecting environmental interferents, use was made of a previously reported catalog of EEM (excitation/emission matrix) fluorescence cross-section measurements [1] and previously reported multiwavelength-excitation biosensor modeling work[2]. In the present study, the biosensor modeled employs a single high-power 365 nm UV LED source plus a IR laser diode for particle size determination. The sensor has four output channels: IR size channel, UV elastic channel and two fluorescence channels. The sensor simulation was used to select the fluorescence channel wavelengths of 400-450 and 450-600 nm. Using these selected fluorescence channels, the performance of the sensor in detecting simulants and rejecting interferents was estimated. Preliminary measurements with the sensor for biowarfare simulants and environmental interferents are presented. These results compare favorably with the simulation results.

References:

1. Campbell et al, “Wavelength Comparison Study for Bioaerosol Detection”, Proc. SPIE, 5778, 130-138 (2005).

2. Campbell et al, “Multiwavelength Bioaerosol Sensor Performance Modeling”, Proc. SPIE, 5990, 138-150 (2005).

6538-27, Session 7

A new paradigm for video cameras: optical sensors

K. Grottle, ENSCO, Inc.; A. Nathan, IntelliVision; C. Smith, ENSCO, Inc.

This paper presents a new paradigm for the utilization of existing video surveillance cameras as optical sensors to augment and significantly improve the reliability and responsiveness of a typical chemical sensor system.

Under this paradigm cameras serve as optical sensors to monitor the environment for indications of the covert release of chemical agents. These agents are highly toxic and cause behavior termed in this paper as ‘duress’. ‘Duress’ symptoms range from simple (a prone position) to complex (hacking, jerkiness, or mass panic) behaviors. Incorporating the detection of these ‘duress’ behavior signatures elevates chemical sensing systems to a new and more robust level.

Optical sensors effectively fill operational gaps present with chemical sensor offerings by providing a broad detection range and rapid alarm response. Toxic chemical agents fall into both warfare and industrial categories and no single sensor today covers the full range. But regardless of which type of agent is released the result is harmful and yields ‘duress’ behavior. Also the time for a typical sensor to test an air sample may be on the order of minutes. Given the rapid onset of ‘duress’ symptoms an optical sensor can detect the effects immediately. In either case the optical sensor can provide a cue to a monitoring system to focus air sampling or correlate results from standard chemical sensors.

Adoption of this new paradigm provides a means to enhance and augment the use of existing chemical sensors. At the same time it doubles the effectiveness and utilization, without impact, to video cameras that are a ubiquitous part of security in most modern buildings.

6538-29, Session 8

Evaluation of robot deployment in live missions with the police, military, and fire brigade

C. Lundberg, R. Reinhold, H. I. Christensen, Kungliga Tekniska Högskolan (Sweden)

Recent technical improvements are increasing the prospects of new applications for field robotics. The driving force being to remove humans from risk, to perform more efficiently or at lower cost and to enable missions unsuited to humans. It is, however, not always obvious when to deploy new technology. To early and unsuccessful attempts might seriously influence the prospects for future investments. Thorough comparison of costs and profits associated with new technology is required, benefits have to be valued against costs for acquisition, integration, training, maintenance as well as mission efficiency and reliability.

Many aspects of this valuation will require a realistic environment and a user with an established and well-experienced knowledge of a particular system. Of these demands the later is prone to pose a paradox. No experienced users will be available for concepts that are still under development. Instead inference has to be done from related fields or through early user evaluation.

This paper reports on a study of three groups: the police, the military and the fire brigade, with several years of experience from deploying robots as part of their operations. The research included surveying of limitations with current technology, desires of future improvements, attitude towards robots within the organization and documentation of common robot missions. Gained information is aimed to serve as a guideline for future development as well as to provide a reference while deciding whether to extend the use of robotics into new applications.

6538-30, Session 8

Mini-RNV

D. R. Erickson, Defence Research and Development Canada Suffield (Canada)

This paper describes the mini Remote Neutralization Vehicle (mini-RNV) project; its state, progress, and future directions. The mini-RNV is a small and expendable EOD ROV system designed to reconnoiter and neutralize EOD/ IED threats faced by troops in Afghanistan.

Based on urgent Army requirements, the mini-RNV project was initiated to explore advancing the state of the art in low-cost, purpose-built, remote neutralization vehicles that can execute a number of IED EOD tasks, such as reconnaissance, blow in place (BIP), target pull, target dozing, and employ disrupters.

This system, like the NAVEODTEC Bombot, is intended to provide another tool for EOD personnel to deal swiftly with IED/EOD threats. The cost of the system makes it practical to accept losses to speed up troops caught in “IED Alleys”. Unlike the Bombot, the mandate is open to include other techniques and tools to achieve this aim. Work is conducted using a spiral model of engineering, where design phases into demonstration and feedback before design improvement.

This paper will capture the up to the date progress and future directions based on October demonstrations.

6538-31, Session 8

Advances in group filter applications to sea mine detection

M. H. An, Prometheus Inc.; J. T. Cobb, Naval Surface Warfare Ctr. Panama City; B. Shenefelt, R. Tolimieri, Prometheus Inc.

Automatic detection of sea mines in coastal regions is a difficult task due to the highly variable sea bottom conditions present in the underwater environment. Detection systems must be able to discriminate objects which vary in size, shape, and orientation from naturally occurring and man-made clutter. Additionally, automated systems must be computationally efficient to be incorporated into unmanned underwater vehicle (UUV) sensor systems characterized by high sensor data rates and limited processing abilities. Using noncommutative group harmonic analysis, a fast, robust sea mine detection system is created. A family of unitary image transforms associated to noncommutative groups is generated and applied to side scan sonar image files supplied by Naval Surface Warfare Center Panama City (NSWC PC). These transforms project key image features, geometrically defined structures with orientations, and localized spectral information into distinct orthogonal components or feature subspaces of the image. The performance of the detection system is compared against the performance of an independent detection system in terms of probability of detection and probability of false alarm.

6538-32, Session 8

OmniBird: a miniature PTZ NIR sensor system for UCAV day/night autonomous operations

S. X. Yi, H. Li, Genex Technologies, Inc.

Supported by NAVAIR and working with Boeing and Northrup Grumman, Technest is in its completion Phase of developing a novel airborne video sensor called OmniBird for day and night UCAV (Unmanned Combat Air Vehicles) deck handling (e.g. taxiing) operations and on-board surveillance. The OmniBird sensor combines a uniquely configured optical structure, a highly sensitive near infrared (NIR) sensor, and a specialized onboard image processing electronics unit into a payload package that is small in size (<8 cubic inches), low cost (~$1,500), lightweight (<5 lb), , and has pan/tilt/zoom capability. Once it is completed, the sensor system will be fully integrated with a gesture recognition system to automatically detect and track the flight deck traffic director, to recognize his/her gestures, and to guide the UCAV for its motion.

Because of its small size, low power consumption, and light weight, OmniGuard sensor will have its significance in UAV based applications such as autonomous taking off and landing, intelligent surveillance, and autonomous safe navigation through collision avoidance. It can also be installed in any remote locations for remote surveillance. In fact, leveraging similar technology, we are working with Sikorsky Aircraft Corp to develop an automatic taking off and landing system for cargo lifting and transporting applications.

6538-33, Session 8

Improving the power, bandwidth, and latency performance of UAV-based imaging systems by structural computation methods

A. Cernasov, Honeywell Defense and Space Electronic Systems

When designing an imaging system to be used aboard small independent platforms, tradeoffs must be made among a number of interrelated parameters such as image resolution, frame rate, compression ratio, latency, power consumption, link bandwidth, physical size and others. While in many cases a standard design comprised of multiple functional blocks integrated together and then adapted to the requirements of the platform, may suffice, further significant improvements can be achieved by a more unitary approach. This presentation details a method of executing complex sum-of-products algorithms by re-designing the geometry of the applicable sensor. For example, by changing the geometry and distribution of pixels of an image sensor array the complete JPEG compression section of an MPEG-2 processor becomes redundant and can be eliminated. Such “structural computation methods” can reduce power consumption, latency and space requirements of UAVs, camcorders or cell phones.

6538-34, Session 9

Effects of prior knowledge on the effectiveness of a hybrid user model for information retrieval

H. Nguyen, Univ. of Wisconsin/Whitewater; E. Santos, Jr., Dartmouth College

To quickly find relevant information from huge amount of data is a very challenging issue for intelligence analysts. Many of them use their prior domain knowledge to improve their process of finding relevant information. In this paper, we explore the influences of a user’s prior domain knowledge on the effectiveness of an information seeking task by using seed user models. In our approach, a user model is created by using the multi-attribute utility theory to evaluate values of the attributes describing a user’s intent in combination with the attributes describing an information retrieval system. Our test bed consists of three collections from the information retrieval community: CRANFIELD, MEDLINE, and CACM. We divide each query set from a collection into two subsets: training and testing sets. We use three different approaches to choose the queries into a training set: the queries generate the largest domain knowledge, the queries relate to most queries in a testing set, and mixture of both. Each seed user model is created by running our enhanced information retrieval system through such a training set. We assess the effects of having more domain knowledge, or more relevant domain knowledge, or mixture of both on the effectiveness of a user in an information seeking task.

6538-35, Session 9

A disaster recovery system featuring uncertainty visualization and distributed infrastructure

L. L. Grewe, California State Univ./East Bay

This paper will present a use and implementation of uncertainty visualization in a disaster recovery tool called DiRecT. DirecT is an emergency response system that couples the visualization mechanism with a distributed computing architecture for a more reliable, failsafe infrastructure. DiRecT is targeted for users involved in emergency response operations.

In managing crisis response tasks the assigned personnel faces the daunting task of processing large amounts of information and formulating an action plan in a timely manner. The uncertainty visualization cues help provide the means of determining the priority of assigning resources to the entities by taking into account various factors such as their identity, location, and health severity. With DiRecT the incident commander would be able to quickly assess the current scenario and make critical and informed decisions. An important part of DiRect is its distributed, real-time infrastructure which supports capture, storage and delivery of data from various sources in the field. DiRect also supports personnel communication through an instant memoing feature.

6538-36, Session 9

Determination of flight composite risk factor for optimal federal air marshal resource allocation

H. M. Jaenisch, J. Handley, M. P. Carroll, Tec-Masters, Inc.

This paper describes our novel capability for calculating composite risk factors for airplane flights. Custom asset vectors are created pre-flight using the flight plan to determine high value assets that are within reach of the flight. Individual asset risks in the asset vector are then combined into a composite risk factor (CRF) which is used to rank overall flight risk and assign available Federal Air Marshals (FAMs). This paper summarizes our algorithm and provides example results.

6538-37, Session 9

The application of image processing techniques and technology for security and surveillance applications

M. I. Smith, T. Riley, Waterfall Solutions Ltd. (United Kingdom)

The range and scope of EO/IR sensor systems within security and surveillance applications is growing, and this places a corresponding demand on the image processing functionality required to meet the end-users needs and requirements. Within this paper, the application of different image processing architectures and techniques is reviewed in terms of situational awareness criteria and is illustrated through specific system applications. The concepts and benefits of multi-modal and distributed sensor systems are also considered together with the attendant data registration and fusion techniques. Finally, the exploitation of a priori information within the integrated security and surveillance picture is considered from both a processing technology and image display perspective.

6538-38, Session 9

Blending real and simulated worlds in an AI-augmented sensor fusion and decision support system for homeland security

J. A. Williams, SimiGon, Ltd.

PROJECT BACKGROUND AND GOALS:

Perimeter defense and facility security applications have historically been alarm management and monitoring functions designed to deter, detect, document and deny/delay any intrusion. Contemporary warfare including counter-terrorism has become hybrid in nature and studies must be conducted for the design of new tools to counter these modern threats. These studies will enable decision makers to choose the appropriate mix of sensor fusion and intelligent agent support in a blended world of real and simulated data. The level to which simulation can support real world imagery and sensor data in an AI-augmented environment is the subject of this study.

METHODOLOGY/PROCEDURE:

The end goal for the security planner is fielding a system which exhibits a low false alarm rate (FAR) with a high probability of detection. This problem set has been successfully managed. This research will focus on augmenting the analysis of threat through sensor fusion and AI-augmented decision support.

PROJECT RESULTS:

A simulation of a simplified urban perimeter configuration has been completed. These results identify the feasibility of real-world sensors overlaid on simulated worlds. Threat models are being developed to assist in reducing FAR. An AI-augmented monitor provides enhanced situational awareness and decision support for the operator.

SIGNIFICANCE:

Previous studies of sensor fusion have shown significant improvement in FAR and intrusion detection. Very few simulations have blended real-world data with replicated architecture and urban components to enhance situational awareness. Modeling large volumetric security operations using blended real and simulated components allows a significant increase in perimeter and internal intrusion detection.

FUTURE WORK:

Simulation of more complex urban or facility areas is needed so that refined threat models can be developed while enhancing the AI-augmented monitoring function.

6538-39, Session 9

Bayesian inferance and conditional probabilities as performance metrics for homeland security sensors

T. P. Jannson, Physical Optics Corp.

In this paper, military and homeland security sensors, sensor systems, and sensor fusion, are discussed in the context of performance metrics parameters,and in the form of direct and inverse conditional probabilities, based on signal theory. In particular, false alarm rate, false positive rate, false negative rate, and the probability of detection are discussed as conditional probabilities within the classical and Bayesian inferences. Several examples from various homeland security areas are also discussed for concept illustration. As a result, it is shown that performance of the vast majority of sensor systems can be discussed in terms of these parameters.

6538-40, Session 9

Three-dimensional visual mechinism by neural networkings

S. Sugiyama, Gifu Univ. (Japan)

There are some computer vision systems that are available on a market but those are quite different from in a sense of a real usage of our daily life, like the surroundings' sensing that needs to recognize the detail description of an object, etc. So here studies on mechanisms of how a pair of human eyes can recognize a distance apart, an object edging, and an ob-ject in order to get the essences of vision mechanisms. And those basic mechanisms of object recognition are simplified and extended logically for applying to a computer vision system as shown below.

"Vision must have started with organisms detecting the difference between light and dark. Molecular genetics reveals that this began in broad daylight with cone photoreceptors (Bowmaker, 1998), a hypothesis suggested earlier by the compara-tive anatomist, Gordon Walls (1942). Under these conditions shadows must have been the main stimuli for detecting movements and objects. A shadow depolarizes, i.e. activates, a cone, which releases a neurotransmitter that depolarizes second order retinal neurons, bipolar cells, called off-center bipolars and horizontal cells. The reappearance of light by movement hyperpolarizes the cones. This stops the release of the transmitter, which in turn stops, i.e. hyperpolarizes, the off-bipolars and horizontal cells. This also disinhibits a parallel system of bipolars, called on-bipolars. Disinhibition occurs because the same transmitter released by the cone inhibits the on- and excites the off-bipolars. On- and off- cone bipolars have different receptors for the same transmitter. This push-pull arrangement of on and off -bipolars provides the main input to the brain about the visual universe. One channel signals darkness; the other signals lightness.", stated by Peter Gouras.

From the above knowledge, we can have the following extractions as the vision mechanisms.

(1) Light and Dark of an object gives a cone two states, "OFF-BIPOLARS" and "ON-BIPOLARS".

(2) "OFF-BIPORLARS" and "ON-BIPOLARS" appear as a transmitter of signal in turn when a situation of object is different from the previous (Dark to Light).

(3) Both Output signals of "OFF-BIPOLARS" and "ON-BIPOLARS" go to the adjacent Horizontal Cell.

By using these mechanisms, some of the results about recognition are introduced on this paper.

6538-41, Session 10

Unattended ground sensor system architecture for reduced information dissemination timeline

P. E. Voglewede, S. Hironori, Harris Corp.

In a multi-layered command structure, information from unattended ground sensor systems has typically been transferred from the observation area to the highest level of command. The information is analyzed from many such regions and disseminated to the appropriate forward operating base as intelligence or action orders. Some missions, like the detection and interdiction of Time Critical Targets, may be hampered by the current data dissemination timeline. Therefore alternate, faster methods of providing actionable intelligence into theater are required for these missions. This paper discusses alternative architectures that reduce the information dissemination time line from the sensor fields through the command center and back down to the quick reactionary forces.

6538-42, Session 10

Intelligent management of distributed sensor networks

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

A universal solution for intelligent management of large dynamic sensor networks will be presented, covering both networking and application layers. It is based on a new type of spatial automaton treating networks as distributed computers and solving problems on them in parallel navigation mode. A network of intelligent modules, overlaying sensor network, collectively interprets mission scenarios in high level World Processing Language (WPL), which can start from any nodes and cover the network at runtime, ruling its behavior. The distributed interpreter has been prototyped and tested on numerous applications, with WPL programs being extremely short as most of synchronization and data/agent exchange is shifted to automatic implementation, allowing us concentrate on global solutions instead. The WPL code will be exhibited and discussed for distributed collection, fusion, generalization, and routing of sensor data; simultaneous tracking and studying of multiple mobile targets in the area covered by sensors; as well as more complex tasks, unattainable by other distributed technologies, like analyzing various distributed dynamic phenomena (flocks, manned or unmanned groups/armies, spreading fire/flooding, etc.) with their spatial tracking by societies of communicating sensors, and regular reporting the generalized data (like shapes and/or centers of weight) to an external user. Other applications of the technology include distributed knowledge bases, distributed interactive simulation, distributed brain for groups of robots, ubiquitous command and control, fighting network crime, and protection/destruction of infrastructures. It can be easily re-implemented on any platform. References: JEM, Vol.4, No.4, July/August 2006, pp.29-36 (www.emergencyjournal.com); also www.amazon.com in books or www.google.com, key sapaty.

6538-43, Session 10

Low-cost acoustic sensors for littoral anti-submarine warfare (ASW)

J. P. Towle, R. Johnson, SI2 Technologies, Inc.; H. T. Vincent II, MIKEL Inc.

Detecting modern diesel-electric submarines operating on batteries in littoral waters is very difficult using traditional sonar technology due in large part to the noisy and reverberant acoustic environment. To address this issue, SI2 Technologies Inc. (SI2) has developed a small, low cost, short range, dual mode acoustic sensor. The sensors can be deployed in large numbers (hundreds or thousands) to provide a high density sensor field depending upon the application of interest. SI2's low cost sensors have a short detection range and therefore are far less susceptible to multipath reverberations and other acoustic artifacts. Simulation results will be presented showing that high probabilities of detection (PD) can be achieved with low false alarm rates (FAR) using a field of a few hundred of these low cost sensors.

6538-44, Session 10

Acoustic threatening sound recognition system

H. Deng, H. Xu, Intelligent Automation Inc.

Threatening sound detection, classification and localization is an example technology that can be effectively used in asymmetric warfare and against terrorist threats. Recently, significant research efforts have been made in this area using wireless sensor networks (WSNs). However, there are two critical issues related to signal processing in WSNs. First, energy-efficiency, memory-consumption, bandwidth-utilization, and computation-complexity are of main concern. Second, the application environments (e.g. battlefield, urban area) contain various types of non-stationary and non-Gaussian noise, multi-path echoes, and simultaneous emission sources. These severe environmental effects make acoustic pattern recognition difficult. Therefore, new techniques are sought for reliable and timely acoustic threat detection, identification and accurate source localization at reasonable energy/memory/bandwidth/computation cost in the presence of significant background noise and multipath effects.

In this paper, we present a novel acoustic threat recognition system with a distributed and hierarchical architecture. The functions of threat detection, classification and source localization are organized in multiple levels, namely, base level, gateway node level and sensing node level. At each level, the information processing task is performed in a distributed manner. On the other hand, the proposed system architecture allows cooperation among sensing nodes to collaboratively detect target signatures, reduce false alarms, classify target types, and estimate the acoustic source location. The system combines recent advances in Wavelet Analysis, intelligent learning and sensor fusion. In particular, the proposed Discrete Wavelet Packet Transform (DWPT)-based power-law detection algorithm is robust to environmental noise, yet computationally efficient. An individual false alarm reduction model is designed to reduce the possible false detections using the knowledge obtained from training samples. The Bayesian and Dempster-Shafer decision fusion techniques are applied to further improve the threat classification accuracy. The performance of the proposed system has been evaluated using both available datasets and extensive experiments. Its advantages include energy efficiency, reliable detection and classification, low detection and classification latency, reduced false alarms, and efficient bandwidth utilization.

6538-45, Session 10

Seismic refraction tomography for detecting shallow buried pipes

C. J. Hickey, W. B. Howard, L. Duddu, The Univ. of Mississippi

Seismic technology has been used for quite some time to interrogate the subsurface from tens to hundreds of meters with applications to groundwater resource management, geoenvironmental issues, and civil

engineering problems. Active acoustic/seismic interrogation of the first meter of the soil is also a proven technology for UXO and landmine detection. Seismic techniques are based upon the propagation of small amplitude mechanical waves. Seismic methods detect anomalous zones in mechanical properties (bulk and shear stiffness/compliance) and densities within the subsurface because these properties control the velocity, attenuation, and impedance of the seismic waves. For the problem of pipe detection, the mechanical and density anomalies associated with the presence of a pipe are immense. The density contrast of an air-filled void within the ground is likely larger than any other natural physical situation that exists in the subsurface. Although the elastic compliance and density contrasts between a pipe and the surrounding material are high, seismic techniques have not been extensively used. Two reasons are: 1) the pipe diameter is relatively small compared to the spatial sampling and averaging from typical seismic surveys and 2) the surrounding soil is highly heterogeneous with respect to its mechanical properties. This presentation will discuss the use of seismic refraction tomography for locating buried pipes. Data from several field sites containing pipes at different depths will be presented.

6538-46, Session 10

Acoustic leak-detection system for railroad transportation security

P. C. Womble, A. P. Barzilov, D. Harper, Western Kentucky Univ.; M. A. F. Harrison, Institute for Scientific Research, Inc.; L. Hopper, E. Houchins, Western Kentucky Univ.; B. Lemoff, R. Martin, Institute for Scientific Research, Inc.; C. McGrath, R. Moore, I. Novikov, J. Paschal, Western Kentucky Univ.; S. C. Rogers, J. F. Spadaro, Institute for Scientific Research, Inc.

Pressurized rail tank cars transport large volumes of volatile liquids and gases throughout the country, much of which is hazardous and/or flammable. These gases, once released in the atmosphere, can wreak havoc with the environment and local populations. We developed a system which can non-intrusively and non-invasively detect and locate pinhole-sized leaks in pressurized rail tank cars using acoustic sensors. The sound waves from a leak are produced by turbulence from the gas leaking to the atmosphere. For example, a 500 mm hole in an air tank pressurized to 689 kPa produces a broad audio frequency spectrum with a peak near 40 kHz. This signal is detectable at 10 meters with a sound pressure level of 25 dB. We are able to locate a leak source using triangulation techniques. The prototype of the system consists of a network of acoustic sensors and is located approximately 10 meters from the center of the rail-line. The prototype has two types of acoustic sensors, each with different narrow frequency response band: 40 kHz and 80 kHz. The prototype is connected to the Internet using WiFi (802.11g) transceiver and can be remotely operated from anywhere in the world. The paper discusses the construction, operation and performance of the system.

6538-47, Session 10

Piezoelectric micromachined ultrasonic transducers with rectangular diaphragms for dual-frequency reception

C. Chao, The Hong Kong Polytechnic Univ. (Hong Kong China)

Piezoelectric micromachined ultrasonic transducer (pMUT) consists of a piezoelectric capacitor built on a micromachined silicon membrane, and usually exploits its flexural vibration mode for ultrasound transmitting and sensing. It typically operates at the fundamental frequency, where maximum sensitivity can be achieved, and is insensitive at higher order of resonances because the harmonic signals generated from different parts of the diaphragm tend to cancel with each other. This leads to a very narrow bandwidth. In this paper, rectangular-shaped pMUTs for dual-frequency reception are proposed and fabricated by using piezoelectric P(VDF-TrFE) copolymer coating and silicon micromachining technologies. The electrode patterns are properly designed to efficiently make use of both (0, 0) and (0, 2) vibration modes of the rectangular membrane. By adjusting the length and width of the diaphragm, the ratio of the two frequencies can be varied on demand within a wide range. The micromachined dual-frequency sensors will be useful for miniaturized ultrasonic systems operating on binary frequency shift-keyed (BFSK) principles, such as precise distance detectors and ultrasonic local-area communication terminals.

6538-48, Session 10

ATDR-based tomographic optical sonar (ATOS)

R. M. Kurtz, R. D. Pradhan, K. Chua, Y. Yang, J. Piranian, G. Fathi, T. R. Forrester, T. P. Jannson, Physical Optics Corp.

We previously reported on a new photorefractive phenomenon we call high-speed photorefractivity. We have studied this effect and predict the amplification bandwidth of this effect, demonstrating that it is sufficient for detection of ultrasonic signals. This has been integrated into a new system that uses acoustic time-domain reflectometry (ATDR) to create an optical sonar system. An array of these optical sonars can be used tomographically to find and partially characterize buried objects or image through the wall. A preliminary implementation of ATOS was used to determine the composition of solid objects, to measure the amount and location of modeled plastic explosive in a sealed box, and to recognize modeled plastic explosives packed in the cavity of a car door.

6538-49, Session 10

A new clustering strategy

J. Feng, J. Tang, G. Wang, Northeastern Univ. (China)

On the basis of the analysis of clustering algorithm that had been proposed for MANET (mobile ad-hoc net), a novel clustering strategy was proposed in this paper. In this strategy, the trust was defined by statistical hypothesis in probability theory and the cluster head was selected by node trust and node mobility. A series of simulation experiments were made for this strategy and the results showed that this strategy can realize the function of the malicious nodes detection which was neglected by other clustering algorithms and overcome the deficiency of being incapable of implementing the relative mobility metric of corresponding nodes in other MOBIC algorithms. It's an effective solution to partitioning MANET securely.

6538-50, Session 10

Development of a mechanically coupled 6-axis force-torque sensor

T. Noh, W. Yoo, Pusan National Univ. (South Korea)

For better moving performance of robots, the measure of force data from the ground is inevitable. The traditional and basic tool for force measurement is to use a force-torque sensor. A 6-axis force-torque sensor can measure all direction's force data, 3 forces and 3 torques applied to the body. This paper describes mechanically coupled design of a 6-axis force-torque sensor using strain gauges especially. In mechanically coupled sensors, force data can not be obtained directly from strain signals. Instead output data should be calculated through a additional matrix calculation. Here we suggested a new design method of a small size 6-axis force-torque sensor module. In this paper, we proposed design guide of the sensor's structure design, amplitude circuit, and details for the data acquisition board.

6538-51, Session 11

Early attack reaction sensor (EARS): a man-wearable gunshot

L. B. Thier, U.S. Army Armament Research, Development and Engineering Ctr.

The Early Attack Reaction Sensor (EARS) is a passive acoustic sensing system that detects gunshots (muzzle blast and/or shockwave) to provide relative azimuth and range information of the shot origin to the

user via audio alert and visual display. The EARS consists of a small microphone array and Digital Signal Processing board packaged for various platform-independent applications including man-wearable. The EARS has been tested in both open field and military operations in urban terrain (MOUT) environment and has provided useable bearing and range information against the firing positions. This paper will describe the EARS system and test results.

6538-52, Session 11

Acoustical model of small caliber ballistic shock waves in air for automatic sniper localization applications

J. R. Aguilar, R. A. Salinas, Univ. de Santiago de Chile (Chile); M. A. Abidi, The Univ. of Tennessee

The phenomenon of ballistic shock wave emission by a small calibre projectile at supersonic speed is quite relevant in automatic sniper localization applications. When available, ballistic shock wave analysis makes possible the estimation of the main ballistic features of a gun fire event. The propagation of ballistic shock waves in air is a process which mainly involves nonlinear distortion, or steepening, and atmospheric absorption. Current ballistic shock wave propagation models used in automatic sniper localization systems only consider nonlinear distortion effects. This means that only the rates of change of shock peak pressure and the N-wave length with distance are considered in the determination of the miss distance. In the present paper we present an improved acoustical model of small calibre ballistic shock wave propagation in air, intended to be used in acoustics-based automatic sniper localization applications. In our approach, we have considered nonlinear distortion, but additionally we have also introduced the effects of atmospheric sound absorption. Atmospheric absorption is implemented in the time domain in order to get faster calculation times than those computed in the frequency domain. Furthermore, we take advantage of the fact that atmospheric absorption plays a fundamental role in the rise times of the shocks, and introduce the rate of change of the rise time with distance as a third parameter to be used in the determination of the miss distance. This leads us to a more accurate and robust estimation of the miss distance, and consequently of the projectile trajectory, and the spatial coordinates of the gunshot origin.

6538-53, Session 11

Time difference of arrival blast localization using a network of disposable sensors

R. A. Knobler, T. J. Plummer, McQ, Inc.

Determining the location of an explosive event using a networked sensor system within an acceptable accuracy is a challenging problem. McQ has developed such a system, using a mesh network of inexpensive acoustic sensors. The system performs a three-dimensional, time-difference-of-arrival (TDOA) localization of blasts of various yields in several different environments. Localization information of the blast is provided to the end user by exfiltration over satellite communications. The system is able to perform accurately in the presence of various sources of error including GPS position, propagation effects, temperature, and error in determining the time of arrival (TOA). The system design as well as its performance will be presented.

6538-54, Session 11

Search-matching algorithm for acoustics-based automatic sniper localization

J. R. Aguilar, R. A. Salinas, Univ. de Santiago de Chile (Chile); M. A. Abidi, The Univ. of Tennessee

Most modern automatic sniper localization systems are based on the utilization of the acoustical emissions produced by the gun fire events. In order to estimate the spatial coordinates of the sniper location, these systems measure the time delay of arrival of the acoustical shock wave fronts to a microphone array. Furthermore, model based estimation of the nonlinear distortion parameters of the N-waves is used to make projectile trajectory and calibre estimations. In this work, we address the sniper localization problem using a model based search-matching approach. The automatic sniper localization algorithm works searching for the acoustics model of ballistic shock waves which best matches the measured data. For this purpose, we implement a previously released acoustics model of ballistic shock waves. Moreover, the sniper location, the projectile trajectory and calibre, as well as the muzzle velocity are regarded as the input variables of such a model. A search algorithm is implemented in order to find what combination of the input variables minimizes a fitness function defined as the Euclidean distance between measured and simulated data. In order to evaluate the performance of the algorithm, we conduct computer-based experiments using simulated gunfire event data calculated at the nodes of a virtual distributed sensor network. Preliminary simulation results are quite promising, showing fast convergence of the algorithm and good localization accuracy.

6538-55, Session 11

A strong tracking extended Kalman observer (EKO) for projectile attitude and position estimation

M. Boutayeb, Univ. Louis Pasteur (France); S. Changey, Institut Franco-Allemand de Recherches de Saint-Louis (France); J. Bara, Univ. Louis Pasteur (France)

During the last four decades, state estimation for non linear dynamical systems has the subject of tremendous research activities. A large wide of applications concerns, in particular, the military domain. In this note we focus on projectile attitude and position estimation using magnetometer sensor only. Attitude is usually estimated by complete system with several sensors. According to important biases on rotations sensors, it is essential to use a fix reference such as earth magnetic field. This paper investigates the comparison of the direction of the earth measured on the projectile with the computation of the projection by the estimation of the attitude. According to non linearity of the evolution and the observation model, only a Kalman type observer (namely EKO or EKF in a stochastic context) can be used. However, it is worth to notice that the main drawback of this standard technique is the extreme sensitivity to initialisations or divergence when the system is poorly observable.

In this contribution we analyse convergence behaviour of a simple and useful design procedure used as a state estimator of the projectile attitude and position. Based on our recent works, we show here the connection between some instrumental matrices and the basin of attraction. Furthermore, from the established sufficient conditions for asymptotic convergence we provide a simple way to design such arbitrary matrices in the goal to ensure strong tracking in spite of very bad initialisations and perturbations. High performances of the proposed approach will be shown through simulation results under worst conditions.

6538-56, Session 12

Deployment of laser illuminated CCD cameras as part of an integrated perimeter management system

D. J. Natelson, Vumii Inc.

Perimeter security typically involves layers of detection and investigation. Much has been invested in detection, yet for decades the accepted approach for night-vision investigation beyond 100 meters has been thermal-based sensor systems. Thermal systems are valuable tools; however, they are challenged by low resolution (320x240, 640x480) vs. today's high-res cameras, operator complications, ongoing maintenance costs, and limited video controls. A new technology has been introduced to the market that overcomes these challenges and can improve an existing perimeter management scheme. This presentation will discuss how a highly controllable, semi-covert NIR zoomable laser coupled with a continuously optical zooming CCD camera on a pan tilt platform that produces natural contrast video can be integrated with other sensors. This system sees

through glass, can recognize faces, and read text from over 1000 meters away and provide human recognition at 1000 meters at night, 3000 meters during the day, all using the same device. Software assocatiated with this system can also improve the process of collecting and communicating ground threat intelligence via the use of an active scene panorama and integrated digital GIS mapping. This patent pending technology pixel by pixel links a terrain map with a, up to 359 degree, day panorama, providing unique capabilities such as distance measurement and GPS location estimation w/o the need for range finders.

6538-57, Session 12

Remote Raman sensor system for testing of rocks and minerals

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Recent and future explorations of Mars and lunar surfaces using rovers and landers have spawned great interest in developing an instrument that can perform in-situ analysis of minerals on planetary surfaces. Of several possible techniques for such analysis, Raman spectroscopy is the best suited because it can unambiguously provide the composition and structure of a material. A remote pulsed laser Raman spectroscopy system for analyzing minerals was demonstrated at NASA Langley Research Center in collaboration with the University of Hawaii. This system utilizes a 532 nm pulsed laser as an excitation wavelength, and a telescope with a 4-inch aperture for collecting backscattered radiation. A spectrograph equipped with a super notch filter for attenuating Rayleigh scattering is used to analyze the scattered signal. To form the Raman spectrum, the spectrograph utilizes a holographic transmission grating that simultaneously disperses two spectral tracks on the detector for increased spectral range. The spectrum is recorded on an intensified charge-coupled device (ICCD) camera system, which provides high gain to allow detection of inherently weak Stokes lines. To evaluate the performance of the system, Raman standards such as calcite and naphthalene are analyzed. Several sets of rock and gemstone samples are tested using the Raman spectroscopy system. The results obtained from these analyses are presented.

6538-58, Session 12

Automatic linear feature extraction from lidar and imagery

C. Poullis, S. You, U. Neumann, Univ. of Southern California

Automatic extraction and modeling of linear features, such as transportation and waterways networks, is important for many applications in civilian, intelligence community, military operations. While this problem has been addressed over the years, the gap between the state-of-the-art and goal is still wide. This paper presents a novel technique for automatically detecting and modeling linear features from LIDAR and aerial imagery. Uniquely, the proposed approach is an integrated solution that merges the power of perceptual grouping theory (Tensor Voting, Gabor filtering) and classification with image-cues under a unified framework to address the problems of linear feature detection and classification. Gabor filtering is employed to extract orientation and frequency information, resulting in a multichannel map that contains only features of special interest. A new data representation, called tensorial-representation, is used to represent the data. Such a tensorial-representation is very efficient when dealing with noisy, incomplete and complicated scenes. It's able to not only describe unambiguously varying geometry elements (point, curve, surface) under a unified framework, but also encode considerably richer information of structures. The feature inference is based on a voting communication process that is governed by a perceptual-field, encoding the constraints and rules of how a point receives/casts votes from/to its neighbors. The accumulation of votes at each point provides an accurate estimate of the features going through the point. By combining the voting results for all channels, the extracted features are modeled and classified, and finally converted to vector maps.

6538-60, Session 13

Configuration of electro-optic fire source detection system

R. Z. Fabian, Z. Steiner, N. Hoffman, RAFAEL Armament Development Authority Ltd. (Israel)

The recent fighting activities in various parts of the world highlighted the need for accurate fire source detection on one hand and fast "sensor to shooter cycle" capabilities on the other hand. Both needs can be met by the Spotlite system which dramatically enhances the capability to rapidly engage hostile fire source with a minimum of casualties to friendly force and to innocent bystanders. Modular system design enable to meet each customer specific requirements and enable excellent future growth and upgrade potential.

The design and built of a fire source detection system is governed by sets of requirements issued by the operators. This can be translated into the following design criteria:

I. Long range, fast and accurate fire source detection capability.

II. Different threat detection and classification capability.

III. Threat investigation capability.

IV. Fire source data distribution capability (Location, direction, video image, voice).

V. Men portability.

In order to meet these design criteria, an optimized concept was presented and exercised for the Spotlite system.

Three major modular components were defined:

Electro Optical Unit -Including FLIR camera, CCD camera, Laser Range Finder and Marker

Electronic Unit -including system computer and electronic.

Controller Station Unit - Including the HMI of the system.

This article discusses the system's components definition and optimization processes, and also show how Spotlite designers successfully managed to introduce excellent solutions for other system parameters.

6538-61, Session 13

Novel optical sensor system for missile canisters continuous monitoring

L. Bukshpun, R. D. Pradhan, N. Tun, V. Esterkin, Physical Optics Corp.; G. Tomczyk, Naval Surface Warfare Ctr.

Missile environmental monitoring dramatically increases missile active service life, saving millions of dollars and reducing the number of missiles needed. This requires a high-speed continuous monitoring sensor system that collects and stores data on environmental shock and vibration (up to 100 g)in missile canisters without electrical hazards. We instigated an effort to develop a Fabry-Perot MEMS-based optical sensor system capable to monitor shock and vibration in missile canisters in three dimensions at high speed (5 kHz) using an entirely optical interrogation approach. The system is planned to be used in All-Up-Round (AUR) environmental exposure monitoring system on AEGIS destroyers or cruisers to collect and store vibration, shock, temperature, or damaging events data over the entire lifetime of a missile canister.

6538-62, Session 13

Electro-optical signature analysis for personnel detection in urban environments

J. M. Cathcart, T. Harrell, T. West, Georgia Institute of Technology

Georgia Tech has initiated a research program into the issues surrounding the detection of covert personnel present in a wide variety

of scenarios. This program focuses on a detailed phenomenological analysis of human physiology and signatures with the subsequent identification and characterization of potential observables - particularly in the context of urban environments. For this current effort, several electro-optical sensing modalities have been evaluated for use as a component in an unattended sensor suite designed to detect personnel. These modalities include active sensors (e.g., vibrometry) and passive sensors (e.g., multi-spectral, thermal). Particular emphasis has been given to the exploitation of short wave infrared signatures. This paper will discuss the utility of these various electro-optical signatures in this application, their impact on sensor requirements, and proposed sensor designs that meet the detection objective. A discussion of the utility of electro-optical sensors as components in a multi-modal sensor platform will also be presented.

This work is supported under a grant from the Army Research Office.

6538-63, Session 13

Rayleigh backscatter mitigation by RF modulation in a 100-km remote fiber sensing system

J. H. Chow, D. E. McClelland, M. B. Gray, The Australian National Univ. (Australia)

One of the main factors limiting high performance remote fiber sensing systems is the Rayleigh backscatter associated with a long length of optical delivery fiber. Rayleigh backscatter introduces amplitude and phase noise during interferometric signal extraction, resulting in degradation of system sensitivity. This noise source increases with the length of optical fiber used in the architecture, and thus traditionally sets the lower limit on signal strength and the total remote sensing distance.

We present the latest results for a 100 km remote fiber dynamic strain sensing system, where a radio-frequency (RF) modulated laser is used to interrogate a fiber Fabry-Perot sensor. The signal extraction is derived interferometrically from the differential phase between the carrier and its RF sidebands. We demonstrate unprecedented remote sensitivity performance by complete mitigation of the debilitating effects associated with Rayleigh backscatter in the 100 km of optical delivery fiber. We show that optimization of the laser modulation depth, as well as fiber Fabry-Perot design both facilitate a large signal-to-noise ratio. This maximized signal-to-noise ratio enables the complete suppression of the noise associated with Rayleigh backscatter. The result is a long-distance remote fiber sensing system that is limited only by the laser frequency noise. This remote sensitivity is an important breakthrough for a range of applications, such as sea floor acoustic sensing arrays, deep sea hydrophone arrays, and remote surveillance arrays.

6538-64, Session 13

Hot embossing of LCP using silicon master tool for short-distance optical interconnects

K. Yadav, S. R. Kirkpatrick, A. Siahmakoun, Rose-Hulman Institute of Technology

A novel method has been developed for manufacturing of chip-to-chip optical interconnects for high-speed data transmission in hybrid printed circuit board (PCB). The method includes wet etch of a (100) silicon wafer using previously discovered anisotropic etching techniques for 45 * and vertical walls. Anisotropically etched surfaces produce a master tool for hot-embossing of the liquid crystal polymer (LCP) substrate. The LCP channels are filled with core-cladding polymers or coated with a reflecting thin film to form optical waveguides for circuit board level short distance optical interconnects. Various waveguide devices such as STAR, Y-splitters, and straight line channels of different lengths are structured onto the silicon substrate. A detailed process flow has been developed which realizes 45o surfaces at the entry and exit positions of the waveguide devices for vertical light coupling. The vertical walls along the length of the waveguide devices are etched to minimize the propagation losses. The angle of the splitters is limited by chemical etching hence all the straight channels, 2 and 4 cm long, except the splitters are observed to transmit the light in free-space from one end to the other. These hot-embossed channels in LCP are sputtered with aluminum after the embossing. The free-space light transmission has also been observed in an 8cm long, 200 μm wide, and 60 μm deep channel of the embossed LCP substrate. We will present the complete process flow explaining the fundamental technique including the hot embossing process with silicon master tool to imprint the waveguide structures onto LCP substrate.

6538-65, Session 14

Real-time air quality monitoring by using internet video surveillance camera

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, Univ. Sains Malaysia (Malaysia)

Nowadays internet video surveillance cameras are widely use in security monitoring. The quantities of installations of these cameras also become more and more. This paper reports that the internet video surveillance cameras can be applied as a remote sensor for monitoring the concentrations of particulate matter less than 10 micron (PM10), so that real time air quality can be monitored at multi location simultaneously. An algorithm was developed based on the regression analysis of relationship between the measured reflectance and the reflected components from a surface material and the atmosphere. This algorithm converts multispectral image pixel values acquired from these cameras into quantitative values of the concentrations of PM10. These computed PM10 values were compared to other standard values measured by a DustTrakTM meter. The correlation results showed that the newly develop algorithm produced a high degree of accuracy as indicated by high correlation coefficient (R2) and low root-mean-square-error (RMS). The preliminary results showed that the accuracy produced by this internet video surveillance camera is better than an internet protocol (IP) camera. Basically the quality of images acquired by the IP camera was poorer compared to the internet video surveillance camera. This is because the images acquired by IP camera had been compressed and there is no compression for the images from the internet video surveillance camera.

6538-66, Session 14

Animal eyes in homeland security systems

A. A. Kostrzewski, M. Gertsenshteyn, V. Grubsky, P. I. Schnitser, I. P. Agurok, M. J. Bennahmias, T. P. Jannson, Physical Optics Corp.

In this paper, various biologically-inspired optical imaging systems are discussed, including fish eye, bug eye, and lobster eye, as new lensing systems for military and homeland security applications. The areas of interest include: UV, VIS, IR, and x-ray part of the electromagnetic spectrum. In particular, recent progress at Physical Optics Corp. (POC) will be discussed, including such applications as hyperspectral/multi-spectral imagery, video surveillance, x-ray inspection, etc.

6538-67, Session 14

24/7 security system: 60-FPS color EMCCD camera with integral human recognition

T. L. Vogelsong, Salvador Imaging; T. E. Boult, Securics, Inc. and Univ. of Colorado/Colorado Springs; D. W. Gardner, Salvador Imaging; R. Woodworth, Securics, Inc.; R. C. Johnson, B. Heflin, Univ. of Colorado/Colorado Springs

An advanced surveillance/security system has been demonstrated for unattended 24/7 image acquisition and automated detection, discrimination, and tracking of humans and vehicles. The day/night video camera incorporates an electron multiplying CCD sensor with a programmable on-chip gain of 1000:1, providing effective noise levels of less than 1 electron. The EMCCD camera operates in full color mode under sunlit and moonlit conditions, and monochrome under quarter-moonlight to overcast starlight illumination. AGC operation ensures optimum image quality across an inter-scene dynamic range of over 10,000,000:1. Sixty frame per second operation and progressive scanning minimizes motion artifacts. Real time image processing including color processing, spatial and temporal filtering optimizes the images for display and for automated detection, discrimination, and tracking.

The acquired image sequences are processed with FPGA-compatible real-time algorithms to detect/localize/track targets and reject non-targets under a broad range of illumination conditions and viewing angles. The object detectors are trained from data, and detectors have been developed and demonstrated for faces, upright humans, crawling humans, large animals, cars and trucks. The camera has been used with real-time software for detection and tracking of targets too small for template-based detection and for general scene surveillance of unknown objects. For face and vehicle targets the results of the detection are passed to secondary processing to extract recognition templates, which are then compared with a database for identification. When combined with a PTZ, the resulting system provides a reliable wide-area 24/7 surveillance system that avoids the high life-cycle cost of infrared cameras and image intensifiers.

6538-68, Session 14

Ultra-real-time video processing and compression in homeland security applications

A. A. Kostrzewski, S. Ro, W. Wang, T. P. Jannson, Physical Optics Corp.

In this paper, Real-time (RT) and Ultra-real-time (URT) video processing and compression techniques are discussed, for military and homeland security applications. This includes such pre-ATR, or image segmentation techniques, that operate in milisecond and sub-milisecond scale, based on highly-parallel computing hardware. In particular, recent progress at Physical Optics Corporation (POC)is reviewed, including Pre-ATR, Multi-faced Inhomogeneous Compression (MIC), Morphing Compression, and other inter-frame and intra-frame video compression methods.

6538-69, Session 14

High-speed high-resolution imagers for aerial reconnaissance

K. L. Boggs, R. Bredthauer, Semiconductor Technology Associates Inc.

A 100-M pixel, 92x92 mm2, full-frame CCD imager with 9x9 um2 pixel size was developed for use in professional applications. Recent interest for ultra-high resolution imagers for electronic imaging OEM customers in various scientific markets, including biotechnology, microscopy, crystallography, astronomy, spectroscopy, and aerial reconnaissance markets lead to the development of the STA1600A 111-M pixel monochromatic charge-coupled device. Innovative design techniques were utilized in the early development of this device, yielding low RMS noise and high MTF for readout speeds ranging from 1 Mpixel/s to 10 Mpixel/sec. This paper will provide detailed information on the previously developed high-speed imagers, the design and performance capabilities of the STA1600A, as well as background information on the military uses for this device.

6538-70, Session 14

Evolution of surveillance: 2001 to present

G. L. Francisco, L-3 Communications Infrared Products; K. LaFleur, M/C/C, Inc.

In the years since the terrorist attacks on September 11, the ways in which we approach security and surveillance have changed dramatically. Security personnel have chosen to utilize new technologies to enhance existing systems for greater protection - chief among them, thermal imaging. Advances in thermal imaging-particularly its ability to integrate with other technologies for security - means the technology offers a complete solution for enhanced security. When used together, powerful technologies provide complementary services from image detection through to control room decision making and can be thought of as stepping blocks in creating a highly-effective security system. By integrating the highest standard technologies at each step, the complete system is the most powerful addition to security systems.

This presentation will discuss the applications and advancements of thermal imaging technology. Speaker Glen Francisco will present different surveillance techniques and offer an explanation of how they have been enhanced with thermal imaging.

6538-71, Session 14

Aerial video reconnaissance using large sensor arrays

D. B. Pollock, The Univ. of Alabama/Huntsville; G. Egnal, Argusight, Inc.; R. Klepfer, P. J. Reardon, T. Rogers, C. N. Underwood, The Univ. of Alabama/Huntsville; B. Wilburn, Argusight, Inc.

Initial instrumentation has experimentally demonstrated the feasibility of a camera operated in an Un-manned Aerial Vehicle at a 7.6 km (25 kft) altitude that acquires 5 frame per second images with a 0.5 m sample size over a 10 x 10 km scene using \>1 giga-pixels for a many hour period. An initial camera capability of 0.4 m sample size of a 0.8 x 0.8 km scene with a camera having 4 mega pixels operated at 6 km (18 kft) verified the image quality performance, primarily built with COTS components. A subsequent test flight with a 28 mega-pixel camera, still with COTS components, validated the ability to pan-tilt and zoom digitally. The concept is expandable to \>1 giga-pixel, and size, weight, power and cost considerations are discussed briefly.

6538-72, Session 15

Infrared and visible combat identification marking materials

E. S. O'Keefe, A. J. Butler, A. J. Shohet, M. Swan, QinetiQ Ltd. (United Kingdom)

Historically, it is believed that fratricide accounts for up to 15% of friendly casualties during operations and a UK MoD report identifies that almost half of all such casualties occur in situations involving ground units only. Such risks can be mitigated, to an extent, via operational awareness and effective communications. However, recent conflicts have involved a much more dynamic, complex and technically sophisticated battlefield than previously experienced, for example, Operation Telic (Desert Storm) with almost one million combatants and ten thousand armoured vehicles in the coalition force advancing across an extensive battlefront at high speed during daylight and at night making effective use of a range of electro-optic sensors. The accelerated tempo of battle means that front lines can undergo rapid, punctuated, advance that can leave individual combat units with a much degraded situational awareness, particularly of where they are in relation to other 'friendly' combatants. Consequently there is a need for a robust, low cost, low weight, compact, unpowered, interoperable, Combat Identification technique for use with popular electro-optic sensors which can be deployed, and is effective, at the individual combat unit level. In this paper we discuss ground-to-ground combat identification materials that meet these requirements based on the air-to-ground Mirage(tm) vehicle marking material. We show some preliminary ground-to-ground and air-to-ground data collected in recent experimental trials of the new variant Mirage(tm) material conducted during the day, evening and at night.

6538-73, Session 15

Infrared remote sensing of hazardous vapors: surveillance of public areas during the Soccer World Cup 2006

R. Harig, Technische Univ. Hamburg-Harburg (Germany)

The German ministry of the interior, represented by the civil defense agency BBK, has established analytical task forces for the analysis of released chemicals in the case of fires, chemical accidents, or terrorist attacks. One of the first assignments of these task forces was the provision of analytical services during the soccer world cup 2006. One part of the equipment of these emergency response forces is a remote sensing system that allows the identification and visualization of hazardous clouds from long distances, the scanning infrared gas imaging system SIGIS 2. The system is based on an interferometer with a single detector element in combination with a telescope and a synchronized scanning mirror. The system allows 360° surveillance. For simple interpretation of the results, the system is equipped with a video camera and the results of the analyses of the spectra are displayed by an overlay of a false color image on the video image. This allows a simple evaluation of the position and the size of a cloud. The system was applied for surveillance of stadiums and public viewing areas, where large crowds watched the games. The system, the data analysis method, and measurement results are presented.

6538-74, Session 15

Critical infrastructure security confidence through automated thermal imaging

G. L. Francisco, L-3 Communications Infrared Products

With terrorist threats continuing to be a top concern at critical infrastructure sites, a complete detection, management, and control system is imperative for providing the confidence that each site has put the appropriate measures in place to prevent unthinkable disasters from occurring.

When used together, powerful technologies provide complementary services from image detection through to control room decision making and can be thought of as stepping stones in creating a highly-effective security system. By integrating the highest standard technologies at each step, the complete system is the most powerful addition to security systems.

Thermal imaging is unsurpassed at detecting intruders in the dark of night and in challenging weather conditions at the sensor imaging level. Automated software detection creates an initial alert. Immersive 3D visual assessment is used for situational awareness and to manage the reaction process. Wide area command and control capabilities allow control from a remote location.

6538-75, Session 15

Improved night vision demonstrator program results

W. Robinson, T. L. Haran, D. Roberts, J. C. James, J. M. Cathcart, K. Lyons, T. Wasilewski, L. West, Georgia Institute of Technology

Although existing night vision equipment provides a significant improvement in target detection in low light conditions, there are several limitations that limit their effectiveness. Focus is a significant problem for night vision equipment due to the low f-number optics required to obtain sufficient sensitivity as well as the dynamic nature of night vision applications, which requires frequent focus adjustments. In addition, digital low light detectors have not yet matured sufficiently to replace the Gen III direct view sensors used in existing sensors such as the AN/PVS-14. The Georgia Tech Research Institute has developed a prototype next-generation night vision device called the Improved Night Vision Demonstrator (INVD) under a contract with the United States Marine Corps in order to address these shortfalls. This paper will describe the design of the INVD system as well as an analysis of its performance. The human factor issues as well as the design trades required for advanced night vision devices will also be discussed.

6538-76, Session 15

Toward single-photon imaging for defense applications

S. Vasile, aPeak

Efficient, single-photon imaging in the visible and infrared providing short exposure time and large area for increased photon utilization at the output aperture of the optical system would enhance the quality of observations in new applications such as 3-D imaging, free space optical communications, and hypertemporal imaging.

The Geiger photodiode (GPD) array technology has recently proved superior advantages for applications requiring high timing resolution and fast imaging of transient events. The detection process in Geiger mode, as compared to CCD and APS sensors, is practically instantaneous (few ns) even for extremely low light levels and its timing resolution could reach 100-200ps, thus allowing the detection of fast photon signals with superior timing resolution.

We present our latest progress on single-photon counting detector array development, detectors performance, and specifications relevant to a wide palette of applications, ranging from 3D imaging to the detection of concealed radiation sources.

6538-77, Session 16

CBRN Crime Scene Modeler (C2SM)

P. Jasiobedzki, MacDonald, Dettwiler and Associates Ltd. (Canada)

Investigating crime scenes where Chemical, Biological, Radiological and Nuclear (CBRN) agents have been deployed poses great dangers to first responders. RN contaminated crime scenes present the most difficult challenges of all, where personal protection is next to impossible to achieve. Any prior decontamination of a crime scene may result in destruction of potentially vital evidence. Technologies that reduce the need to enter the scene or to reduce exposure of first responders are essential.

In this paper we describe an on going project that is developing a CBRN Crime Scene Modeler (C2SM), a 3D modeling system for CBRN contaminated scenes. The system processes images from mobile stereo cameras and creates photorealistic 3D models of the environment. The models are augmented with information from CBRN sensors: gamma, chemical and an infra red camera.

C2SM operates either or as a hand-held device or in an automated mode. In the hand-held mode, the operator uses the system similarly to a video camera to acquire the images and data. In the automated mode, C2SM operates on board of a mobile platform and is controlled remotely from an operator station. The data is processed in an embedded computer and models are available within minutes. The multi-modal models are visualized in 3D and may be augmented with annotations and additional information. All this information is stored in an event database and transferred to a command centre.

The project involves members from Canadian first responder community, industry and academia, and funded by CBRN Research Technology Initiative (CRTI). C2SM system will be tested in field trials and final prototypes will be delivered to the first responders.

6538-78, Session 16

Enhanced Raman scattering of nitro-explosives on nanoparticles substrates: Ag and Au colloids and Au-Ag alloys

J. I. Jerez-Rozo, S. P. Hernández-Rivera, A. M. Chamoun, Univ. de Puerto Rico Mayagüez

Surface Enhanced Raman Scattering (SERS) combines extremely high sensitivity, due to enhanced Raman cross-sections comparable or even better than fluorescence, with the observation of vibrational spectra of adsorbed species, providing one of the most incisive analytical methods for chemical and biochemical detection and analysis. Nanoparticles, which often are the principal players in SERS are of fundamental interest since they possess unique size-dependent properties optical and chemical, which are quite different from the bulk and the atomic state. The focus of this study was to modify silver and gold colloids by using variations in pH, concentration of the reducing agent and temperature. The nanoparticles used in this work were characterized using techniques such as UV-VIS spectrophotometry and Scanning Electron Microscopy (SEM). The nanoparticles colloidal suspensions were developed for the identification of trace amounts of nitroexplosives with detection limits down femtomolar concentrations.

TNT SERS spectra were excited VIS and near infrared (NIR) wavelengths of 532 and 785 nm. The SERS spectra were obtained in the 100-3500 cm-1 range.

6538-79, Session 16

Effects of isotopic substitution on the vibrational spectra of RDX

R. Infante-Castillo, S. P. Hernández-Rivera, Univ. de Puerto Rico Mayagüez

The cyclic nitramine hexahydro-1,3,5-trinitro-s-triazine, commonly known as RDX exists in two polymorphic forms known as α and β. RDX molecules adopts C3v symmetry in the vapor, solution, and β-solid phases, in contrast to stable α-RDX solid phase which has close to Cs symmetry. Infrared and Raman spectra in solid state and solution of RDX and of 13C, 15N (on ring) and fully 15N enriched RDX analogues have been recorded and their fundamental frequencies have been assigned using isotopic frequency shifts. Chemical calculations applying ab initio Density Functional Theory (DFT) have been carried out for the three RDX isotopomers at the 6-311G** basis set level and the computed vibrational frequencies have been compared with the experimental ones. The calculated isotopic frequency shifts, induced by 13C and 15N labeling are in very good accordance with measured ones. The changes in vibrational modes associate with the isotopic substitutions are well modeled by the calculation and previous assignments of the vibrational spectra are revised especially where the exact nature of the vibrational modes had been either vague or contradictory.

6538-80, Session 16

Surface enhanced Raman scattering of TNT on colloidal nanoparticles of Ag/TiO2

E. De La Cruz-Montoya, S. P. Hernández-Rivera, T. Luna-Pineda, G. Pérez-Acosta, Univ. de Puerto Rico Mayagüez

Silver nanoparticles coated with titanium dioxide were synthesized via a simple route, where the reduction of Ag+ to Ag0 and the controlled polymerization of TiO2 on the surface of silver crystallites take place simultaneously. The nanoparticles prepared were characterized by UV-VIS absorption and by Energy Dispersive X-ray spectroscopy (EDAX). The spectrum of the suspension of Ag nanoparticles had a maximum absorption at 420 nm arising from the surface plasmon of the particles, in which is characteristic of Ag colloidal dispersion. Similar surface plasmon absorption due to Ag nanoparticles was observed for the suspension of Titania-coated Ag nanoparticles at longer wavelength (red-shifted) than for the suspension of Ag nanoparticles. This absorption shift is caused by refractive index changes due to Titania and suggests coverage of Ag nanoparticles with Titania. Ag/TiO2 colloids were used to measure Raman spectra by capillary tube method at different excitation sources to observe the enhancement of the Raman signatures of solutions of TNT at different pH. At pH = 10.3 showed an increase of the NO2 stretching mode at the 1365 cm-1 in comparison with the other pH values and the solution without colloids. In addition, the bands ca. 1213 cm-1 and * NO2 (1360 cm-1) are slightly shifted to higher wavenumbers, indicating a strong adsorbate-surface interaction.

6538-81, Session 16

Characterization of thermal conductivity of liquids through a metallic skin

M. L. Ramirez, S. P. Hernández-Rivera, O. Ruiz, L. Pacheco-Londoño, Univ. de Puerto Rico Mayagüez

According to recent reports the bombing attempt to a London-US airline and world safety involved the use of liquids to create an explosive mixture. This improvised explosive device (IED) is undetected by current airport safety technologies and could be activated during flight. This revealed a new modality and vulnerability of transportation security systems: the use of liquid explosives based devices. Most methods to detect explosive liquids are based of spectroscopic methods and they are not effective characterizing liquids in a thick glass bottle and/or liquids concealed in cans. An alternative for detection in this scenario can be thermal conductivity. Thermal conductivity is based in an interfacial heat reflectance device which contacts a constant current heat source to the powder sample. The temperature of the interface is monitored and the rate of temperature rise is then related to the thermal conductivity of the unknown sample. Higher thermal conductivity samples produce a lower rate of temperature rise because the heat is being conducted away from the interface. Measurements of thermal conductivity through a common aluminum soda can make it possible to discriminate materials that have different thermal conductivity behavior. This technique has the potential use as an airport safety detector for hazardous liquids that have different thermal conductivity properties from soda formulations. The technology can be employed to find hidden liquids in soda cans.

6538-82, Session 16

Characterization and differentiation of high-energy amine peroxides by direct analysis in real-time-TOF

A. J. Peña-Quevedo, S. P. Hernández-Rivera, N. Mina, Univ. de Puerto Rico Mayagüez

Characterization of hexamethelene triperoxide diamine (HMTD), tetramethylene diperoxide dicarbamide (TMDD) and tetramethylene diperoxide acetamide (TMDA) using Direct Analysis in Real Time (DART) Time of Flight (TOF) Mass Spectrometry. The study also centered in the detection of their precursors such as hexamine and formaldehyde in an attempt to prevent any attempts of in situ syntheses in mass transportation media. Analysis of the compounds by GC-MS was also conducted. HMTD shows a clear peak of 209 m/z that allowed its detection in standard solutions and lab made standards. TATP samples with deuterium enrichment were also analyzed to compare results that could differentiate from HMTD and similar substances such as sugar, talc and cosmetics. All samples were characterized by Raman and FT-IR to confirm the DART results. Some of the vibrations observed were in the υ(O-O), υ(N-C), υ(N-H), υ(C-O), δ(CH3-C) and δ(C-O). Methods developed for trace detection of these compounds were compared to GC/MS and HPLC-MS results previously reported for HMTD and TATP.

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6539-02, Session 1

Performance analysis of three-dimensional ridge acquisition from live finger and palm surface scans

L. G. Hassebrook, D. L. Lau, V. Yalla, A. Fatehpuria, Q. Lao, Univ. of Kentucky

A new area of fingerprint technology, known as “3D fingerprinting” uses non-contact methods to map 2-Dimensional texture images onto a 3-Dimensional surface in the shape of a finger. Performing this “nail to nail” mapping gives what is analogous to “fingerprint DNA” to law enforcement. Our group has taken this a step further in that we do not map 2-D texture images, but instead, directly measure and capture the ridge heights. The texture information is simultaneously captured during this process. We do this using a well known approach of Structured Light Illumination. We have implemented two prototype systems, one for finger print and one for palm print. Our long term goal is to scan the entire hand but for this paper we will evaluate the performance of the finger and palm prints separately. We will focus on answering two questions: (1) How should the 3-D data be prepared for optimum mapping into existing 2-Dimensional “rolled” fingerprint data bases? And (2) how can the ridge depth information be optimally used to recover a representation of a latent finger or palm print? Subtopics within these questions are the affects of lateral and depth resolution, measurement accuracy, affects of hand movement during scanning period and affects of interlacing multiple scan patches to achieve wrap around or rolled equivalent data. We will study these issues in terms of NIST/FBI standards as well as standard signal processing performance measures.

6539-03, Session 1

Robust fingerprint acquisition

R. K. Rowe, K. A. Nixon, S. Parthasaradhi, U. Uludag, Lumidigm, Inc.

A comparative study on multiple participants was undertaken to quantify the ability of a multispectral imaging (MSI) fingerprint sensor to perform reliable biometric matching in the presence of sampling influences that included finger wetness, dirt, chalk, acetone, bright ambient light, high pressure and low pressure sampling conditions. The study was conducted in conjunction with three commercially available total internal reflectance (TIR) sensors run in parallel under identical sampling conditions. Representative images as well as receiver operating characteristic (ROC) curves demonstrate the ability of the MSI sensor to collect usable images under conditions in which the performance of the other optical sensors degrade or even cease to operate. In addition, results are presented that demonstrate the interoperability of MSI images with images collected by these other optical sensors.

6539-27, Session 1

Three-dimensional surface reconstruction and recognition

D. J. Bardsley, B. Li, The Univ. of Nottingham (United Kingdom)

In this paper we propose a novel 3D face recognition system. Furthermore we propose and discuss the development of a 3D reconstruction system designed specifically for the purpose of face recognition. The reconstruction subsystem utilises a capture rig comprising of six cameras to obtain two independent stereo pairs of the subject face during a structured light projection with the remaining two cameras obtaining texture data under normal lighting conditions. Whilst the most common approaches to 3D reconstruction use least square comparison of image intensity values, our system achieves dense point matching using Gabor Wavelets as the primary correspondence measure. The matching process is aided by Voronoi segmentation of the input images using strong confidence correlations as Voronoi seeds. Additional matches are then propagated outwards from the initial seed matches to produce a dense point cloud and surface model. Within the recognition subsystem models are first registered to a generic head model, and then a novel similarity metric based on modified ICP (Iterative Closest Point) is applied between the recognition subject and each model in the comparison database, using alignment error as the recognition metric. Our system takes full advantage of the additional information obtained from the shape and structure of the face, thus combating some of the inherent weaknesses of traditional 2D methods such as pose and illumination variations. This novel reconstruction / recognition process shows competitive recognition rates on databases of 150 subjects.

6539-04, Session 2

Quality dependent fusion of intramodal and multimodal biometric experts

J. Kittler, Univ. of Surrey (United Kingdom)

No abstract available

6539-05, Session 3

Classification of handwritten signatures based on name legibility

J. Galbally-Herrero, J. Fierrez-Aguilar, J. Ortega-Garcia, Univ. Autónoma de Madrid (Spain)

Thanks to its common use in many different applications, handwritten signature is one of the most widely accepted authentication methods. It covers to some extent all of the main characteristics of a biometric trait (i.e., universality, distinctiveness, permanence and collectability so it is feasible to develop automatic recognition systems based on it.

Automatic signature verification systems have been shown to be sensitive in some degree to signature complexity. Recognition rates of some systems drop when coping with easy to forge signatures which are normally the readable ones. Therefore an automatic classification scheme to separate between legible and non-legible signatures would be desirable in order to improve the general performance of the verification system. In this case two different recognition strategies could be applied for legible and non-legible signatures thus maximizing the overall recognition rate.

From a privacy point of view, signatures in which the name of the signer is readable could involve a special treatment to protect the identity of the signer. From this perspective, an automatic legibility classification system would be relevant in order to adopt different measures for each signature depending on the specific legal guidelines for privacy protection of each country.

In this work an automatic classification scheme of on-line handwritten signatures will be presented using a Multilayer Perceptron (MLP) with a hidden layer as classifier. Two different signature classes will be considered, namely: legible and non-legible name. Experimental results will be given on the MCYT signature database comprising 330 signers.

6539-06, Session 3

A new approach to hand-based authentication system

G. Amayeh, G. N. Bebis, A. Erol, M. Nicolescu, Univ. of Nevada/ Reno

Hand-based authentication is a key biometric technology with a wide range of potential applications both in industry and government. The focus of this work is on improving the ease of use and accuracy of hand-based authentication systems. Specifically, we employ high-order Zernike moments to represent the segmented parts of the hand silhouette including the palm and the fingers. Segmentation allows us to compensate for finger motion more effectively compared to the initial

version of this system that uses Zernike moments of the whole hand. Due to the rotation and translation invariance of the descriptors, the similarity between the query and the template is computed efficiently using Euclidean distance. The proposed hand-based authentication system has been tested on a database of 1000 images from 100 subjects illustrating promising performance. Qualitative comparisons with state of the art systems illustrate that the proposed system has comparable or better performance.

6539-07, Session 4

Using support vector machines to eliminate false minutiae matches during fingerprint verification

P. Mansukhani, S. Tulyakov, V. Govindaraju, Univ. at Buffalo

To compensate for the different orientations of two fingerprint images, matching systems use a reference point and a set of transformation parameters. Fingerprint minutiae are compared on their positions relative to the reference points, using a set of thresholds for the various matching features. However a pair of minutiae might have similar values for some of the features compensated by dissimilar values for others; this tradeoff cannot be modeled by arbitary thresholds, and might lead to a number of false matches. Instead given a list of potential correspondences of minutiae points, we could use a static classifier, such as a support vector machine (SVM) to eliminate some of the false matches. A 2-class model is built using sets of minutiae correspondences from fingerprint pairs known to belong to the same and different users. For a test pair of fingerprints, a similar set of minutiae correspondences is extracted and given to the recognizer, using only those classified as genuine matches to calculate the similarity score, and thus, the matching result. We have built recognizers using different combinations of fingerprint features and have tested them against the FVC 2002 database. Using this recognizer reduces the number of false minutiae matches by 19%, while only 5% of the minutiae pairs corresponding to fingerprints of the same user are rejected. We study the effect of such a reduction on the final error rate, using different scoring schemes.

6539-08, Session 4

Augmenting ridge curves with minutiae triplets for fingerprint indexing

A. A. Ross, R. Mukherjee, West Virginia Univ.

Given a query fingerprint, the goal of indexing is to identify and retrieve a set of candidate fingerprints from a large database in order to determine a possible match. This significantly improves the response time of fingerprint recognition systems operating in the identification mode. In this work, we extend the indexing framework based on minutiae triplets by utilizing ridge curve parameters in conjunction with minutiae information to enhance indexing performance. Further, we demonstrate that the proposed technique facilitates the indexing of fingerprint images acquired using different sensors. Experiments on the publicly available FVC database confirm the utility of the proposed approach in indexing fingerprints.

6539-09, Session 4

Use of ridge points in partial fingerprint matching

G. Fang, S. N. Srihari, H. Srinivasan, P. Phatak, Univ. at Buffalo

Matching of partial fingerprints has important applications in both biometrics and forensics. It is well-known that the accuracy of minutiae-based matching algorithms dramatically decrease as the number of available minutiae decreases. When singular structures such as core and delta are unavailable, general ridges can be utilized. Some existing highly accurate minutiae matchers do use local ridge similarity for fingerprint alignment. However, ridges cover relatively larger regions, and therefore ridge similarity models are sensitive to non-linear deformation. An algorithm is proposed here to utilize ridges more effectively- by utilizing representative ridge points. These points are represented similar to minutiae and used together with minutiae in existing minutiae matchers with simple modification. Algorithm effectiveness is demonstrated using both full and partial fingerprints. The performance is compared against two minutiae-only matchers (Bozorth and k-minutiae). Effectiveness with full fingerprint matching is demonstrated using the four databases of FVC2002- where the error rate decreases by 0.2-0.7% using the best matching algorithm. The effectiveness is more significant in the case of partial fingerprint matching- which is demonstrated with thirty partial fingerprint databases generated from FVC2002 (with five levels of numbers of minutiae available). When only 15 minutiae are available the error rate decreases 5-7.5%. Thus the method, which involves selecting representative ridge points, minutiae matcher modification, and a group of minutiae matchers, demonstrates improved performance on full and especially partial fingerprint matching.

6539-10, Session 4

A geometric transformation to protect minutiae-based fingerprint templates

Y. Sutcu, H. T. Sencar, N. D. Memon, Polytechnic Univ.

The increasing use of biometrics in different environments presents new challenges. Most importantly, biometric data are irreplaceable. Therefore, storing biometric templates, which is unique to individual user, entails significant security risks. In this paper, we propose a robust one-way transformation for securing the minutiae based fingerprint templates. The proposed scheme employs a one-way transformation that maps geometrical configuration of the minutiae points into a fixed-length code vector. This representation enables efficient alignment and reliable matching. Experiments are conducted by applying the proposed method on a synthetically generated minutiae point sets. Preliminary results show that the proposed scheme provides a simple and effective solution to the template security problem of the minutiae based fingerprint.

6539-11, Session 5

Correlation filters for large population face recognition

B. Vijaya Kumar, C. Xie, M. Savvides, Carnegie Mellon Univ.

Reliable person recognition is important for secure access and commercial applications requiring human identification. Face recognition (FR) is an important technology being developed for human identification. Algorithms and systems for large population face recognition (LPFR) are of significant interest in applications such as watch lists and video surveillance. In this paper, we present correlation filters-based feature analysis methods to effectively exploit available generic training data to represent a large number of subjects and thus improve the performance for LPFR. We first introduce a general framework - class-dependence feature analysis (CFA), which applies correlation filters to provide a discriminant feature representation for LPFR. We then introduce two variants of the correlation filter-based CFA methods: 1) the kernel correlation filter CFA (KCFA) that generates nonlinear decision boundaries and significantly improves the recognition performance without greatly increasing the computational load, and 2) the binary coding CFA that uses binary coding to reduce the number of correlation filters and applies error control coding (ECC) to improve the recognition performance. These two variants offer ways to tradeoff between the computational complexity and the recognition accuracy of the CFA methods. We test our proposed algorithms on the face recognition grand challenge (FRGC) database and show that the correlation filter-based CFA approach improves the recognition rate and reduces the computational load over the conventional correlation filters.

6539-12, Session 5

Application of superresolution to long-range face images

Y. Yao, B. R. Abidi, The Univ. of Tennessee; N. D. Kalka, N. A. Schmid, West Virginia Univ.; M. A. Abidi, The Univ. of Tennessee

Most existing face recognition algorithms require face images to have a minimum resolution. A resolution of 60 pixels between the eyes is recommended by the well-know recognition engine, FaceIt(r) developed

by Identix. Meanwhile, the rapidly increasing need for near-ground long range surveillance calls for a migration in face recognition from close-up distances to long distances and accordingly from low and constant resolution to high and adjustable resolution. Although adjustable zoom cameras are commonly used in indoor and outdoor surveillance systems, most of them provide a maximum optical magnification in the range of 20Å~~30Å~ [1]. For long range surveillance and target identification, this magnification is insufficient to obtain the required number of pixels on target. Super-resolution (SR) can provide a promising solution with no additional hardware requirements. In this paper, a brief review of existing SR algorithms is conducted and their capabilities towards improving face recognition rates (FRR) of long range face images are studied. Algorithms applicable to real-time scenarios [2, 3] are implemented and their performances in terms of FRR are examined using the IRIS-LDHM face database [4]. Our experimental results show that the use of SR followed by the proper enhancement, such as wavelet based processing, is able to achieve comparable FRR when equivalent optical zoom is employed. In addition, SR is capable of compensating certain amounts of illumination changes. From our experiments, performance improvements similar to those using the Retinex algorithm are observed in terms of illumination variations. This study lays the foundation for the development of pure image based SR algorithms for long range face recognition applications.

6539-13, Session 5

Locality preserving projections as a new manifold analysis approach for robust face superresolution

S. W. Park, M. Savvides, Carnegie Mellon Univ.

In this paper, we propose a novel method for performing robust super-resolution of face images by solving the practical problems of manifold analysis. The face super-resolution is to recover a high-resolution face image from a given low-resolution face image (e.g. captured from surveillance footage) by modeling the face image space. Thus, face super-resolution should be preceded by analyzing the characters of the face image distribution. In literature, it has been shown that face images lie on a nonlinear manifold, so if the manifold structure is taken into consideration for modeling the face image space, the results of face super-resolution can be improved. However, there are some practical problems which prevent these algorithms from being applied to super-resolution. Almost all of the manifold learning methods cannot generate mapping functions for new test images which are absent from a training set. Also, there exists another significant problem when applying manifold analysis to super-resolution; super-resolution seeks to recover a high-dimensional image from a lower-dimensional one while manifold learning methods perform the exact opposite as they deal with finding representative dimensionality reduction.

To break those limitations of applying manifold analysis to super-resolution, we propose a novel face super-resolution method using Locality Preserving Projections (LPP). LPP gives an advantage over other manifold learning methods in that it has well-defined linear projections which allow us to formulate well-defined mappings between high-dimensional data and low-dimensional data. Moreover, we show that we can infer high-resolution LPP coefficients for a given low-resolution test image using a MAP estimator to produce better reconstruction images with high-frequency details.

6539-14, Session 6

Biometric identification: a holistic perspective

L. D. Nadel, Mitretek Systems

No abstract available

6539-15, Session 7

Neyman-Pearson biometric score fusion: as an extension of the sum rule

J. P. Hube, L-1 Identity Solutions

We define the biometric performance invariance under injective functions on match scores as normalization symmetry. We use this symmetry to clarify the essential difference between the standard score-level fusion approaches of sum-rule and Neyman-Pearson. We then express Neyman-Pearson fusion assuming match scores defined using false acceptance rates on a logarithmic scale. We show that by stating Neyman-Pearson in this form, it reduces to sum-rule fusion for ROC curves with logarithmic slope. We also introduce a one parameter model of biometric performance and use it to express Neyman-Pearson fusion as a weighted sum-rule.

6539-16, Session 7

Nonparametric statistical data analysis of fingerprint minutiae exchange with two-finger fusion

J. C. Wu, M. D. Garris, National Institute of Standards and Technology

A nonparametric inferential statistical data analysis is presented. The utility of this method is demonstrated through analyzing results from minutiae exchange with two-finger fusion. High-accuracy vendors are selected and mean error rates are compared between two modes of matching standard fingerprint templates: 1) Native Matching - where the same vendor generates the templates and the matcher, and 2) Scenario 1 Interoperability - where vendor A's enrollment template is matched to vendor B's authentication template using vendor B's matcher. The purpose of this analysis is to make inferences about the underlying population from sample data, which provide insights at an aggregate level. This is very different from the data analysis presented in the MINEX04 report in which vendors are only individually ranked and compared. Using the nonparametric bootstrap bias-corrected and accelerated (BCa) method, 95% confidence intervals are computed for each mean error rate. Nonparametric significance tests are then applied to further determine if the difference between two underlying populations is real or by chance with a certain probability. Results from this method show that at a 95% confidence there is a significant degradation in accuracy of Scenario 1 Interoperability with respect to Native Matching with on average a two-fold increase in False Non-Match Rate. Additionally, it is proved why two-finger fusion using the sum rule is more accurater than single-finger matching under the same conditions. Results of a simulation using the nonparametric bootstrap are also presented to show the significance of the confidence intervals derived from the small size of samples, in our case, six vendors.

6539-30, Session 7

Empirical-mode decomposition for removal of specular reflections and cast shadow effects

R. Bhagavatula, M. Savvides, Carnegie Mellon Univ.

Facial recognition is fast becoming one of the more popular and effective modalities of biometrics when used in controlled environments. Controlled environments referring to those where variables such as facial expression, pose, relative camera position, and illumination effects are either completely or partially controlled in the interest of improved performance. Regulation of such factors has an immediate effect on the performance of facial recognition algorithms, in particular illumination effects which can not be controlled by even the most cooperative of users. In this paper we describe a method to address illumination effects in the biometric modality of face recognition using signal processing analysis such as Empirical Mode Decomposition (EMD) to identify illumination modes that compose the image. After identifying the intrinsic mode function that corresponds to the dominant illumination factors, we reconstruct the facial image without these illumination distortion components to synthesize a more neutral facial image. We then perform recognition and verification experiments using different algorithms such as Principal Component Analysis (PCA), Fisher Linear Discriminant Analysis (FLDA), and Advanced Correlation Filters (ACF's) to demonstrate the fundamental effectiveness of EMD as an illumination compensation method. Results are reported on the Carnegie Mellon University Pose-Illumination-Expression (CMU PIE) database.

6539-17, Session 8

Robust low-dimensional Kernel correlation feature spaces

R. Abiantun, M. Savvides, B. Vijaya Kumar, Carnegie Mellon Univ.

In this paper we analyze and demonstrate the subspace generalization power of the kernel correlation feature analysis (KCFA) method for producing compact low dimensional subspace that has good representation ability to work on unseen, untrained datasets. Examining the portability of an algorithm across different datasets is an important practical aspect of face recognition applications where the technology cannot be dataset-dependant for practical real-world applications. In most face recognition literature, algorithms are demonstrated on datasets by training on some part of the dataset and testing on the remainder. Most times the training and testing data have the same people but different capture sessions so in essence, some of the expected variation and people are modeled in the training set. In this paper we describe how we efficiently build a compact feature space using kernel correlation filter analysis on the generic training set of the FRGC dataset, and test the built subspace on other well-known face datasets. We show that the feature subspace produced by KCFA has good representation and discrimination to unseen datasets and produces good verification and identification rates compared to other subspace methods such as PCA. Its efficiency, lower dimensionality (the KCFA is only a 222 dimensional subspace) and discriminative power make it more practical and powerful than PCA as a powerful lower dimensionality reduction method for modeling faces and facial variations.

6539-18, Session 8

Multi-stream face recognition for crime fighting

S. A. Jassim, Univ. of Buckingham (United Kingdom); H. Sellahewa, Gray Cancer Institute (United Kingdom) and Univ. of Buckingham (United Kingdom)

Automatic face recognition is a useful tool in the fight against crime and terrorism. The use of Closed-circuit television (CCTV) cameras in public places has increased dramatically over that last few years. It is often used for surveillance in areas where there is an increased need for security such as airports, train stations, shopping centers, banks, sport arenas, and entertainment clubs. They are used to detect and prevent crime, shoplifting, public disorder, terrorism, and illegal immigration. The work of law-enforcing and intelligence agencies is becoming more reliant on the use of databases of biometric data for large section of the population as well as visitors. Face is one of the most natural biometric traits that can be used for surveillance and automatic human identification. However, variations in lighting conditions, facial expressions, face size and pose are a great obstacle to automatic face recognition. This paper is concerned with the using wavelet-based face recognition schemes in the presence of variations of expressions and illumination. In particular, we will investigate the use of a combination of wavelet frequency channels for multi-stream face recognition. The proposed schemes extend our recently developed face verification scheme for implementation on mobile devices. We shall demonstrate that the multi-stream approach is robust against variations in illumination and facial expressions than the previous single-stream approach. We shall present experimental results on the performance of our proposed schemes for a number of publicly available face databases including a new AV database of videos recorded on a PDA.

6539-19, Session 8

Real-time face tracking and pose correction for face recognition using active appearance models

J. Heo, M. Savvides, Carneige Mellon Univ.

This paper presents a fully automatic real-time face recognition system from video by using Active Appearance Models (AAM) for fitting and tracking facial fiducial landmarks and warping the non-frontal faces into a frontal pose. By implementing a face detector for locating suitable initialization step of the AAM shape searching and fitting process, new facial images are interpreted and tracked accurately in real time (15fps). Using an Active Appearance Model (AAM) for normalizing facial images under different poses and expressions is crucial to providing improved face recognition performance as most systems degrade matching performance with even smallest pose variation. Furthermore the AAM is a more robust feature registration tracking approach as most systems detect and locate the eyes while AAMs detect and track multiple fiducial points on the face holistically. We show examples of AAM fitting and tracking and pose normalization including an illumination pre-processing step to remove specular and cast shadow illumination artifacts on the face. We show example pose normalization images as well as example matching scores showing the improved performance of this pose correction method.

6539-20, Session 9

Similarity measure functions for strategy-based biometrics

R. V. Yampolskiy, V. Govindaraju, Univ. at Buffalo

Functioning of a biometric system in large part depends on the performance of the similarity measure function. Frequently a generalized similarity distance measure function such as Euclidian distance or Mahalanobis distance is applied to the task of matching biometric feature vectors. However, often accuracy of a biometric system can be greatly improved by designing a customized matching algorithm optimized for a particular biometric application. In this paper we propose a tailored similarity measure function for behavioral biometric systems based on the expert knowledge of the feature level data in the domain. We compare performance of a proposed matching algorithm to that of other well known similarity distance functions and demonstrate its superiority with respect to the chosen domain.

In this paper we compared three general similarity measure functions (Euclidian, Mahalanobis, Manhattan) with two domain specific functions developed by us (Weighted Euclidian, 2D Style). We begin with an overview of strategy based behavioral biometrics. This is followed by a survey of the most popular similarity measure functions used in biometric applications. Finally, we present our similarity measure functions and describe experiments we performed in order to establish the best performing similarity distance function. Customized Weighted Euclidian measure function specifically designed for the domain of strategy-based behavioral profiles showed the best performance on all types of data representation. This similarity measure function improved algorithms verification accuracy to as low as the 7% EER for the behavioral profiles enhanced with temporal and spatial information.

6539-22, Session 9

An eye model for uncalibrated eye gaze estimation under variable head pose

J. M. Hnatow, A. E. Savakis, Rochester Institute of Technology

Gaze estimation is an important component of computer vision systems that monitor human activity for surveillance, human-computer interaction, and other applications. Gaze estimation methods that are non-intrusive, do not require calibration, and generalize well across users are particularly valuable for such systems.

This paper presents a novel eye model that is employed for efficiently performing uncalibrated eye gaze estimation. The proposed eye model was constructed from a geometric simplification of the eye and anthropometric data about eye feature sizes in order to circumvent the requirement of calibration procedures for each individual user. The positions of the two eye corners and the midpupil, the distance between the two eye corners, and the radius of the eye sphere are required for gaze angle calculation. The locations of the eye corners and midpupil are estimated via processing following eye detection, and the remaining parameters are obtained from anthropometric data. This eye model is easily extended to estimating eye gaze under variable head pose.

The eye model was tested on still images of subjects at frontal pose (0 degrees) and side pose (34 degrees). An upper bound of the model's performance was obtained by manually selecting the eye feature

locations. The resulting average absolute error was 2.98 degrees for frontal pose and 2.87 degrees for side pose. The error was consistent across subjects, which indicates that good generalization was obtained. This level of performance compares well with other gaze estimation systems that utilize a calibration procedure to measure eye features.

6539-25, Poster Session

Indexing biometric database of binary feature template

P. Gupta, A. Sana, H. Mehrotra, Indian Institute of Technology Kanpur (India)

Indexing is required to reduce the search zone of large biometric database which in turn reduces the response time for an identification system. The paper proposes an efficient indexing technique for unique binary feature template using Haar wavelet transform. In this technique the input image is decomposed into approximation, vertical, horizontal and diagonal coefficients using the wavelet transform and the approximation coefficient is further decomposed into four coefficients. The extracted approximation coefficient matrix is binarised. This binary matrix is divided into four quadrants of equal size and Hamming distance (HD) between each quadrant with the chosen unique sample template is calculated. Each HD is used to generate a key in a certain range. The upper and lower range values for four quadrants are inserted into B+ tree where root node is unique sample template. At the first level of the tree the node contains the lower and upper values for first quadrant only. Similarly, lower and upper range values for the three quadrants are stored in the second, third and fourth level respectively. Finally leaf node contains the identifier.

In the case of identification, test image is used for generation of HD for four quadrants. Then the B+ tree is traversed comparing the values of HD at every node. If these HD lie within the range of values of existing nodes then it terminates to a leaf node with a set of identifiers. The corresponding feature vector for each identifier is retrieved from the secondary memory and matched with test feature template to get top matches. The proposed technique is implemented on ear biometric database at IITK.

6539-28, Poster Session

Template protection and its implementation in 3D face recognition systems

X. Zhou, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

As biometric recognition systems are widely employed in different application areas, security and privacy risks have recently attracted the attention of the biometric community. Template protection techniques prevent stored reference data from revealing biometric information and enhance the security of biometric systems against attacks such as identity theft and cross matching. This paper concentrates on a template protection algorithm that merges methods from cryptography, error correction coding and biometrics. The key component of the algorithm is to convert biometric templates into binary vectors. The paper shows that the binary vectors should be robust, uniformly distributed, statistically independent and collision-free so that verification performance can be optimized. Depending on statistical character of the biometric template, different approaches for transforming biometric templates into compact binary vectors are presented. The proposed methods are integrated into a 3D face verification system and tested on the FRGC 3D face database. It is shown that resulting binary vector provides verification performance comparable to the original 3D face templates. A high security level can be achieved with reasonable false acceptance and false rejection rates of the system, based on an efficient statistical analysis. The algorithm estimates the statistical character of biometric templates from a number of biometric samples in the enrollment database. For the FRGC 3D face database, classification results under the assumption of uniquely distributed templates are more successful than for Gaussian distributed templates in our tests.

6539-29, Poster Session

Ear authentication using log-Gabor wavelets

A. Kumar, Indian Institute of Technology Delhi (India); D. Zhang, The Hong Kong Polytechnic Univ. (Hong Kong China)

This paper investigates a new approach for human ear identification using holistic grey-level information. We employ log-Gabor filters to extract the phase information, i.e. ear-codes, from the 1D gray-level signals. Thus each ear is represented by a unique ear code or (phase template). The query ear images are compared with those in the database using hamming distance. The minimum hamming distance obtained from the rotation of ear-code/template is used to authenticate the user. Our experiments on three different ear database achieves promising results and suggests its utility in ear-based authentication.

1. Introduction

Reliability in personal authentication is key to the stringent security requirements in many application domains ranging from airport surveillance to electronic banking. Many physiological characteristics of humans, i.e., biometrics, are typically invariant over time, easy to acquire, and unique to each individual. Most of the current research in biometrics is focussed on face, fingerprint, gait, signature, iris, palmprint or hand-geometry [11]. However, there have been very little efforts to investigate the human ear for personal authentication despite its significant role in forensic science. The ear is quite attractive biometric candidate mainly due to its (i) rich and stable structure which is preserved since birth, (ii) being invariable to the changes in pose and facial expression, and (iii) relatively immune from anxiety, privacy and hygiene problems with several other biometric candidates.

1.1 Prior Work

Table 1 presents a summary of prior work on the usage of 2D ear images for personal authentication. Researchers have also investigated the ear recognition using 3D imaging [6], [10] and acoustic characteristics [7].

Authors / Approach / Classifier / Database Size /

A. Ianarelli [1] / Manual Ear Measurements / / 1000 images

Chang et al. [5] / PCA / Eucledian Distance, k-NN / 197 subjects

Burge and Burger [2] / Veronoi Diagram /

Mottaleb and Zhou [8] / Differential Geometry / Hausdorff Distance / 29 subjects

Zhang et al. [10] / ICA / RBF Network / 60 subjects

Hurley et al. [4] / Force Field Transform, PCA / Eucledian Distance, k-NN / 63 subjects

Kumar and Zhang / Log-Gabor Wavelets / Hamming Distance, k-NN / 116 subjects

2. Proposed Method

The accurate ear recognition requires the extraction of most discriminating information and exclusion (masking) of those regions that do not form the reliable features. Our approach extracts the reliable ear features using Log-Gabor filters and generates a phase template to characterize phase information. Figure 1 shows the block diagram of proposed approach for ear authentication.

3. Experiments and Results

The experiments reported in this paper utilize the face database available at [11]. We employed the side face images of 116 subjects and extracted the ROI using a fixed size mask as shown in Figure 1.

4. Conclusions

This paper has presented a new approach for ear authentication using phase information extracted from Log Gabor wavelets. The preliminary experimental results shown in this paper are promising. These results also suggest that the exploitation of Gabor phase information performs significantly better that the eigen-ear approach presented in the literature. This paper will also provide detailed analysis/discussion/comparison on the distribution of genuine and imposter scores, from the proposed method, for the performance evaluation.

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6540-01, Session 1

Homeland security R&D budgets and conference overview

T. T. Saito, Lawrence Livermore National Lab.

Highlights and interesting aspects of the FY06 & 07 R&D Homeland Security budgets will be given. Highlights will include discussions that significant portions of the R&D budgets lay outside the Department of Homeland Security. An overview of this conference will include an overview of the program as well as an update on the Port and Harbor Security and Drinking Water Safety sub-committees.

6540-02, Session 2

Combination of an on-line biomonitor using light emitting bacteria and a UV spectrometer probe for homeland security and drinking water safety

J. Appels, microLAN B.V. (Netherlands)

Analytical Monitoring systems can only cover a part of the range of potential contamination in water. Therefore the interest in the last years in on-line Biomonitors has increased significantly. This has resulted in the introduction of new Biomonitors which can provide a (near) real-time information on water quality. They can also be used for drinking water protection against Intential Contamination. But still no universal monitor is available which protects against all kinds of threats and a combination of systems and techniques is required if all criteria are to be met. This can not be realised with the use of a single monitor. However, the combination of complementary systems into a single integrated monitoring platform will greatly enhance the applicability of real time monitoring devices for water quality monitoring.

For this the TOXcontrol, a biological toxicity monitor (using luminescence bacteria) with the S::CAN spectro::lyserTM, an analytical sensor (a submersible UV-VIS spectrophotometer probe) will be combined and a software tool will help the user to make better judgements and give more insight information to make decisions. This combination allows verification of alarm signals from one instrument with the signal of others reducing false alarm rates.

After a study it was concluded that both the UV-VIS spectrophotometer and the Toxicity Biomonitor are valuable sensors in an Water Security Monitoring System, capable of detection a broad range of contaminants at low concentrations. Results of both lab and field tests for Homeland Security and Drinking Water Safety monitoring, will be presented.

6540-03, Session 2

AquaSentinel: a real-time reagentless biosensor system for standoff detection and classification of toxins in source water

E. Greenbaum, M. Rodriguez, Jr., Oak Ridge National Lab.

AquaSentinel is an automated and field-deployable real-time technology for detection of source water environmental toxins that is based on the fluorescence induction properties of algae that grow naturally in the water. We report here that the algal biosensors can be used as a sentinel alarm system based on toxin-induced fluorescence readout as the characteristic signature for identification and verification of environmental pollutants in source drinking waters. This reagentless self-contained optoelectronic detection system naturally lends itself to mapping and ranging of the presence of pollutants in source waters. We have developed an original algorithm for performing the analysis of the readings from the biosensors. The approach is based on differential offset between the fluorescence signatures of healthy algae and that of the poisoned algae. The technique yields a set of time-dependent numbers that uniquely maps the transformation of the normal or healthy fluorescence induction curve to that of the poisoned curve. We show that the set of numbers generates a characteristic signature that can be used to group and identify the specific pollutant that caused the alteration of the fluorescence. Data on five well-known toxins will be presented: cyanide, methyl parathion, atrazine, diuron and paraquat. This data was generated from dose-response experiments performed with "as is" water samples collected from the Clinch River. The Clinch is the primary source of drinking water for the City of Oak Ridge, Tennessee.

6540-04, Session 2

Rapid response toxicity and chemical agent kits for initial threat assessment

D. C. Deardorff, Abraxis

Assays based on the measurement of bacterial luminescence are widely used in eco-toxicology. Luminescence is connected to the metabolism of the bacteria, if the metabolism is obstructed or totally stopped (death of the bacteria) by a toxic sample the level of luminescence decreases. Bioluminescent bacteria kits based on the V. fischeri strain NRRL B-11177 are excellent tools in responding either to general toxicity or a specific chemical threat. They are rapid, cost-effective and easy to use. With prior generation instrument technology, capital equipment outlays ranging from $8,000 to $22,000 have long been a barrier to water quality or rapid response personnel. New, less expensive technologies including portable luminometers and camera detection systems make the chemical threat assessment as easy as taking a picture.

Enzymatic test kits, generally designed to be handheld and portable, detect the presence of chemical agents, carbamate pesticides, and/or OP pesticides by relying on the reaction of the cholinesterase enzyme. Under normal conditions, the enzyme reacts as expected with other chemicals present in the test kit. The activity of the enzyme is inhibited, however, by chemical agents, carbamate pesticides, and OP pesticides. The effects of this inhibition will then generally lead to a color change, indicating the presence or absence of these compounds. A recombinant acetyl cholinesterase enzyme allows the highly sensitive detection of nerve agents, organophosphate and carbamates chemical agents at the sub ppb levels.

New developments on low cost bioluminescence and enzymatic assays that can be used to determine rapid acute toxicity of chemical agents to assess threats as well as data obtained from EPA Environmental Technology Verification (ETV) will be presented.

6540-05, Session 2

Nectophotometer: an infrared motility monitor used to rapidly quantify toxicity

R. W. Lo Pinto, J. Santelli, Fairleigh Dickinson Univ.

Changes in the motility of fish and aquatic invertebrates have long been used to signal the presence of toxins in water. We have discovered that the level of motility change occurring within 2.5 hours of exposure to each concentration of toxin correlates well with the mortality observed at each concentration after a three day exposure. This correlation allows mortality and EC50's to be determined near the beginning of a toxicity test rather than at its conclusion. Motility is monitored and automatically recorded using a Nectophotometer, an automated bio-monitor with computer interface that senses interruptions of infrared beams when organisms separately exposed to multiple concentrations of a toxin move through the beams. In our tests changes in the motility of Artemia salina within the first 2.5 hours of exposure predict 3 day mortality with an average accuracy of 89.33%. The Nectophotometer has promise for allowing rapid assessment of the toxicity of liquids using invertebrates and fish, and may also be used to assess airborne toxicity if motile insects respond in a similar manner.

6540-06, Session 2

Water security: continuous monitoring of water distribution systems for chemical agents by SERS

S. R. Farquharson, F. E. Inscore, Real-Time Analyzers, Inc.

Ensuring safe water supplies requires continuous monitoring for potential poisons. In the case of chemical warfare agents (CWAs) analyzers are needed that have sufficient sensitivity (microgram/liter), selectivity (differentiate the CWA from its hydrolysis products), and speed (less than 10 minutes) to be of value. We have been investigating the ability of surface-enhanced Raman spectroscopy (SERS) to meet these requirements by detecting CWAs and their hydrolysis products in water. The expected success of SERS is based on reported detection of single molecules, the one-to-one relationship between a chemical and its Raman spectrum, and the minimal sample preparation requirements. Recently, we have developing a simple sampling device designed to optimize the interaction of the target molecules with the SERS-active material with the goal of increasing sensitivity and decreasing sampling times. This sampling device employs a syringe to draw the water sample containing the analyte into a capillary filled with the SERS-active material. Recently we used such SERS-active capillaries to measure 1 microg/L cyanide in water. Here we will describe these measurements as well as those for blister and nerve agent hydrolysis products, and portable analyzers suitable for continuous water monitoring.

6540-07, Session 3

Use of robotics and EO/IR sensors for border security

R. A. Bell, iRobot Corp.

No abstract available

6540-08, Session 3

Remote optical interrogation of radiation sensitive infrared polarizers

R. R. Boye, S. A. Kemme, P. Nandy, D. R. Wheeler, S. M. Dirk, Sandia National Labs.; S. Samora, Sandia National Labs. and L&M Technologies, Inc.; C. M. Washburn, Sandia National Labs.

Remote detection of radiation is a difficult problem due to the 1/r2 fall-off. Recent advances in polymer research and nanoscale fabrication methods along with advances in optical polarimetric remote sensing systems suggest a solution. The basic device uses a micro-wiregrid infrared polarizer fabricated in conductive polymer. When the polymer is exposed to hard radiation, its conductivity will be affected and the polarization properties of the device will change in a corresponding manner. This change in polarization properties can be determined by optically interrogating the device, possibly from a remote location. We will report on the development of a radiation-sensitive passive dosimeter polymer with very low optical visibility. Progress on material development, lithographic fabrication and optical characterization will be presented.

6540-09, Session 3

True-color night vision cameras

J. M. Kriesel, Opto-Knowledge Systems, Inc.; N. Gat, Opto Knowledge Systems, Inc.

The paper describes True-Color Night Vision cameras that are sensitive to the visible to near-infrared (VNIR) portion of the spectrum allowing for the “true-color” of scenes and objects to be displayed and recorded under low light level conditions. True Color technology offers advantages over traditional monochrome (gray or green) image-intensified cameras that have been the standard for years. For example, color increases information content and has proven to enable better situational awareness, faster response time, and more accurate target identification.

Two different prototype cameras, employing two different true-color night vision technological approaches, are described and compared in this paper. One camera uses a fast-switching liquid crystal filter with optimized transmission profiles in front of a custom Gen-III image intensified CMOS camera. The construction of color images is performed onboard the cameras using a fast DSP or FPGA enabling color video output at 30 frames/second. The second camera is based around an EMCCD sensor with a mosaic filter applied directly to the sensor. In addition to visible light, both cameras can utilize NIR to (1) increase the signal and (2) enable the viewing of laser aiming devices.

The performance of the true-color cameras, along with the performance of standard (monochrome) night vision cameras, are reported and compared under various operating conditions in the lab and the field. In addition to subjective criterion, figures of merit designed specifically for the objective assessment of such cameras are used in this analysis.

6540-10, Session 3

Enhanced surveillance system based on panomorph panoramic lenses

S. Thibault, ImmerVision (Canada)

Modern surveillance and security systems must be based on a technological approach because only technology can provide vigilance with efficiency and can supply certainty of detection and fast response one hundred percent of the time. The development of new wide angle lenses, advanced cameras, IP networks and video analysis technology, provide great improvements in system performance and flexibility. This paper presents a new advanced surveillance system based on the use of a panoramic Panomorph lens for event detection, recognition and identification over 360 degrees with 100% coverage rate. This innovative approach provides enhanced performance with better pixel/cost ratio. Intelligent video technology enables the video camera to be more than just a video camera. Intelligent video technology allows the panoramic image to follow events such as moving objects or unauthorized behaviors in real time. This in turn helps the operator to focus their activity on a narrow field pan/tilt camera, without loosing any information in the field. Incrementally adding capabilities such as a panomorph lens based imager to an existing surveillance video system can provide improvements in operational efficiency and effectiveness. Foreseen applications are in the field of border surveillance, highly secured environments, aerospace and defense, mass transit, public security and wherever the need for total awareness is required.

6540-11, Session 3

360 degrees optical system

W. Tan, M. X. Lu, STELOP Pte. Ltd. (Singapore)

Everyone likes to have an all round picture in real time. They include the security, police, military, shop owner, tourist, house owner, property agent, interior designer, drivers, etc. So far, there is no satisfactory solution yet. The current solutions available in the market are mainly based on multiple camera system, rotating camera system and parabolic camera system. These solutions are either more expensive, higher in power consumption, lower in reliability, not real time, more complex in software, large distorted images or lower in image resolution.

The reason is because typical commercial imaging detector or camera has a standard format of 4:3 aspect ratios. This determines the horizontal field of view (HFOV) and vertical field of view (VFOV) with the same aspect ratio. Hence, such detector is not suitable for panoramic view. The detector should be of higher aspect ratios such as 8:1.5 or 16:0.75. However, even if there is an elongated detector, the optics will be complex and design difficult to optimise.

The paper shall present an innovative solution to provide a low distortion and high resolution panoramic view in real time and under low light condition. It is non scanning system and easily scalable to provide long range performance. It can be also applied to thermal imager camera to provide a V360 night camera.

6540-12, Session 3

EO/IR sensors for border security applications

R. V. McDaniel, Kollsman, Inc.

No abstract available

6540-13, Session 3

Review of EO/IR sensors for border security

J. Egerton, A. K. Sood, Magnolia Optical Technologies, Inc.

No abstract available

6540-14, Session 3

Polarization-holographic protection system

B. N. Kilosanidze, G. A. Kakauridze, Institute of Cybernetics (Georgia)

Polarization-holographic system of protection of a new type is offered. The system uses specially synthesized polarization-sensitive materials on which the polarization holograms are recorded and the identifying device. The polarization holographic method uses an essentially bigger possibility that lies in light wave polarization. Polarization hologram is able to record all characteristics of the polarization ellipse - ellipticity, direction of rotation and orientation of the major axis, as well as a degree of polarization. Such an ample quantity of the initial data recorded on the material carrier makes it possible to record respectively physically as much complete information as possible. Polarization holograms-labels are recorded by two polarized beams with different polarization state. As there are infinitely many combinations of polarization state of writing beams, then while using the material with certain characteristics a specific combination can be chosen for each concrete system of protection to which diffracted beams with a concrete polarization state will unambiguously correspond. The identifying device forms an illuminating beam, makes an analysis of polarization state of beams diffracted on the hologram-label and compares their state of polarization with the standard for the given concrete system of protection. The polarization-holographic element created by us is used in device for the analysis of polarization state of diffracted beams. It gives the possibility to determine all parameters of polarization ellipses of diffracted beams simultaneously and in real time. The suggested system has advantage that visually protective polarization hologram-labels look completely homogeneous. It is impossible to determine by any devices usually used for verification of authenticity (ultra-violet and infra-red irradiation, magnetic and electrical fields, microscopes etc.) what is written on the given hologram-labels. It is easy to determine the authenticity only while using the identifying device, designed by us. Besides unlike existing holographic protection systems an essential advantage of such a system of protection is that it is impossible to copy polarization hologram-labels by optical methods as registering material has high absorption on actinic wavelength and the irreversible destruction of the recorded information occurs while big power density of the actinic illuminating light is used. This system is simple enough and noise- protected.

6540-15, Session 4

DHS Counter-MANPADS Program update

K. D. Wilson, U.S. Department of Homeland Security

No abstract available

6540-16, Session 4

Northrop Grumman Counter-MANPADS Guardian™ system

L. Danielides, Northrop Grumman Corp.

No abstract available

6540-17, Session 4

JETEYE™: commercial airliner IR missile protection system

S. S. duMont, BAE Systems

No abstract available

6540-18, Session 4

Countering MANPADS: study of new concepts and applications II

J. P. Robineau, D. Maltese, M. Renaudat, Sagem SA (France); F. Gendry, Sagem Communication (France)

Nowadays, Air-to-Air and Ground-to-Air IR guided missiles are considered to be a tremendous threat for military and civil aircraft. Man Portable Air Defense systems (MANPAD) turn out to be high probable weapons threatening high value platforms in war and terrorism contexts. Besides, such amazing figures as about a few hundred of thousand of missile stockpiles of different types make this threat a main issue.

Nonetheless, Aircraft protection against IR seeker guided missiles is currently becoming feasible thanks to new laser technologies and efficient pointing systems. By and large, a typical protection suite is composed of a Missile Warning System (MWS) which already exists and satisfies operational need, and a Directed Infra Red Counter Measure system (DIRCM) which is nowadays at pre series maturity for basic functionality, and at conception and feasibility demonstration state for most advanced functional concepts.

SAGEM DEFENSE & SECURITY company aims at next generation DIRCM development, including advanced identification function, seeker defeat assessment, multi missiles thwarting management and 4th and 5th IR seeker generation defeating capabilities. Target Designations are provided by a MWS. Multiple missile engagement scenarios have been considered to design the system architecture. A complete software operational simulation tool has been developed and used in order to validate first system design but also to compare different DIRCM functional architectures to optimize working modes and to identify critical parameters and related values.

As a continuation of the former paper presented last year at the SPIE 2005 (6203-15), this new article :

* describes the software simulation tool for DIRCM evaluation in operational environment,

* presents a selected set of runs for the next generation DIRCM specification and design,

* and highlights the primary conclusions for DIRCM functional architecture choice, including the MWS specification.

Eventually, a technical road map is put forward by SAGEM DEFENSE & SECURITY in order to reach the ambitious goal of aircraft protection against last generation Focal Plane Array IR seeker.

6540-19, Session 4

Improved self-protection using dynamically optimized expendable countermeasures

H. Hovland, Forsvarets Forsknings Institute (Norway)

Expendable countermeasures are still found to be a viable choice for self protection against Man Portable Air Defense Systems (MANPADS) due to their simplicity, low cost, flexibility, recent improvements in

decoy technology, the ability to handle multiple threats simultaneously and the off-board nature of these countermeasures. In civil aviation, the general hazards linked to the use of pyrotechnics is the main argument against expendable countermeasures, whereas for military platforms, the limitation in capacity due to a limited number of rounds is often used as an argument to replace expendable countermeasures by laser-based countermeasures. This latter argument is in general not substantiated by modeling or figures of merit, although it is often argued that a laser based system allows for more false alarms, hence enabling a more sensitive missile approach warning system. The author has developed a model to determine the statistical effects of running out of expendable countermeasures during a mission, in terms of the overall mission survival probability. The model includes key parameters of the missile approach warning system (MAWS), and can handle multiple missile types and missile attack configurations, as well as various statistical models of missile attacks. The model enables quantitative comparison between laser based and expendable countermeasures, but also a dynamic optimization of the countermeasures in terms of whether to use small or large countermeasure programs, as well as the dynamic tuning of MAWS key parameters to optimize the overall performance.

Example calculations are made to illustrate the effect of implementing this model in new defensive aids suites.

6540-20, Session 4

Advances in Raman spectroscopy for explosive identification in aviation security

J. D. Santillan, Ahura Corp.

In the operational airport environment, the rapid identification of potentially hazardous materials such as improvised explosive devices, chemical warfare agents and flammable and explosive liquids is increasingly critical. Peroxide-based explosives pose a particularly insidious threat because they can be made from relatively innocuous household chemicals, such as bleach and hydrogen peroxide. Raman spectroscopy has been validated as a valuable tool for rapid identification of chemicals, explosives, and narcotics while allowing “line-of-sight’ interrogation through bottles or other translucent containers. This enables safe identification of both precursor substances, such as acetone, and end-products, such as TATP, without sampling by security personnel.

While traditional Raman systems are laboratory-based, expensive and require careful operation and maintenance, recent advances in spectroscopic technologies have dramatically reduced the footprint and improved the reliability and ease of use of Raman spectroscopy systems. Such technologies are not only bringing the lab to the field, but are also protecting security personnel in the process.

From this talk, participants will gain:

* A basic understanding of Raman spectroscopy.

* An understanding of how this technology can be used to quickly screen for and identify substances used in production of explosives as well as the explosive end-products.

6540-21, Session 5

Virtual sea border

D. V. Ferriere, National Infrastructure Institute

Establishing a Virtual Sea Border by performing a real-time, satellite-accessible, Internet-based, dynamic and interactive threat assessment of arriving foreign-flagged cargo ships and their seafarers, their management and ownership, their arrival terminal operator and owner, and for those having proven security protocols in place as legitimate operators rewarding them with an economic incentive for their transparency by eliminating further port security related delays. In contrast with current practices this developing concept could simultaneously improve port security and maritime transportation efficiencies.

6540-22, Session 5

Maritime security laboratory for maritime security research

B. J. Bunin II, A. M. Sutin, M. S. Bruno, Stevens Institute of Technology

Stevens Institute of Technology has established a new Maritime Security Laboratory (MSL) to facilitate advances in methods and technologies relevant to maritime security. MSL is designed to enable system-level experiments and data-driven modeling in the complex environment of a tidal estuary. The initial focus of the laboratory is on the threats posed by divers and small craft with hostile intent. The laboratory is, however, evolvable to future threats as yet unidentified.

Initially, the laboratory utilizes acoustic, environmental, and video sensors deployed in and around the Hudson River estuary. Data associated with boats and divers are collected on a special purpose computer deployed on board a boat specifically designed and equipped for these experiments. The experiments are controlled remotely from a Visualization Center on campus. Early experiments utilizing this laboratory have gathered data to characterize the relevant parameters of the estuary, acoustic signatures of divers, and normal surface and air traffic. Individual hydrophones were deployed to collect data to enable the development of methodologies for maximizing SCUBA diver detection distance.

Initial results involving characteristics of the estuary, signatures of divers, ambient acoustic noise in an urban estuary and its correlation with water traffic, and transmission loss of acoustic signals in a wide frequency band are presented. These results will enable characterization of abnormal traffic and improvement of underwater communication in shallow water estuary.

This work was supported by ONR Award # N00014-05-1-0632: Navy Force Protection Technology Assessment Project.

6540-23, Session 5

Houston ship channel security: a case study

P. A. Bellamy, H. Q. Le, S. S. S. Pei, Univ. of Houston

The Houston Ship Channel is a major port with a uniquely critical role with respect to the US petroleum energy supply. The Channel security system is currently being considered for a major and comprehensive upgrade under the auspices of the Houston-based Port Strategic Security Council. This paper describes a theoretical study of technical issues in support of this project. The ultimate objective is a state-of-the-art command, control, communication, information, and surveillance system for total situational awareness to address the FBI’s Channel threat matrix. The fundamental metric is the level of risk reduction. The challenge is to achieve order-of-magnitude improvement in intrusion detection and the capability to mitigate CBRNE threats. The key aspects include an advanced sensor network and response system supported by a high-capacity internetworking infrastructure. The study considers not only existing advanced CBRNE detectors and surveillance sensor suites that include fence/boundary sensors and volumetric sensors including focal plane array imagers of various spectral bands (UV-VIS, M/LWIR), RADAR, and SONAR, but also emerging technologies (e. g. 3D imagers) that may become available over the system lifetime. Sensor fusion and video analytics are anticipated to grow significantly. The response capability will include boat patrols and robots. The system must also be designed not only for normal operational environment (day, night, regular weather) but also for hazardous weather (tornadoes, hurricanes). The true and ultimate challenge however is to achieve the minimum risk given the allocated budget to achieve a system that serves the Channel at least for a decade to come.

6540-24, Session 6

A smart camera system for fixed facility security surveillance

J. T. Love, D. K. Van Dover, S. W. Law, Night Vision Systems

In response to a serious homeland security threat as is illustrated by a chemical plant with on-site stores of dangerous substances and rendered vulnerable by itslocation on public waterways, we have developed and described a viable approach to persistent optical surveillance for detecting and assessing an adversary attack sufficiently early to permit probable interdiction by a responding guard force. Last year we outlined some of the technical challenges encountered in securing a chemical plant on a waterway. This paper described some of the attributes, of a smart camera system as a key part of the overall security solution for the chemical plant. We described the relative strengths and weaknesses of various sensors as well as the benfits of software systems that add a degree of intelligence to the sensor systems. This year we will elaborate further on the actual hardware and software implementation and operating protocols of this smart camera system. The solution we recommend is to use a series of smart camera systems of different configurations positioned for the most effective coverage of the facility and integrated with other hardware and procedures to meet any security challenge. The smart cameras systems could include any or all of the thermal detectors, low light camera sensors, intelligent video functions, networking protocols and other features intended to maximize security coverage.

6540-25, Session 6

Underwater olfaction for real-time detection of submerged unexploded ordnance

R. J. Harper, M. L. Dock, Nomadics, Inc.

The presence of underwater unexploded Ordnance (UUXO) represents a considerable threat in the marine environment. Elevated concentrations of dissolved explosive compounds, such as TNT and RDX, may be produced in the vicinity of degraded UUXO shell casings and are known to have significant toxicant effects on local marine organisms. During World War II and in subsequent years, the US military inadvertently or, in some cases intentionally, deposited many thousands of tons of UUXO in US coastal waters. Much of this material is difficult to locate by magnetometry or sonar imaging techniques, and can be extremely challenging to identify by visual means after lying on the bottom of the ocean for several decades. The present work is focused on advances in underwater olfaction, wherein trace amounts of dissolved explosive compounds may be detected and discriminated from other chemical species found in the marine environment, for the purpose of establishing safe cordons and/or neutralization of the explosives.

ICx Nomadics has developed the first known real-time sensor system that is capable of detecting chemical signatures emanating from underwater explosives. The SeaPup sensor, which is based on the fluorescence-quenching transduction mechanism of an amplifying fluorescent polymer (AFP), is capable of real-time detection of the trace chemical signatures emanating from submerged explosive compounds. The SeaPup system has been successfully tested on various marine platforms, including a crawler robot, an autonomous underwater vehicle (AUV), and a remotely operated underwater vehicle (ROV). In one study, the SeaPup was shown to effectively map liquid phase “explosive scent plumes” emanating from an underwater source of TNT. The presented paper will provide an overview of the history, current status, and future development of explosive analyte detection in the underwater environment.

6540-27, Session 6

Low cost MEMS hydrophones

K. J. Rebello, D. Kitchin, R. Henrick, F. Tejada, Johns Hopkins Univ.

One of the principal problems faced today by the Department of Homeland Security is maritime security. Seaborne and undersea threats from terrorists and smugglers at ports and in coastal areas threaten our safety and economy. A solution is the development of distributed hydrophone sensors, but recent studies have shown that these systems prove too expensive and power hungry for large scale deployment in sensor arrays of order hundred elements or more.

A new approach for microelectromechanical systems (MEMS) hydrophones is discussed, which yields miniature, low power, and high performance hydrophones. The prototype devices use a laser interferometer with integrated low power electronics built on conventional silicon on sapphire (SOS) complimentary metal oxide semiconductor (CMOS) technology to optically detect pressure waves. Results show sensitivities better than 10 μV/Pa, comparable to or better than piezoelectric or capacitive condenser approaches. The implication is to make very low cost hydrophones while drastically reducing the power and computational requirements of acoustic arrays; this is viewed as a disruptive technology for areas where cost, size and power consumption are key.

6540-28, Session 6

Low-dose optically stimulated luminescence of exotic materials

D. I. Godfrey-Smith, S. M. Khanna, Defence Research and Development Canada (Canada)

We present the results of optically stimulated luminescence (OSL) analyses of the radiation dose response of substrates and non-conductors present in ubiquitous small consumer electronics: watches, cell phones, small portable radios, laptops, and miscellaneous peripherals related to them; on-body or in-body medical devices: hearing aids, pacemakers; and in exotic materials: SiC and AlN substrates currently under development for future generation electronics. Our experimental protocol included exposure of the materials described above to a calibrated 90Sr/90Y beta source with a 0.13 Gy/s dose rate, and detection of the absorbed dose using stimulation with ~40mW of monochromatic light from an array of blue light emitting diodes. Dose response luminescence was detected in a UV band centered at 340nm. Preliminary data from several of these materials have yielded an excellent signal, in some cases yielding a statistically meaningful response to sublethal radiation doses of 0.004 - 0.02 Gy, and linear dose response behaviour over a wide dose range. The results could be used in a wide range of forensic radiation detection situations, including the detection of asymmetric threats before their fruition, rapid response to radiation exposure events involving the general population, and needs for triage.

6540-29, Session 6

Sensing and characterization of explosive vapors near 700 cm-1

A. R. Ford, W. A. Burns, S. W. Reeve, Arkansas State Univ.

Optical sensing of trace atmospheric constituents is now a well established field. For example, the HITRAN (High Resolution Transmission Molecular Absorption) database contains spectra (over 1.7 million spectral transitions) for 37 different molecules. This extensive database provides a ready means for sensing and extracting atmospheric species concentrations via a principal component analysis from absorption spectra. The extension of these same techniques to the field of explosive detection has been proposed by a number of scientists. One of the challenges that must be overcome however is that the vapor pressures of most explosive compounds is quite small. The gold standard in explosives detection is still the trained canine nose. Recent studies have indicated that canines alert not on a specific explosive compound, but rather on the chemicals used to manufacture and process the explosives. Here we will present high resolution infrared data for several of these volatile organic compounds in the 700 cm-1 region that is required for real time optical sensing of energetic materials as well as a preliminary principal component analysis of a sample in a real world matrix.

6540-30, Session 6

Automatic high throughput empty ISO container verification

A. L. Chalmers, American Science and Engineering, Inc.

This paper presents a concept to verify that ISO containers passing through a high throughput portal are empty. A low dose X-ray beam is proposed to collect image data from a stream of continuously moving vehicles; including tractor units, conveyances and ISO containers of various sizes. Advanced image processing algorithms are applied to the collected x-ray data in real time. These algorithms locate, extract and process the contents of ISO containers passing through the portal. The processing includes an assessment of the cargo contents and raises an alarm if the ISO container is not empty. Additional algorithms are applied to quantify the contents and identify any known threats.

6540-32, Session 6

Novel all-optical gamma-ray spectrometer

N. V. Menon, T. P. Jannson, R. D. Pradhan, Physical Optics Corp.

Physical Optics Corporation (POC) is developing a revolutionary Dirty Bomb Gamma-ray Identification (DOGID) system that is based on a new class of radiation absorbing material consisting of a hybrid nanostructured semiconductor/polymer matrix material that uniquely combines the high radiation absorbing and room temperature capability of scintillating material with resolution and speed of semiconductors. The charge fragments generated within the material by ionizing radiation are optically measured by precisely quantifying the changes in the photorefractivity of the hybrid matrix. The unique optical method combined by the novel material results in a detection system with \>95% efficiency in detection ~1MeV gamma-rays with ~1% resolution at ambient operating conditions. POC demonstrated the efficacy of this system by building a prototype capable of 4% resolution (40KeV FWHM) in detecting 1MeV gamma-rays while operating at room temperature. This resolution is consistent with the theoretical capability of the prototype material and system. The DOGID system operates at ambient conditions and does not require cryogenic active cooling.We will report on the ongoing research into this revolutionary Gamma-Ray spectrometer.

6540-33, Session 6

Determining water properties with remote sensing in littoral zones...What’s available?...What’s possible?

P. Pratt, B. K. Baldauf, Northrop Grumman Space Technology

Deriving water constituents: water clarity, turbidity, bottom type and depth from remote sensing continues to be a challenge in coastal waters. Because relatively large regions can be observed in a short amount of time, the development of data integration techniques to combine multiple elements from satellite and airborne sensors (ie: AVIRIS, Hyperion, EOS, MODIS and NPOESS) is highly desirable. Proficient implementation is also multifaceted. As concerns for homeland security have elevated to higher priority, characterization of littoral domains has moved from being driven by environmentally sensitive issues to politically vital matters. In the vulnerable transitional area between ocean and land there exists a void of defined parameters, confident characterization and reliable strategies for operational analysis. This paper surveys traditional optical and photonic techniques for the classification of maritime features, predominantly in the 0 to 100 meter depth range. We discuss the most recent methods and compare them by water depth and practicality as well as present the inherent physical limitations and constraints. The research presented here updates the ocean community and apprises security managers of the primary issues in using satellite and airborne data in littoral zones and suggests perfunctory paths for immediate innovation based on available techniques. This field has great opportunity for breakthroughs in technology such as the NGST “OnePicture Workstation” providing useful information for critical decision making. This work provides an overview of this emerging technology designed to benefit harbor defense/port security as well as promising strategies using data fusion, LUT, higher-dimensional analysis and new visualization techniques.

6540-34, Session 6

Network of wireless gamma-ray sensors for radiological detection and identification

A. P. Barzilov, P. C. Womble, I. Novikov, J. Paschal, J. Board, K. Moss, Western Kentucky Univ.

The emergent threat of improvised nuclear and radiological dispersal devices has elevated the demand for autonomous radiological detection sensors that have a cost-effective and operationally-effective design. They should provide high sensitivity and low false alarms. We are developing a system of wireless radiological sensors that can operate in common network architecture. The system is intended for gamma-ray detection and automatic identification of nuclear materials and radioactive isotopes. The sensor is a gamma-ray spectrometer that uses wireless technology to distribute the results. A small-size sensor module contains a lanthanum halide detector (or other scintillation detector) along with a credit card size data acquisition system, PDA, battery, and WiFi radio or a cell phone modem. The PDA with custom data acquisition and analysis software analyzes the accumulated spectrum on real-time basis and returns results to the screen reporting the isotopic composition and intensity of detected radiation source. The system has been programmed to mitigate false alarms from medical isotopes and naturally occurring radioactive materials. The decision-making software can be trained to indicate specific signatures of radiation sources like SNM. Results are stored in time-stamped files in the memory of the sensor, and transmitted to a remote computer database. The sensor is supplied with GPS tracker coupling radiological information with geographical coordinates. The sensor is designed for easy use and rapid deployment. The paper describes the design and development of a network of wireless gamma-ray sensors based on cell phone or WiFi technology.

6540-35, Session 6

An underwater system for explosive detection

V. Valkovic, D. Sudac, Institut Ruder Bo‰kovic (Croatia); D. Matika, Institute for Researches and Development of Defense Systems (Croatia); G. Nebbia, S. Pesente, Istituto Nazionale di Fisica Nucleare (Italy)

The location of an object on the bottom of the shallow coastal sea water is performed by optical means as well as by using data obtained from sonar and magnetometer. Once the presence of the anomaly is confirmed it is necessary to establish if it contains explosive charge. This task could be performed by using neutron sensor whose “vertex” is installed at the end of a retractable robotic arm. When positioned above the object, or to its side, the system inspects the object for the presence of the explosive by using 14 MeV neutrons.

Various versions of neutron sensor for the detection of explosive presence in the underwater object are characterized by the choice of sealed tube d+t neutron generator (with or without detection of associated alpha particles) and gamma detector (low or high energy resolution).

In order to evaluate various components and geometries a test basin containing sea water and sand was constructed. Components of the neutron sensor were placed inside a waterproof stainless steel box which could be moved up and down inside the basin.

Measurements were performed with sealed neutron generators with and without detection of associated alpha particles. Low energy resolution gamma detectors (BGO and NaI) were used. Monte Carlo calculations were performed for the design of the best shield between the detector and the neutron source.

The most common military explosives are characterized by H, C, N, O concentration ratios. Carbon signature was used in the present measurements. The sensor using neutron generator was found to have a superior performance since the detection of alpha particles defines the neutron beam which helps the reduction of the background.

6540-36, Session 7

Biological and chemical terrorism scenarios and implications for detection system needs

S. P. Gordon, Sandia National Labs.

Terrorists intent on causing many deaths and severe disruption to our society could, in theory, cause hundreds to tens of thousands of deaths and significant contamination of key urban facilities by using biological or chemical agents. The attacks that have occurred to date, such as the 1995 Aum Shinrikyo chemical and biological (CB) attacks and the 2001 Anthrax letters, have been very small on the scale of what is possible. In order to defend against and mitigate the impacts of large-scale terrorist attacks, defensive systems for protection of urban areas and high-value facilities from biological and chemical threats have been deployed. This presentation will review analyses of such scenarios and the efficacy of potential response options, will discuss defensive systems that have been deployed and detection systems that are being tested, and finally will outline the detection systems that will be needed for improved CB defense in the future. Sandia's collaboration with San Francisco International Airport on CB defense will also be briefly reviewed, including an overview of airport facility defense guidelines produced in collaboration with Lawrence Berkeley National Lab. The scenario and countermeasures analyses that will be discussed were conducted by Sandia National Laboratories' Systems Studies department in support of the Department of Homeland Security Science and Technology Directorate, and include quantitative analyses utilizing simulation models developed through close collaboration with subject matter experts, such as public health officials in urban areas and biological defense experts. Biological and chemical attacks and responses have been considered for exterior and interior environments.

6540-37, Session 7

Field-capable biodetection devices for homeland security missions

G. Dougherty, Lawrence Livermore National Lab.

Lawrence Livermore National Laboratory is a leader in the development and fielding of advanced liquid analysis systems for the detection of chemical and biological threats. Experience in bringing technologies from the basic research laboratory to integrated fieldable instruments suggests several key lessons for the engineering of these systems. This overview will cover a number of examples of such systems developed at LLNL, with emphasis on the modular components that they share, with emphasis on optical and photonic components. Several recent and ongoing research efforts exploring novel component technologies will be reviewed, including those targeting the critical area of front-end sample processing. Some observations about future opportunities for microfluidic analyzers will be presented.

6540-38, Session 7

Challenges and opportunities in nanotechnology for defense and homeland security

M. J. Heller, Univ. of California/San Diego

One of the grand challenges in nanotechnology is the development of fabrication technologies that will lead to cost effective nanomanufacturing processes. In addition to the more classical top-down processes such as photolithography, so-called bottom-up processes are also being developed for carrying out self-assembly of molecules and nanostructures into higher-order materials and devices. To this end, considerable efforts have been carried out on Layer-by-Layer (LBL) self-assembly processes as a way to make three dimensional structures. However, limitations of both passive and active LBL self-assembly processes provide considerable incentive to continue the development of better paradigms for this type of nanofabrication. Over the past decade, electronic microarray devices have been used to carry out the parallel addressing and selective binding of charged biomolecules such as DNA, RNA, biotin/streptavidin, and antibodies; as well as quantum dots, metallic and polymeric nanoparticles, cells and even micron sized semiconductor devices. More recently, we have developed an electronic microarray process for the rapid and highly parallel assisted self-assembly of protein and DNA derivatized nanoparticles into multi-layer structures. This process allows 3D structures with as many as forty alternating nanoparticle layers to be completed in less than one hour. Electric field assisted self-assembly represents an example of combining some of the best aspects of "top-down" and "bottom-up" technologies into viable process for the hierarchical assembly and integration of nanocomponents into 3D structures. Such a process will be useful for a variety of nanoelectronic, nanophotonic, energy conversion (fuel cells, photovoltaics, and batteries), nanocomposite material and therapeutic/drug delivery and biosensor/bioagent detection applications.

6540-39, Session 7

Portable field-capable decontamination system for chemical, biological, and radiological agents (SPEEDS)

N. L. Teta, Technical Solutions Group International; S. Darby Piedrahita, SPARTA, Inc.; R. Miceli, SPARTA, Inc. and U.S. Army Dugway Proving Ground

TECHNICAL SOLUTIONS GROUP INTERNATIONAL (TSGI) specializes in tactical-oriented products and solutions for high-risk situations and complex operations in both foreign and domestic arenas. This talk will provide an overview of TSGI products and provide a detailed description of SPEEDS, a self-contained and fully validated device for personnel CBRN decontamination during tactical operations in the field. SPEEDS is portable, rapid and effective. SPEEDS is the only validated CBRN tactical decontamination system available on the market. SPEEDS is currently deployed worldwide with DoD, OGA, state and local, and corporate security forces.

6540-40, Session 7

Saliva-based diagnostics for disease monitoring

D. T. Wong, Univ. of California/Los Angeles

The ability to monitor health status, disease onset and progression, and treatment outcome through non-invasive means is a most desirable goal in health care promotion and delivery. There are two prerequisites to materialize this goal: specific biomarkers associated with a health or disease state and the technologies to discriminate the biomarkers. Being able to engage these prerequisites on a noninvasive biofluid like saliva will be very helpful. A recent initiative catalyzed by the National Institute of Dental & Craniofacial Research (NIDCR) has created a roadmap to achieve these goals through the use of oral fluids as the diagnostic medium to scrutinize the health and/or disease status of individuals. This is an ideal opportunity to bridge state of the art saliva-based biosensors, optimized to disease discriminatory salivary biomarkers, for diagnostic applications. Oral fluid (saliva) is a perfect medium to be explored for health and disease surveillance. The translational applications and opportunities are enormous.

The UCLA School of Dentistry is engaged in both the technology development as well as molecular target harnessing from saliva for disease detection. The development of the Oral Fluid NanoSensor Test (OFNASET) and the cataloging of the human salivary proteome as well as the discovery of the salivary transcriptome for disease detection importantly advance this non-invasive diagnostic portfolio.

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6540-41, Session 7

Saliva-based early-warnings system for civilian exposures to health threats

S. O. Southern, GAIA Medical Institute

Terror attacks, industrial accidents and natural disasters produce a wide spectrum of factors that have adverse effects on human health. This presentation will review detection systems for these health threats, and describe a new early-warnings system developed by the Gaia Medial Institute. The new technology includes specific biomarkers, a microfluidic bioassay with photonic detection and advanced data analysis. The biomarkers provide a universal diagnostic platform for health threats. The platform is applicable to physical threats (radiation, heat, noise), chemical threats (toxins), biological threats (pathogens, injuries) and also psychological threats (fear). Threats are detected using an impact-oriented strategy that enables analysis of unknown threats such as new chemical and biological agents. The bioassay is suitable for microsamples of saliva as well as other types of tissues and biofluids. The biomarker panel is applicable to humans, animals and cultured cells. The new technology could contribute to the national Health Security in several ways including non-invasive personalized diagnostics of threat exposures, prediction of health outcomes, threat detection in sentinel animals and cells-on-chips biosensors, and monitoring mitigation efforts.

6540-42, Session 7

Environmental biomarkers: the challenge and the promise

T. L. Stewart, J. G. Pounds, A. L. Miracle, J. R. Campbell, Pacific Northwest National Lab.

Researchers are taking an integrated approach that uses new analytical, imaging, and computational tools to identify biosignatures of response to environmental stressors. Biosignatures are reproducible patterns of complex high-dimensional data, including expressed genes, proteins, metabolites, and lipids that describe a biological system stressed by the environment and/or disease. Bioinformatics and novel statistical approaches are critical to identify the information containing features, or biomarkers, from the biosignature. These biomarkers can be used as early, predictive indicators of an environmental stress or disease. The challenges to efficient discovery and implementation of biomarkers include 1) quantitatively identifying and defining the presence of environmental stressors and disease using emerging, multi-modal and non-invasive imaging modalities, 2) using efficient and integrated experimental design and methods to capture the appropriate biosignatures, 3) integrating heterogeneous data sets, 4) identifying patterns and confounding variables across datasets and experiments, 5) identifying biomarkers within the biosignature, and 6) developing and deploying sensor platforms on site or in clinic for rapid, sensitive, and economic measurement of biomarkers. The promise is the ability to predict events and threats early enough, i.e., pre-symptomatically, to take preventive action that reduces human suffering and economic impact. With the tools, the science, and the drivers now in place, we are poised to shape predictive risk assessment in the near future.

6540-43, Session 7

A simple nucleic acid dipstick for rapid field pathogen detection

H. Cai, Los Alamos National Lab.

A rapid, inexpensive, specific, sensitive and easy-to-operate pathogen diagnostic assay suitable for field use and point-of-care (POC) is urgently needed for early diagnosis of emerging infectious diseases (e.g. SARS and avian influenza) as well as potential biothreat attacks. However, current methods are either antigen/antibody-based immunoassays, which often fail to provide sufficient sensitivity, specificity and multiplicity, or PCR (polymerase chain reaction) amplification-based nucleic acid (NA) assays, which require elaborate instrumentation (e.g. micropipette for sample handling, centrifuge for NA extraction, thermal cycler for amplification, and fluorescence detector for signal read out) and extensive personnel training. To overcome these limitations, we propose to develop a integrated, sensitive, inexpensive (<$20/assay), and easy-to-operate nucleic acid-based dipstick device (of the size of ball point pen, like those in home pregnancy test strips) to detect and distinguish multiple pathogens in 60 minutes (incl the sample handling, NA extraction, amplification and visualization). Here, we report the sensitive detection of as little as a few copies of Bacillus anthracis DNA using isothermal amplification and nucleic acid dipstick assay. We are in the process to adapt this novel approach to develop a rapid field dipstick assay/device for the detection and distinction of pathogens that produce influenza-like symptoms incl SARS, Avian flu H5N1, Type A human flu, RSV and Parainfluenza etc. Specially, we will develop three critical components involved in a truly instrument-independent diagnosis kit: a simple NA extraction cartridge, isothermal assays and a nucleic acid lateral flow dipstick device.

6540-44, Session 7

System integration and development for BW agent surveillance

P. S. White, Los Alamos National Lab.

REVIEW: The search for integrated, multidisciplinary solutions to complex problems can be obscured by focus on individual components, allowing chokepoints to greatly limit overall system performance. Teams at LANL are working to identify, and provide technical solutions for critical system chokepoints for applications in BW agent surveillance, forensics and attribution, as well as data analysis and interpretation. This presentation will provide an overview of BW surveillance capabilities and programs at LANL, and provide more detailed discussion of a subset of them.

ABSTRACT: The development cycle of deployed solutions for decision makers involves a large number of components, working together to turn resources into decision recommendations. For many applications in BW agent surveillance, chokepoints exist that can be addressed with instrumentation, sample handling protocols and automation, assay development, or data analysis tools. Or even novel combinations of existing components. In this talk we will provide examples where we have identified and addressed critical chokepoints in systems for BW agent surveillance and screening applications, to include multiplexed assays and platforms and/or field deployable instrumentation and assays.

6540-45, Session 8

Effectiveness of electrostatic shielding and electronic subtraction to correct for the hole trapping in CdZnTe semiconductor detectors

R. B. James, A. E. Bolotnikov, G. S. Camarda, G. A. Carini, Y. Cui, Brookhaven National Lab.

Cadmium zinc telluride (CZT) is one of the most promising materials for the production of large-volume gamma-ray spectrometers and imaging arrays operable at room temperature. The performance of CZT devices, the global capacity for growth of detector-grade crystals, and the size of the commercial market have progressed steadily over the past 5-10 years. Because of deficiencies in the quality of the material, commercial high-resolution CZT spectrometers are still limited to relatively small dimensions (< 2-3 cm3), which makes them inefficient at detecting high photon energies (\> 1 MeV) and somewhat ineffective for weak radiation signals except in proximity to the source. The detectors are very attractive for a much broader range of spectroscopic and imaging applications; however, increases in their efficiency are needed without sacrificing the ability to spectrally resolve gamma energies. Achieving the goal of low-cost efficient CZT detectors requires progress in the following areas: better uniformity of detector response, growth of large uniform single crystals, and improved device fabrication procedures. Despite the current material constraints, several types of electron-transport-only detectors have been developed: pixel, coplanar-grid, cross-strip, drift-strip, orthogonal coplanar strip, and virtual Frisch-grid, some of which are now addressing important applications. This talk summarizes the material factors limiting performance of CZT detectors and provides new insight into the critical role of small-scale defects (i.e., tellurium-rich inclusions) on the energy resolution and efficiency of detectors. Conclusive data demonstrating the relationship between Te inclusions(size, concentration, and spatial distribution) and the performance of CZT detectors are presented, together with a model of charge trapping for electrons transiting through areas populated with Te secondary phases.

6540-46, Session 8

Transportable neutron-based probes for the detection of explosives and landmines

G. Vourvopoulos, Science Applications International Corp.

Several industries including the cement and coal industries have been using for the last 25 years neutron-based technology for the quantitative determination of various chemical elements either for quality control or for limiting environmental pollution. The same technology evolved in the last decade towards transportable probes capable of differentiating explosives and landmines from other innocuous materials. These probes use neutrons produced either from a radio-isotopic source, or from a neutron generator that can be turned on and off. Several types of probes will be described, their characteristic properties will be discussed, and test results will be shown.

6540-47, Session 8

The role of non-intrusive inspection technologies in nuclear-counter terrorism for homeland security

J. C. Rynes, U.S. Department of Homeland Security

No abstract available

6540-48, Session 8

Special nuclear material detection using pulsed neutron interrogation

F. H. Ruddy, J. G. Seidel, R. W. Flammang, Westinghouse Electric Co.

The development of methods for detection of concealed Special Nuclear Material (SNM) is an important goal in order to prevent a terrorist nuclear detonation within the United States. SNM is the key constituent of nuclear weapons and improvised nuclear devices.

A new, non-intrusive neutron interrogation technique for detection of concealed SNM is being developed. This technique is a combination of timing techniques from pulsed prompt gamma neutron activation analysis with silicon carbide (SiC) semiconductor fast neutron detector technology. SiC detectors are a new class of radiation detectors that are ultra-fast and capable of processing high count rates. SiC neutron detectors can operate during and immediately following intense neutron or gamma-ray bursts, providing the ability to detect the prompt neutron emissions from fission events produced in concealed SNM by the bursts on a much faster time scale than has been achieved by other techniques.

Neutron-induced fission neutrons in 235U have been observed in the time intervals during and between pulses of 14-MeV neutrons from a deuterium-tritium electronic neutron generator. Source neutron pulsing and time-sequenced fission-neutron counts were carried out on a hundreds of microseconds time scale, enabling the observation of prompt fission neutrons induced by the die-away of thermal neutrons following the 14-MeV pulse. Initial measurements, emphasizing the detection of SNM using thermal-neutron induced fission were reported at this meeting last year. More recent measurements, which have resulted in dramatic improvements in both the detection sensitivity and signal-to-noise ratio, will be reported.

6540-49, Session 8

Fast digitization and discrimination of prompt neutron and photon signals using a novel silicon carbide detector

B. W. Blackburn, J. T. Johnson, S. W. Watson, Idaho National Lab.; F. H. Ruddy, Westinghouse Electric Co.; D. L. Chichester, Idaho National Lab.

No abstract available

6540-50, Session 8

Neutron and photon dosimetry using plastic scintillators in pulsed radiation fields

D. L. Chichester, B. W. Blackburn, J. T. Johnson, D. T. Rohrbaugh, Idaho National Lab.

No abstract available

6540-51, Session 8

Statistical signal processing for UXO fill material classification using pulsed fast/thermal neutron analysis

S. L. Tantum, Duke Univ.; C. Shyu, D. T. Holslin, Science Applications International Corp.; L. M. Collins, Duke Univ.

Pulsed fast/thermal neutron analysis (FPTNA) has been developed for non-intrusive and non-destructive examination of closed containers to classify and/or identify the material within. This technique utilizes pulsed neutrons to induce gamma ray emissions from the interrogated target. The emitted gamma ray energies are characteristic of the nuclei with which the neutrons interacted. Thus, classification and/or identification of the material within the closed container can be achieved via PFTNA. Therefore PFTNA is a viable technology for classification and identification of UXO fill materials. The conventional approach to analyzing the gamma ray spectra is to estimate the elemental composition by utilizing measured elemental spectral responses and applying a least squares estimation technique. In this work, alternative approaches to analyzing the gamma ray energy spectra for UXO fill material classification and identification are presented. The alternate spectral analysis techniques include principal components analysis (PCA) and a variant of the multiple signal classification (MUSIC) algorithm. These spectral analysis techniques produce features which are then utilized within a Bayesian framework for fill material classification and identification. Classification and identification results obtained using both simulated gamma ray spectra and gamma ray spectra data measured with the PELAN system are presented. The results indicate that the proposed signal processing approaches provide better performance than conventional elemental composition estimation by least squares analysis.

[This work is supported by ESTCP.]

6540-52, Session 8

Active millimeter wave detection of concealed layers of dielectric material

N. J. Bowring, Manchester Metropolitan Univ. (United Kingdom); J. G. Baker, The Univ. of Manchester (United Kingdom); N. Rezgui, M. Southgate, Manchester Metropolitan Univ. (United Kingdom)

Extensive work has been published on millimetre wave active and passive detection and imaging of metallic objects concealed under clothing. We propose and demonstrate a technique for revealing the depth as well as the outline of partially transparent objects, which is especially suited to imaging layer materials such as explosives and drugs.

The technique uses a focussed and scanned FMCW source, swept through many GHz to reveal this structure. The principle involved is that a parallel sided dielectric slab produces reflections at both its upper and lower surfaces, acting as a Fabry-Perot interferometer. This produces a pattern of alternating reflected peaks and troughs in frequency space.

Fourier or Burg transforming this pattern into z-space generates a peak at the thickness of the irradiated sample.

It could be argued that though such a technique may work for single uniform slabs of dielectric material, it will give results of little or no significance when the sample both scatters the incident radiation and gives erratic reflectivities due to its non-uniform thickness and permittivity . We show results for a variety of materials such as explosive simulants, powder and liquid, both alone and concealed under clothing or in a rucksack, which display strongly directional reflectivities at millimeter wavelengths, and whose location is well displayed by a varying thickness parameter as the millimetre beam is scanned across the target.

With this system we find that samples can easily be detected at standoff distances of at least 4.6m.

6540-53, Session 8

Non-scanning x-ray backscattering inspection systems based on x-ray focusing

M. Gertsenshteyn, V. Grubsky, G. D. Savant, T. P. Jannson, Physical Optics Corp.

Non-invasive real-time bulk detection and identification of high explosives and improvised explosives, illicit materials hidden in suitcases, vehicles, containers or behind metal and non-metal walls are of critical importance for safety and security worldwide. Existing techniques for non-invasive detection such as microwaves, acoustic, thermal and terahertz- and mm-wave imaging systems penetrate only selected materials. Scanning X-ray pencil beam backscatter imaging systems can penetrate many materials, but they are bulky, and ineffective at standoff distances and on moving targets. This paper discusses a non-scanning, portable, real-time detection X-ray backscattering system based on novel lobster eye X-ray focusing optics. The system focuses backscatter photons from an obscured object several meters away that is being irradiated by short high-power X-ray pulses. The ability of lobster-eye lenses to focus X-rays allows such an imaging system to collect more photons into a smaller spot than traditional scanning or pinhole systems. This results in a higher signal-to-noise ratio and better spatial resolution. The gated X-ray camera will support high-resolution backscatter imaging analysis enabling obscured target recognition. Real-time image acquisition/ processing hardware and software will collect X-ray backscatter target imagery produced by lobster-eye optics from each X-ray pulse. The images can be further enhanced by software processing, which allows reconstruction of the object with high accuracy for detection with high probability and a low false alarm rate.

6540-54, Session 8

Bimodal detection of underground detection in two dimensional systems

M. F. Serrano-Guzman, I. Y. Padilla, R. Rodriguez, Univ. de Puerto Rico Mayagüez; C. M. Rappaport, Northeastern Univ.

An environmental issue that has reached interest in the academic and industry is groundwater contamination. Moreover, government agencies are concerned, for example, about the widespread of dense non-aqueous phase liquids (DNAPLs) in the underground due to incorrect disposal of this substance. Over the last five years we have done a great effort to enhance Cross Well Radar as a technology for detection of compounds which can be used to predict the mobility and persistence of chemicals in the unsaturated near surface. Image acquisition and processing has also been applied for contaminant detection and monitoring.

In this paper, we describe a two-dimensional multiphase flow experiment that was designed to develop and evaluate two modes of concurrent detection and monitoring technologies: Cross Well Radar (CWR) and Image Analysis (IA). DNAPL transport experiments are conducted in unsaturated soil under transient conditions. Loop antennas preset at specific locations are used to evaluate wave scattering properties in the presence of contaminants, while color images are acquired. CWR and IA are used to establish the relation between electrical soil properties variations and changes spatial and temporal mass of contaminants. The technologies used in this research are both in development, but they can be successful tools for the detection, monitoring and imagining of underground contaminants and process. Once develop, the technology may be applied for detection and monitoring of other buried objects.

6540-55, Session 8

Neutron and Gamma generators developed at LBNL for homeland security applications

J. Reijonen, N. Andresen, F. M. Gicquel, R. A. Gough, T. V. Kalvas, M. J. King, T. P. Lou, J. H. Vainionpaa, S. B. Wilde, Lawrence Berkeley National Lab.

There is a growing urgency in developing suitable neutron- and/or photon-sources for homeland security applications. The Plasma and Ion Source Technology Group has been active in developing high yield D-D, D-T and T-T fusion reaction based neutron generators but also in developing nuclear reaction based high energy gamma generators. One common feature in these various devices is the use of high efficiency RF-induction discharge ion source. This discharge method provides high plasma density for high output current, high atomic species from molecular gases for high efficiency neutron or gamma generation and long lifetime. Predictable discharge characteristics of these plasma generators allow accurate modeling for both the beam dynamics and for the heat loads at the target spot. During the past few years, the Plasma and Ion Source Technology Group has developed, fabricated and delivered various neutron generator systems for multiple U.S. and foreign entities. Current status of the current neutron and gamma generator development with experimental data will be discussed in this presentation.

6540-57, Session 8

Remote explosive and chemical agent detection using broadly tunable min-infrared external cavity quantum cascade lasers

T. Day, M. J. Weida, M. B. Pushkarsky, T. J. Rayner, Daylight Solutions

Civilian soft targets such as transportation systems are being targeted by terrorists both with IEDs and suicide bombers. Although explosive detection technologies exist and are used effectively in aviation, these technologies do not lend themselves well to protecting open architecture soft targets, as they are focused on a checkpoint form factor which limits throughput. However a remote detection capability of explosives and other chemicals would enable these kinds of targets to be protected without interrupting the flow of commerce.

Tunable Mid IR Laser technology offers the opportunity to detect explosives and other chemicals remotely and quickly. Most chemical compounds, including explosives have their fundamental vibrational modes in the mid-infrared (3 to 15µm). There are a variety of techniques that focus on examining interactions that have proven effective in the laboratory but could never work in the field due to complexity, size, reliability and cost. Daylight Solutions has solved these problems by integrating quantum cascade gain media into external tunable cavities that has resulted in miniaturized, broadly tunable mid-IR laser sources. The laser sources have a capability to tune to +/- 5% of their center wavelength which means they can sweep through an entire absorption spectrum to ensure very good detection and false alarm performance compared with fixed wavelength devices. These devices are also highly portable, operate at room temperature, generate 10's to 100's of mW in optical power in pulsed and continuous wave configurations. Daylight Solutions is in the process of developing a variety of standoff explosive and chemical weapon detection systems using this technology.

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6541-02, Session 1

A custom LWIR microscope for high-speed temperature measurements

J. I. Barletta, J. O. M. Karlsson, Z. M. Zhang, Georgia Institute of Technology

A custom infrared microscope was designed to measure the temporal and spatial temperature distribution of a thin, 50-micron wide stainless-steel filament that heats at 1 million °C/s. Using a MCT detector sensitive in the 9 to 10 micron wavelengths and two aspheric lens the microscope achieved a 7x magnification with a dynamic range of approximately 0 to 800 °C (blackbody). Video images at 96 x 96 pixels of the heating event were acquired at rates of approximately 2800 fps. However, a variety of optical and technical challenges made conversion from detector counts to temperature difficult. Calibration of the camera at these speeds required attention to the rapid intensity change of the steel, so a special setup was developed to calibrate the system's radiosity measurements. Additionally, diffraction at this magnification and these wavelengths significantly reduced the spatial resolution. An additional post-processing deconvolution step was implemented using an optical transfer function determined through experimentation with bar targets. Furthermore, the emissivity of the stainless steel was found to be specular and temperature dependent while also being greatly effected by surface oxidation. A variety of experiments were required to determine a suitable emissivity correction. Although originally an elusive task, accurate temperature measurements using these methods were obtained which correlated well with computer simulations of the temperature distribution.

6541-04, Session 1

The effects of surface reflection and surrounding environment on target temperature estimation using an infrared FPA

M. Voigt, Siemens Corporate Research; D. H. LeMieux, V. Jonnalagadda, Siemens Power Generation

To improve the accuracy of temperature estimation for enclosed objects with reflective surface properties, the surface emissivity, reflectance, geometry and incident radiation from the surrounding environment can be considered. This paper describes a basic model of the incident radiation on a FPA sensor element considering a target object, surrounding environment, surface temperatures, surface emissivity/reflection and optics. The model is used to characterize the direct (one color method) temperature estimation error as a function of the reflection and the geometry of the environment in near infrared. Two approaches to improve the temperature estimation accuracy are discussed. The first approach focuses on the estimation of maximum temperatures in the scene. The second approach is based on the idea to recover the thermal emitted surface radiation from the mixture of measure reflected and thermal emitted radiation.

6541-05, Session 2

Application of visible image mixing function for thermography

A. Ichikawa, Nippon Avionics Co., Ltd. (Japan)

By combining visible image with thermal image, Image mixing function allows you to pinpoint location of hot spot or cold spot on the object. Mixing image data are gathered from wide variety of application including R&D, PPM and process monitoring.

6541-06, Session 2

Benefits of IR/visible fusion

R. N. Schmidt, Fluke Thermography

For years thermogaphers have wanted images with fine infrared detail and a wide field of view (FOV). Fusion of a wide FOV visible image with a smaller FOV infrared image provides just that at a nominal cost. The major benefit of this technology is that the camera operator can identify the exact location and temperature of infrared points-of-interest in a visible picture. Thermographers can see infrared problem areas on wide FOV visible image. Maintenance technicians now have a direct couple between visible pictures and infrared identified problem areas. Building inspectors for example can use this to advantage in negotiations and legal arbitration and litigation needs. Commercial cameras with IR/visible fusion technology have been available for about a year. This paper will present real case applications for a number of different uses.

6541-07, Session 2

High-speed short-wave infrared (SWIR) imaging

D. S. Malchow, Goodrich Corp.; M. H. Ettenberg, Sensors Unlimited, Inc.; J. Battaglia, Goodrich Corp.

Imaging in the Short Wave Infrared (SWIR) provides unique surveillance capabilities, both with passive illumination from the night glow in the atmosphere or with active illumination from covert LED or eye-safe lasers. Spectral effects specific to the 0.9 to 1.7 um wavelength range reveal camouflage and chemical signatures of ordinance. Increased military interest in cameras that image all laser range finders and target designators on the battlefield has driven development of a new class of uncooled InGaAs cameras with higher resolution and larger field of view than previously available. Current and upcoming needs include:

* range gating the camera to image through obscurants or beyond unimportant objects; and

* high speed capture of muzzle flare, projectile tracking, guide star and communications laser-beam tracking and wavefront correction.

This paper will present images from new COTS cameras now available, showing high speed images and spectra of small arms weapons and rifles.

6541-08, Session 2

Retrieval of air quality information using image processing technique

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, Univ. Sains Malaysia (Malaysia)

This paper presents and describes an approach to retrieve concentration of particulate matter of size less than 10- micron (PM10) from Landsat TM data over Penang Island. The objective of this study is test the feasibility of using Landsat TM for PM10 mapping using our proposed developed algorithm. The development of the algorithm was developed base on the aerosol characteristics in the atmosphere. This study is unique because the algorithm used a combination of reflectance measurement from the visible bands and the corresponding apparent temperature values of the thermal band. PM10 measurements were collected using a DustTrak Aerosol Monitor 8520 simultaneously with the image acquisition. The station locations of the PM10 measurements were detemined using a hand held GPS. The digital numbers were extracted corresponding to the ground-truth locations for each band and then converted into radiance and reflectance values. The reflectance measured from the satellite [reflectance at the top of atmospheric, * (TOA)] was subtracted by the amount given by the surface reflectance to obtain the atmospheric reflectance. Then the atmospheric reflectance was related to the PM10 using regression analysis. The surface reflectance values were created using ACTOR2 image correction software in the PCI Geomatica 9.1.8 image processing software. The proposed developed algorithm produced high accuracy and also showed a good agreement (R =0.8406) between the measured and estimated PM10. This study indicates that it is feasible to use Landsat TM data for mapping PM10 using the proposed algorithm.

6541-09, Session 3

The importance of spatial resolution in IR thermography temperature measurement: three brief case studies

R. P. Madding, G. L. Orlove, B. R. Lyon, Infrared Training Ctr.

This paper discusses the differences in temperature measurement among three infrared (IR) cameras with different spatial resolutions. The targets used were actual field problems. This was not a laboratory experiment, but a real-world test of these cameras. Images were taken under the same conditions at the same distance with all the IR cameras. The results show there can be dramatic differences in temperature readings illustrating the importance of adequate resolution when making temperature measurements with IR cameras.

6541-10, Session 3

How water behaves thermally

J. R. Snell, R. W. Spring, Snell Infrared

Water is a remarkable substance in many regards, not the least of which is the fact that it often easily exists in all three phases, gas, liquid and solid, at terrestrial temperatures. It also readily evaporates, has the highest thermal capacitance of any common material, and is quite conductive to heat in liquid and solid phases. In its gas phase it is also highly absorbing of infrared radiation.

For all these reasons, and more, thermographers must have a full understanding of how water behaves thermally. This presentation will discuss the relevant fundamentals and behaviors including conduction, capacitance and evaporation and the interaction among several behaviors at one time. The presentation will be illustrated with thermal images and the discussions grounded in the practice of thermography, especially for building scientists.

6541-11, Session 4

Application of thermographic imaging in exotic animal medicine

M. T. Walsh, Univ. of Florida

No abstract available

6541-13, Session 4

Thermal imaging in preventive maintenance and safety applications for mining

P. Pregowski, Pregowski Infrared Services (Poland); J. Cuber, D. Babecki, P. Wiszniowski, EMAG (Poland)

Due to exceptionally hard environmental conditions and complexity of applied equipment, an extraordinary set of threats and events can occur in every underground coal mine. Some of these threats are beyond absolute control of man and machine. In such conditions, maximizing opportunities of preventing injury or death to miners or to rescue and recovery personnel, plays a particularly important role. We intend to present the results of IR thermographic camera applications for various categories of tasks: person relocation, rescue or fire fighting as well as searching for thermal signatures of defects and natural hazards. This type of thermal imaging and thermography implementation may be very effective, although presages difficult, sometimes extremely hard conditions of IR surveys - both for camera and its operator.

6541-15, Session 5

Investigations of proton beam entry window cooling of liquid metal target of spallation neutron source using infrared thermography

J. A. Patorski, F. Groeschel, Paul Scherrer Institute (Switzerland)

During the integration test (MIT) of the MEGAPIE neutron spallation source target the infrared thermography (IRT) has been used to investigate the liquid metal (LM) lead-bismuth eutectic (LBE) alloy cooling of the proton beam entry window of the target. Investigations have been performed few months before of proton irradiation started in August 2006 at PSI SINQ facility; for more details see web page http://megapie.web.psi.ch/ . Goals of thermo-hydraulics investigations of the liquid LBE “flow in flow” cooling (the ca. 1.25 m/s speedy by-pass jet flow into the slower ca. 0.33 m/s main flow) of the steel window, have bifocal perspective. On one hand the goal was visualization for an observation of time and geometrical changes of the cooling field pattern of the by-pass jet flow, i.e. the qualitative behavior of the cooling in terms of the sufficient covering of the proton beam irradiation “foot print” area. On second hand the goal was determination of local convection heat transfer coefficient (HTC) on the steel wall of the proton beam entry window area of the MEGAPIE target, i.e. the quantitative distribution of cooling.

For the qualitative visualization of the real target window cooling we have take advantage of slightly higher temperature of the LBE by-pass jet flow streaming (ca. 3°C) and we have performed so called “MIT-Warm-Jet” experiment series. For the quantitative determination of HTC instead of the real target window we have used specimen sensor dish and performed so called “MIT-KILOPIE” experiment series using the two dimensional and dynamic infrared thermography (2DD-IRT) method [1].

The results of measurements are presented in form of IRT thermograms or thermogram sequences which are extracted from the raw temperature field measurements.

References:

[1] J.A.Patorski & F.Groeschel, “Experimental determination of local convection heat transfer coefficient field using two-dimensional and dynamic infrared thermography (2DD-IRT) method”, Thermosense XXVIII, Jonathan J. Miles, G. Raymond Peacock, Kathryn M.Knettel Editors, Proceedings of SPIE Vol. 6205, 2006, April, SPIE The International Society for Optical Engineering, Bellingham, Washington 98227-0010 USA

6541-16, Session 5

Evaluation of land surface temperature retrieval over Mecca by digital image processing

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, Univ. Sains Malaysia (Malaysia)

An algorithm has been developed using Landsat TM thermal channel for the retrieval of land surface temperature (LST) over Saudi Arabia. The objective of this study was to demonstrate the effectiveness of Landsat TM 5 imageries in mapping Land Surface Temperature. The data used was captured by Thematic Mapper (TM) sensor onboard the Landsat 5 satellite. Landsat TM has only one thermal band, and therefore the spilt-window algorithm cannot be used for the retrieval of LST. We used mono window technique in this study. The proposed LST algorithm included three parameters, brightness temperature, surface emissivity and incoming solar radiation in the algorithm regression analysis. The correlation between the LST and the brightness temperature had increased significantly after the surface emissivity and solar zenith angle were included in the algorithm. The reference values LST were determined using ATCOR2_T in the PCI Geomatica image 9.1 processing software for algorithm calibration. The results indicate that LST values retrieved from remotely sensed data were strongly dependent on the surface emissivity and solar zenith angle.

6541-17, Session 6

Automated applications of the infrared imagers in the automotive assembly lines: products and process control

M. A. Omar, Clemson Univ.; O. Suzuki, Hitachi, Ltd. (Japan); J. Liu, Toyota Motor Manufacturing Kentucky

This work discusses the automated application of the micro-bolometric and the photonic cooled infrared arrays, in the context of the automotive assembly operations. Such usages comprise: static thermographic applications as in seam welding, protective coating coverage inspection, and Seed detection on newly painted car shells; in

addition to dynamic applications as in porosity and delaminations evaluation. This discussion will also include a variety of processing algorithms dedicated for handling the acquired infrared sequences or scans. Challenges in emissivity variations, sensor saturation, and surrounding contribution are also discussed, with some possible solution schemes introduced. The physics and detection methodology are presented through modeling and simulation work. A further development in the accurate temperature mapping is briefly presented for the automotive die-casting and forging stations; using a multi-spectral approach.

6541-18, Session 6

Arc-welding process control based on back face thermography: application to the manufacturing of nuclear steam generators

A. Cobo, J. M. Mirapeix, O. M. Conde, P. B. Garcia-Allende, F. J. Madruga, J. M. López-Higuera, Univ. de Cantabria (Spain)

The possibility of reducing defects in the arc welding process has attracted research interest, particularly, in the aerospace and nuclear sectors where the resulting weld quality is a major concern and must be assured by costly, time-consuming, non-destructive testing (NDT) procedures. One possible approach is the analysis of a measurand correlated with the formation of defects, from which a control action, like changing the welding speed, is derived. Among others, the thermographic analysis of the weld pool and the heat-affected zone has proven to be a useful technique, since the temperature profile of the material being welded has a clear correlation with the process parameters.

In this paper, we propose a control system for the submerged-arc welding (SAW) process, based on thermographic analysis from the back face of the joint. It is intended for defect reduction in the welding of shell sections of nuclear steam generators, for which top face inspection is not possible, while visual inspection by an operator from the back face (inside the generator) has safety concerns.

From the thermal image, the proposed system identifies the weld pool and its temperature profile, from which the condition of full penetration without perforation is checked. Preliminary results using a ThermaCAM SC2000 are discussed in the paper. Additionally, a study of the feasibility of using a colorimetric approach with a conventional CCD color camera for temperature estimation is presented. It is possible since the temperature of the weld pool is around 900 ºC, with significant light emission in the visible spectrum. As an additional advantage of this alternative, a critical defect to be corrected, perforation, is easily detected as plasma emission from the arc.

6541-19, Session 6

Survey of thermal profiling in electronics quality characterization

S. Hsieh, Texas A&M Univ.

This paper surveys the current state of thermal profiling for electronic faults, defects detection and reliability investigation. Issues essential to the successful application of infrared techniques to electronics manufacturing and circuit card maintenance are investigated. These issues include basic know-how such as scanning time intervals and screening variables; a description of the types of defects and faults these methods have been used to detect; and a comparison of infrared thermal imaging and other detection means, such as X-ray and functional testers. The work concludes with a summary of potential problems and remedies. Future directions include design for infrared diagnosis, development of integrated testing techniques for detection and root-cause analysis, and thermal profile library development.

6541-20, Session 6

Application of on-line infrared thermography in steel making industry

M. Viale, O. A. Martin, Ternium (Argentina)

This work is about three real applications in the steel industry where the infrared technology is used online, to control the process and to increase safety.

All the applications where developed by the automation group of Ternium-Siderar. The main objectives to use the infrared thermography in steel plant are to reduce production costs and to prevent mayor damages.

The first work is about automatic slag detection during the tapping operation of the BOF converters by thermographical image processing. The benefit is to reduce fluxes due to less slag passing and also to eliminate the ladle recirculation for excessive slag. Additionally, the steel shop process engineers are using the camera information to estimate some other process variables. There is a project to make all the BOF tapping fully automatic, using the camera information.

The second work is about on-line ladle hot spot detection. A failure of the ladle refractory bricks may cause damages in the ladle car, mechanical equipment, and cabling in the ladle furnace. To detect these failures, a system of four infrared cameras with an image processing software was developed. Also in future applications, the thermal information is going to be used for data correlation with other process variables.

The third one is in the sinter plant, where the camera temperature information is used to optimize the process control. Before the system installation, there was not available information about the sinter material temperature. Nowadays there is an on-line information that is used to close the control loop.

6541-21, Session 6

Process control monitoring of gasification units in petrochemical and power plants

G. E. Strahan, Infrared Cameras, Inc.

This paper describes the applications of wireless radiometric imaging technology to the monitoring and control of various process points in gasification units in petrochemical production facilities and in power plants.

Thermal images are displayed in a spectrum of colors from dark blue for the coolest temperatures to red/orange/yellow for the hottest. The colors are keyed to a temperature graph covering the range of temperatures encountered in the particular system. The operator can cross-reference a color to a temperature graph located alongside an image on the same screen.

Several other past and future petrochemical applications will also be discussed.

6541-23, Session 6

Images processing and flow measurement applied to the thermographic analysis of heat-losses in boilers' isolation

M. A. Hurtado, H. Benítez, H. Loaiza, Univ. del Valle (Colombia); J. Millan, Anter Ltda (Colombia); J. A. Gonzalez, Univ. del Valle (Colombia); C. Ibarra-Castanedo, Univ. Laval (Canada)

Infrared thermography is a non-contact evaluation technique which allows not only the registration of the temperature distribution on a surface, but also the calculation of the amount of heat flowing through it. Boilers are important for industry and the quantification of the heat losses is beneficial to avoid fuel waste.

The present work suggests a methodology to calculate the thermic flow through boiler's isolation surfaces, using thermic images. With this, it is possible to find the flow by using a thermogram taking into consideration: the thermogram's range, knowing the camera's FOV,

surface's emmisivity and characteristic length, object-to-camera distance, environmental temperature, and the assigned grey-level calibration curve to determined temperature range.

A software tool to upload and process the information was developed. This tool can calculate the surface's average convection coefficient hc by using empiric correlations developed for common geometries and heat transfer equations to calculate the thermic flow.

To test the technique functioning, the information given by the software tool was compared to the data given by the heat flow measurement thermal sensor. This comparison showed a 3% error range of relative error. The final validation was made on a waterwall-boiler´s home isolated walls and the highest error obtained was close to 15%.

Regardless the calibration curve was found under laboratory conditions and the empiric correlations to calculate hc are for isometric surfaces, the methodology presented a good performance. This then is a first step to quantify the global heat losses on boiler's isolation surfaces.

6541-24, Session 7

Building thermography surveys for moisture detection and assessment

N. P. Avdelidis, EBETAM S.A. (Greece)

Usually, building moisture surveys are performed using moisture-detecting equipment other than infrared imaging. These include non-destructive and penetrating moisture meters. Both types of these moisture meters require direct contact with the building material surface, as well as considerable amount of time necessary to "scan" all surfaces of the building being surveyed. Because contact is required, hard to reach locations limit the effective use of moisture meter instruments. In contrast, an infrared camera detects moisture by imaging the different temperatures of wet versus dry building materials. On the other hand, building assessments for water detection can routinely be performed using an infrared - thermal imaging system (i.e. it can locate probable wet conditions of building material surfaces). In this work, infrared camera surveys were performed at various locations in buildings to evaluate moisture in building materials and surfaces. The rapid IR camera surveys allowed for hard to reach area evaluation, quick survey of the buildings, as well as provided images for the survey report. Results indicate that thermography allows for non-destructive detection of water entry, quick survey of an area, automatic visual documentation and images that can reveal potential threats to the building.

6541-25, Session 7

A nondestructive method for diagnostic of insulated building walls using infrared thermography

M. Larbi Youcef, A. Mazioud, Univ. Paris 12 Val-de-Marne (France); P. Bremond, Cedip Infrared Systems (France); L. Ibos, Y. Candau, Univ. Paris 12 Val-de-Marne (France); M. Piro, EDF (France)

This work deals with the development of an experimental protocol for the diagnostic of multi-layered insulated building walls. This study is a part of a project which aims at supplying a control method for conformity of the heat insulation of buildings after restoration, which represents 60 % of the flats park in France.

First, a test bench is set up in order to measure front and back sides temperatures of standard panels. Theses panels are compounded of 1cm of plaster and various thicknesses of polystyrene. The panels considered in this study have thicknesses of respectively 2, 6 and 10cm. The front side is heated by two halogen lamps of 500 W. The temperature measurements during an exposure time te of heating and subsequent cooling are carried out with thermocouples and a long wave infrared camera (CEDIP Jade LWIR with Altair Software).

In a second time, a one-dimensional model based on thermal quadruples and Laplace transforms was developed under Matlab environment. The model simulates a two-layered wall heated with a constant power P on its front side and using constant global convective heat transfer coefficients on front and back sides. Also, we developed a three dimensional model based on finite volumes using Fluent computational code.

Finally, a method of identification of physical parameters is developed by performing a least-square minimization based on Levenberg-Marquardt method. The experimental measurements are compared to theoretical results and by minimization we obtain the thermal conductivity and diffusivity as well as the thickness of the two layers.

6541-26, Session 7

Integration of optical, active, and passive IRT procedures for characterization of restoration mortars surface

N. Ludwig, Univ. degli Studi di Milano (Italy); E. Rosina, Politecnico di Milano (Italy)

Texture of the material affects the distribution of surface temperature, especially at transient condition. Moreover, the roughness of surface has some influence on both water and radiation absorbance of the surface. The research starts from the observation in the field of the degradation behaviour of different texture of mortars with high RH rate and low ambient temperature: textures obtained with hard tools (e.g. spatula, trowel) have harder surfaces, more compacted, which facilitate the condensation of water vapour; on the contrary, use soft tools (sponge, sponge float) causes rough surface of the finishing, which facilitate the absorption and evaporation of moisture. In case of contiguity between two different finishing, the edges of rougher surface (around more compact texture) show major damage.

Early detection of these risk areas, by use of IRT, is a great deal for preservation of historical buildings without a controlled heating, ventilation and air conditioning system, and an advancement for the restoration techniques of precious surfaces. For that, authors studied the surfaces properties of responding to thermal stimulation and humidity exchange between surfaces and ambient, by means of thermographic technique both in active and passive approach. Measurements of the reflectance in the visible-NIR spectral band (400-1100 nm) and emissivity in the thermal IR (8-14 micron) allowed to verify differences in thermal effusivity of the external layers of the samples with different finishing. As a conclusion, the comparison between thermal behaviour and localization of mortar grains allows to evaluate how much the finishing techniques affect the thermal characteristics.

6541-27, Session 7

Trestles anyone? a thermographic nightmare

J. L. Grossman, Hi-Tech Inspection Services, Inc.

Railroads are close to capacity and there is only so much that can be squeezed through a pipe. The result is insufficient equipment, longer trains, tighter schedules and of course the stretching of personnel. Now, imagine that as one of these freight trains, comprising among other things, chemical tankers and boxcars containing a variety of different materials (including hazardous materials) while crossing a river has the trestle collapse underneath it. Hundreds of thousands of pounds of steel, wood and of course the hazardous chemicals fall into the river, pollute the land and the river and shut down a port. Farfetched?

This paper will reveal the results of a unique thermographic inspection, the findings, the results and the protocols.

6541-28, Session 7

Requesting and specifying thermographic inspection services through National Master Specification (NMS) Canada

A. Colantonio, M. Theauvette, Public Works and Government Services Canada (Canada)

National Master Specification (NMS) is the generic specification format used extensively in the Canadian construction industry for the development of specifications used in bid documents for new and retrofitted commercial building projects. The NMS group, though consultations with the building industry and departmental experts in Public Works and Government Services Canada have developed four sections for commonly implemented infrared thermographic services associated with building construction and maintenance. These include inspection services for building envelopes, roofs, mechanical equipment, and electrical equipment. This paper will introduce these sections and discuss the relevant information in each section that is pertinent to each type of inspection service. The paper will highlight the important differences of each type of inspection that precipitated the need for individual sections for each type of infrared thermographic inspection service. These sections have been developed to include all aspects of such services and are all encompassing in their scope. The users of the NMS generic format are free to use and modify any part of these sections that are relevant to their building project. Building owners and property managers can also employ the specification format to call up services for building condition studies. Although the sections have been developed for use in the commercial building industry, the residential construction industry can modify any section for their use. This paper will discuss these differences, and provide suggestions for the development of such a residential specification format.

6541-29, Session 7

Building thermography as a tool in energy audits and building commissioning procedure

T. T. Kauppinen, VTT (Finland)

A Building Commissioning-project (ToVa) was launched in Finland in the year 2003. A comprehensive commissioning procedure, including the building process and operation stage was developed in the project. Similar to Cx-procedures used in the USA, this procedure will confirm the precise documentation of client's goals, definition of planning goals and the performance of the building. The method has been tested in pilot buildings and the aim is to develop it further in practical construction projects.

It is rather usual, that within 1-2 years after introduction the users complain about the defects or performance malfunctions of the building. Often the reasons are related to problems in building envelope, in building services, in HVAC-system, in automation system and, as combined effect, failures in indoor climate.

The performance has been tried to confirm by various quality control methods during design-, construction and mobilization stages. The completed building, however, has not been as such as the client has ordered or wanted.

Thermography is one important manual tool in verifying the thermal performance of the building envelope. In this paper the results of one pilot building (a school) will be presented.

In surveying the condition and energy efficiency of buildings, various auxiliary means are needed. We can compare the consumption data of the target building with other, same type of buildings by benchmarking. Energy audit helps to localize and determine the energy saving potential.

The most general and also most effective auxiliary means in monitoring the thermal performance of building envelopes is an infrared camera. In this presentation some examples of the use of thermography in energy audits are presented.

6541-30, Session 8

Heat-transfer mechanisms in fiber-reinforced polymer composites bonded to concrete

J. R. Brown, R. L. Baker, L. Kallemeyn, Hope College

This research project investigated heat transfer mechanisms that occur during radiant heating of glass/epoxy composites bonded to concrete. The ultimate goal is to develop a field procedure for estimating the thickness of fiber-reinforced polymer (FRP) composites used to strengthen existing reinforced concrete structures. Thickness is an important parameter in the design and implementation of nondestructive testing procedures that evaluate bond in FRP systems. Four concrete samples (15 cm x 30 cm x 5 cm) were constructed with glass/epoxy composite bonded to the surface. The thickness of the composite varied from 1mm to 4mm and thermocouples were placed at 1mm intervals throughout the composite. Experimental data was compared with a simple theoretical model that predicts the surface temperature response of a layered system subjected to a uniform heat flux. Two factors were shown to significantly influence the heat transfer mechanism: surface absorptivity of the FRP composite and convective cooling. Additional analytical modeling using the finite element method was performed to account for these affects in an effort to obtain a better estimate of FRP thickness based on experimental data.

6541-31, Session 8

Control of CFRP strengthening applied to civil structures by IR thermography

R. Trentin, E. G. Grinzato, P. G. Bison, S. Marinetti, Consiglio Nazionale delle Ricerche (Italy)

An increasing demand of checking the effectiveness of strengthening and repair intervention on structural components, both in buildings and bridges, promotes NdT methods. In particular when innovative materials as CFRP (Carbon Fiber Reinforced Polymer) are used, IR thermography exhibits excellent performances. Non destructive control by the use of thermographic analysis is used to detect adhesion defects or imperfections, which can lead the component to brittle and unexpected collapse. This paper shows as the geometrical evaluation of delaminated areas is carried out. Laboratory tests both on reduced or full scale are performed to set up and validate the proposed procedure.

An experimental study on samples bonded with FRP and containing defects appropriately applied at the interface, will be presented. A series of beams (10 m long) have been tested under bending loads and strengthened conditions, by placing a pre-impregnated thin carbon (CFRP) laminate at the intrados. Different reinforcement configurations have been adopted in the beams (ordinary steel reinforcement and with addition of prestressed strands), using mechanical devices for the anchorage of the supplementary pre-tension of the strips. At local level, the simulation of possible lack of bonding during loading or intrinsic defects and imperfections has been contextually analysed on specifically dimensioned samples.

Different algorithms have been applied at the evaluation stage in order to estimate the defect size and location. Particularly, the extension of the delamination is estimate with a simple and robust algorithm. In facts, the standards set the limit for acceptable defects, both in terms of number and size.

The most significant results of the experimental tests and the mathematical simulation obtained through the application of thermographic inspection on preliminary samples and full-scale beams are discussed in the paper.

6541-33, Session 9

IR thermographic inspection of filament wound CFRP shell samples

J. Lahiri, S. Kuchipudi, A. O. Siddiqui, Advanced Systems Lab. (India); V. P. Vavilov, Tomsk Polytechnic Univ. (Russia)

Thin Carbon Fiber Reinforced Plastic (CFRP) composites have proven to be a convenient object for transient thermal nondestructive testing (TNDT). Due to CFRP medium thermal diffusivity, surface temperature signals survive for a relatively long time. Blackbody-like optical properties of this composite ensure good absorption of heating radiation and efficient emission while the composite sample is monitored thermographically. Also, parts made of thin CFRP can be typically inspected in both one- and two-sided tests.

Inspecting thick (5-15 mm) CFRP composites of a curved (cylindrical) shape represents a more challenging task. First, the manufacturing technology (filament wound shell samples) results in chaotic anisotropy and, consequently, a higher surface and volumic noise. Second, curved shape of samples does not allow efficient heating of larger areas and surface thermal emission might deviate from lambertian character. Third, defects can be located through whole sample thickness, thus requiring heating optimization, e.g. substituting 'harsh' flash simulation with milder square-pulse heating. Nevertheless, one-sided tests of thick CFRP composites, even being optimized, are strongly limited by defect depths (up to 4-5 mm). Oppositely, in two-sided tests, it is typically impossible to pump enough energy into a sample to ensure a reasonable excess temperature on rear surface.

The paper is devoted to developing strategy of thermal NDT of thick CFRP cylindrical samples by studying the following issues: 1) determining anisotropic diffusivity, 2) analyzing noise statistics, 3) modeling 3D defect situations and developing inversion algorithms for estimating detection limits and evaluating defect parameters, 4) taking into account curved shape of samples, and 5) performing experiments and applying advanced image processing techniques in order to enhance signal-to-noise ratio and improve detection efficiency.

6541-34, Session 9

Development of thermal response spectroscopy technique for determination of defect parameters

T. Sakagami, D. Imanishi, S. Kubo, Osaka Univ. (Japan)

An inverse analysis method for the thermal response spectroscopy is proposed for quantitative measurement of size and depth of the defects. Sequential thermal response data observed on the surface of objective body under active step heating were processed by lock-in analysis scheme based on the Fourier series expansion. Fourier coefficients synchronizing with sine and cosine waves were calculated, and they are represented in spectroscopic diagram. Fourier coefficients data of certain defect depth and size obtained for various thermal fluctuation periods showed characteristic curves in the spectroscopic diagram. In this study, least residual inverse analysis scheme was applied to the defect parameter determination based on the Fourier coefficient values in the spectroscopic diagram.

6541-35, Session 9

Alternative approaches to modeling the thermographic NDT process

S. M. Shepard, Y. Hou, J. R. Lhota, J. Golden, Thermal Wave Imaging, Inc.

Modeling of active thermography using optical excitation has generally relied on either numerical (finite difference) methods, or analytical approaches based on an integrated Green's function that result in an infinite series solution. Unfortunately, these methods are too complex and require too much a priori knowledge of sample thermophysical properties to be useful to the typical NDT inspector. We have extended the series solution approach using observed properties of its logarithmic derivatives to create a closed form expression for the front surface temperature for a plate. That expression may also be used to generate a 2nd, simplified model that is suitable for use in normal NDT practice to determine inspection parameters based on simple estimates of material properties and infrared camera characteristics.

6541-36, Session 9

Defect quantification with reference-free thermal contrast and artificial neural networks

H. D. Benitez Restrepo, Univ. del Valle (Colombia); C. Ibarra-Castanedo, A. Bendada, X. P. V. Maldague, Univ. Laval (Canada); H. Loaiza, E. Caicedo, Univ. del Valle (Colombia)

Infrared nondestructive testing (IRNT) is a technique in which the specimen surface is thermally stimulated to produce a temperature difference between "sound" (free of defects) areas and eventual defective regions. It is well known that thermal contrast-based quantification methods are strongly affected by the non-uniform heating and the chosen sound area.

In previous works, Artificial Neural Networks (ANN) were used for defect detection and quantification. Different kinds of data have been proposed to train and test the ANN, for instances: raw temperature, time derivatives, TSR (Thermal Signal Reconstruction) polynomial fitting coefficients, phase, phase contrast and thermal contrast.

The thermal contrast approach allows evaluating defect visibility and enhancing image quality. However, the ANN defect detection and quantification is strongly affected by the selected reference point.

The Differential Absolute Contrast (DAC) has been successfully used as an alternative method to eliminate the need of a reference point by defining the thermal contrast with respect to an "ideal" sound area. The DAC technique has been proven effective to inspect materials at early times since it is based on the 1D solution of the Fourier equation. A modified DAC version using thermal quadrupoles explicitly includes the sample thickness in the solution, extending in this way the range of validity when the heat front approaches the sample rear face.

We propose to use ANN to detect and quantify defects in composite materials using data extracted from the modified DAC with thermal quadrupoles in order to decrease the non-uniform heating impact on the inspection.

6541-37, Session 9

Identifying hidden defects in thermal insulation of revolving kilns by IR thermographic monitoring

V. P. Vavilov, V. G. Torgunakov, Tomsk Polytechnic Univ. (Russia)

IR thermography is routinely used in monitoring quality of thermal insulation of revolving kilns used in cement production. As in many other IR thermography applications, a typical approach to nondestructive testing of kilns is essentially qualitative thus being limited by defect detection (a standard threshold procedure is used to enhance visibility of hidden defects). In order to evaluate some defect parameters, we have recently proposed a simple identification procedure which is based on solving a steady-state heat conduction problem (see proceedings of Thermosense-XXV, XXVI). The assumption of the steady-state heat conduction is an essential limit in improving efficiency of defect characterization. In practice, there are some transient phenomena which affect identification accuracy, namely, spatial/temporal variations in gas jet shape, local deficiencies of thermal insulation, wind speed and ambient temperature variations and intensive precipitations.

In the ongoing research, the above-mentioned non-stationary phenomena have been taken into account by solving a 1D heat transfer problem which involves the analysis of both the heat conduction in multilayer thermal insulation and the convec-tion/radiation heat exchange on kiln external surfaces.

The related mathematical problem is solved numerically. In order to avoid the problem divergence caused by insignificant temperature variations, only those temperature increments are considered which exceed a particular threshold, otherwise a steady-state procedure is applied.

The hardware of the developed IR thermographic line-scanning system remains as described elsewhere, and the new approach to quantitative defect identification is implemented in the system software with the system being currently explored at some Russian plants.

6541-39, Session 10

The application of thermal NDE to assist damage repair of the shuttle remote manipulator arm system

K. E. Cramer, P. Howell, NASA Langley Research Ctr.

This paper will present the application of infrared thermography to ensure quality by monitoring the preparation of composite material for repair. In this application infrared thermography is used to verify that sufficient removal of damaged material has occurred and that no collateral damage is introduced at the repair site. The paper will discuss the thermographic technique employed to inspect the Space Shuttles Remote Manipulator Arm System for damage after accidental impact in the Orbiter Processing Facility at Kennedy Space Center. A delamination, measuring 5.8cm long and 0.6cm wide, was found adjacent to one of two impact regions. The second region was confirmed to be damage free. Thermography can be performed rapidly (approximately 5 seconds for the entire inspection) and without surface preparation or the addition of coupling material, typical of ultrasonic inspection. Results presented will demonstrate the excellent agreement achieved between thermography and ultrasonic inspections, resulting in the ability of the thermography system to track the damaged material removal process.

6541-40, Session 10

Results of on-orbit testing of an extra-vehicular infrared camera inspection system

K. E. Cramer, P. Howell, M. Gazarik, NASA Langley Research Ctr.

This paper will discuss an infrared camera inspection system that has been developed to allow astronauts to demonstrate the ability to inspect reinforced carbon-carbon (RCC) components on the space shuttle as part of extra-vehicular activities (EVA) while in orbit. Presented will be the performance of the EVA camera system coupled with solar heating for inspection of damaged RCC specimens and NDE standards. The data presented was acquired during space shuttle flights STS-121 and STS-115 as well during a staged EVA from the ISS. The EVA camera system was able to detect flat-bottom holes as small as 2.54cm in diameter with 25% material loss. Results obtained are shown to be comparable to ground-based thermal inspections performed in the laboratory using the same camera and simulated solar heating. Data on both the time history of the specimen temperature and the ability of the inspection system to image defects due to impact will likewise be presented.

6541-41, Session 10

Infrared thermographic diagnostic aid to aircraft maintenance

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Thermographic data can be used as a supplement to aircraft maintenance operations in both back shop and flight line situations. Aircraft systems such as electrical, propulsion, environmental, pitot static and hydraulic/ pneumatic fluid, can be inspected using a thermal infrared imager. Aircraft systems utilize electro-hydraulic, electro-mechanical, and electro-pneumatic mechanisms, which if accessible, which can be diagnosed for faults using infrared technology.

Since thermograms are images of heat, rather than light, the measurement principle is based on the fact that with any physical object radiating energy at infrared wavelengths-(within the IR portion of the electro-magnetic spectrum), it can be accurately detected with infrared imaging equipment. All aircraft systems being tested with infrared are required to be energized for troubleshooting. However, fully operational aircraft can be utilized for collecting valuable baseline data which can be archived and referenced for future comparisons.

6541-42, Session 11

Detecting low-velocity impact damage in composite plates using infrared thermography

J. R. Brown, R. Anderson, Hope College; D. Visser, Hope Colege

This research investigated low velocity impact damage in fiber-reinforced polymer (FRP) composites. Small-scale glass/epoxy laminates (approximately 200mm x 200mm x 2mm) were subjected to varying degrees of dynamic impact energies ranging from 5 to 20 J and infrared thermography inspections were performed on the damaged specimens. Three distinct damage modes were observed: penetration resulting in highly localized fiber rupture through the thickness of the composite; penetration/delamination in which localized fiber rupture was observed on the impacted surface and additional delamination occurred around the point of impact; and delamination/reverse side fiber rupture in which no visible damage occurred on the impacted surface but fiber rupture and delamination occurred beneath the surface. A modified lock-in thermography procedure was used in the nondestructive evaluation (NDE). Phase images were constructed by applying a least-squares sinusoidal curve fit to a series of thermal images collected over one cycle of sinusoidal heating. This method was shown to increase contrast for subsurface delaminations compared to raw thermal data. Finally, thermography results for FRP composite samples containing simulated damage (back-drilled holes) were compared with thermography results from impact-damaged samples.

6541-43, Session 11

The influence of crack shapes and geometries on the results of the thermo-inductive crack detection

G. Wally, B. Oswald-Tranta, Montan Univ. Leoben (Austria)

For thermo-inductive crack detection, a metallic work-piece is placed in a high frequency magnetic field which induces eddy currents in a very thin layer of the surface. This eddy current heats up the sample and the emitted infrared radiation is viewed by an infrared sensitive camera. An inhomogeneous temperature distribution on the surface corresponds to inhomogeneities and cracks in the material. The main goal of the thermo-inductive crack detection is on the one side to find cracks and on the other side to determine their depths. For this purpose an examination of all parameters affecting the result of the measurements has to be made.

In previous publications it has been shown how the thermal contrast ((Tcrack-Tsurf)/Tcrack) depends on several parameters (i.e.: time, pulse length, penetration depth of the eddy current and crack depth). All these investigations were made for rectangular shaped cracks. But metallographic cross-sections show that real cracks have different shapes and different angles depending on the circumstances of the origin of the crack. In this paper results of finite element simulations are presented demonstrating what kind of influence the different shapes have to the thermal contrast. It is also shown in which way the crack geometry affects the temperature distribution on the crack near surface. The calculations take into consideration the distribution of the eddy currents around the crack for both magnetic and non-magnetic materials. The simulations are based on coupled modeling of magnetic and thermal phenomena. The calculated results are in very good agreement with the measurements.

6541-45, Session 11

Nondestructive inspection of open micro-cracks in thermally sprayed coatings using ultrasound excited vibrothermography

J. A. Piau, A. Bendada, X. P. V. Maldague, Univ. Laval (Canada); J. Legoux, National Research Council Canada (Canada)

While other nondestructive testing methods hardly reveal microscopic open cracks, ultrasound excited vibrothermography provides very promising results by converting mechanical waves into local heat by friction. This phenomenon enhances thermal gradients in temperature maps as compared to conventional techniques. To detect temperature gradients caused by hidden cracks, high temperature and spatial resolution infrared cameras are usually used.

Recently, it has been shown that the HVOF (High Velocity Oxy Fuel)-spraying of tungsten carbide or cobalt coatings onto steel substrates, seems to be a suitable alternative to the non-environmentally friendly chromium coating material. However one major issue with these thermal-sprayed coatings is the possibility of the appearance of microscopic cracks when they are submitted to excessive bending loads. If the open cracks spread through the whole coating thickness (typically 100 to 200 µm), they might also propagate at the coating-substrate interface causing the coating to delaminate in between adjacent open cracks. The latter disbonding phenomenon is therefore strongly dependent on the distance between adjacent open cracks. Therefore, a non destructive technique enabling the detection of cracks and the evolution of their density is critical to preserve the components integrity.

The aim of this work is to investigate the ability of ultrasound excited vibrothermography to detect such cracks. To do so, we investigated tungsten carbide coatings where cracks were artificially generated using a controlled bending test. Results on different samples are presented and discussed.

6541-46, Session 11

Arc-welding defect detection by means of principal component analysis and artificial neural networks

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The introduction of arc and laser welding in the aerospace, automotive and nuclear sectors, among others, has led to a great effort in research concerning the quality assurance of these processes. The complexity of the arc-welding process has made it difficult to find a generic theoretical model. The specific characteristics of the arc-welding processes make Artificial Neural Networks (ANN) a highly suitable solution to solve this lack of mathematical foundation, and in several papers, different ANN topologies have been proposed to establish a correlation between some input welding parameters and, commonly, the weld pool geometry or the seam penetration.

An on-line, real-time welding monitor system able to detect instabilities affecting the welding quality would be of great interest, as it would allow to reduce the use of off-line inspection techniques, some of them by means of destructive-testing, thus improving the process productivity. Among several different approaches, plasma spectroscopy has proved to be a feasible solution for the on-line detection of weld defects. However, the direct interpretation of the results offered by this technique tends to be difficult, and, again, ANNs have been used to identify and detect disturbances along the seam, like fluctuations in the bead width.

In this paper the plasma spectra captured during the welding test is compressed by means of Principal Component Analysis (PCA) and, then, processed in a back propagation ANN. Tests performed with stainless steel plates show the feasibility of the proposed solution to be implemented as a real-time on-line arc-welding quality monitor system.

6541-47, Session 11

Thermal nondestructive evaluation of scaling in boiler tubes

S. Awasthi, R. Mulaveesala, S. Tuli, Indian Institute of Technology Delhi (India)

Boiler tubes in thermal power plants can be classified into water wall tubes, re-heater tubes, super heater tubes, boiler drum tubes, risers and down comers. Most commonly encountered problems in boiler tubes are erosion, corrosion and deposition. Corrosion and scaling are the major waterside problems in industrial boilers. Calcium, magnesium, iron, copper and silica predominate in most boiler deposits. These deposits usually form a dense layer that impedes heat transfer and leads to tube failure.

This paper highlights the modeling, simulation and detection of deposited scales, of the order of 50 - 500 microns, in 3 - 6 mm thick boiler tubes, by active InfraRed Thermography (IRT).

IRT involves mapping the surface temperature over a test sample for detecting surface and subsurface features of the test sample. It is a fast, whole field, non-contact and a non-destructive testing method for subsurface feature detection. Since most solids conduct heat, IRT has actual and potential use in detecting subsurface features in a variety of materials (metals, semiconductors and composites).

The present paper highlights a novel data analysis method, based on variations of slopes in time-temperature profiles, to detect subsurface features. The slopes are obtained for different pixels in the field of view of the captured image sequence during transient heating of the boiler tube. Relative thickness variation of deposited scales as well as tube material loss has been estimated from the calculated slopes. Experimental results are presented in support.

6541-48, Session 11

Investigation of metals and metallic composites for defect detection and fatigue monitoring in the micro scale using thermography

N. P. Avdelidis, EBETAM S.A. (Greece); C. A. Charitidis, National Technical Univ. of Athens (Greece); Z. P. Marioli-Riga, Hellenic Aerospace Industry S.A. (Greece); C. Ibarra-Castanedo, X. P. V. Maldague, Univ. Laval (Canada)

Infrared thermographic (IRT) imaging system was used for the non-destructive evaluation of different metallic materials and metallic composites. In particular, this paper presents the potential of pulsed thermography (PT) and/or pulsed phase thermography (PPT) for assessing defects (i.e. impact damage and inclusions for delaminations) on different metallic composites. Furthermore, in this research work, real-time monitoring of damage during fatigue loading using thermography was attempted in the laboratory on aircraft repaired panels (i.e. composite patch applied on aluminium alloy); crack propagations during fatigue were observed and assessed by thermography. Thermography can potentially provide an effective method to in-situ monitor temperature evolution and material stress-strain behavior during fatigue, which can lead to new applications of thermography in detecting mechanical damage of materials and components in real time. Examples of these case studies are presented and discussed.

6541-49, Session 11

Inspection of aerospace materials by pulsed thermography, lock-in thermography, and vibrothermography: a comparative study

C. Ibarra-Castanedo, X. P. V. Maldague, A. Bendada, Univ. Laval (Canada)

Inspection of aerospace components has always been a challenge. Infrared thermography has demonstrated to be a useful tool for this matter. In this paper, we offer a comparative study involving three active techniques: pulsed thermography, lock-in thermography and vibrothermography. Some of these techniques have proven to be more effective than others for a specific type of system. We compare the experimental results from these three techniques as applied to typical aerospace parts: honeycomb structures, composites (CFRP, GFRP), aluminum and Glare. The later is perhaps the most challenging of all as will be pointed out. Some insights are provided regarding the most suitable technique for a number of typical situations.

6541-50, Session 12

Detection of localized fatigue damage in steel by thermography

J. Medgenberg, T. Ummenhofer, Technische Univ. Braunschweig (Germany)

Fatigue damage in ductile unalloyed steels as e.g. S355 in the high cycle regimen is governed by localized plastic deformations due to cyclic plasticity and subsequent crack initiation. The spatial extension of these early microplastic deformations is highly dependent on the applied stress level, stress concentration at macroscopic notches, surface treatment etc. and can be regarded as an early indicator of fatigue damage.

During fatigue loading thermoelasticity and thermoplasticity cause characteristic local temperature variations in tested specimens which are measured by a highly sensitive infrared camera. A specialized data processing method in the time domain has been developed which allows separating the different contributions to the measured temperature signal. In contrast to other methods - e.g. measuring the rise of mean temperature during fatigue loading - the applied method offers a very high spatial resolution and though resolves extremely localized phenomena.

Investigations have been made on cylindrical, notched and welded specimens. The results reconfirm the close relation between the local

temperature signal and fatigue phenomena as reported by many researchers. However the data processing allows a much better localization and quantification of events as cyclic plasticity, crack initiation, crack growth etc. In order to verify the findings insitu microscopic pictures of the fatigued specimens have been recorded parallel to the thermographic investigations.

For the purpose of the investigations an automated setup including a servohydraulic testing machine, a long range light-microscope, a high resolution infrared camera and a 3-axis positioning system has been build up. The setup allows for thermographic and visual microscopic insitu observations of fatigue damage phenomena.

The proposed presentation shows experimental results and further considerations of an application of thermography to the local assessment of fatigue damage.

6541-51, Session 12

Identification of heterogeneous fatigue properties by the use of thermography

M. Poncelet, École Normale Supérieure de Cachan (France); C. Doudard, S. Calloch, ENSIETA (France); F. Hild, École Normale Supérieure de Cachan (France); B. Weber, ARCELOR S.A. (France)

For several years, the link between fatigue properties and thermal response under cyclic loading is investigated. A unified framework based on a probabilistic description of microplasticity allows on the one hand, to describe the thermal effect, and on the other hand, a fast prediction of fatigue limit and its scatter for samples under uniform states of stresses through thermal measurements. An accurate investigation of heterogeneous thermal fields is possible thanks to infrared thermography. Is it then possible to detect heterogeneous fatigue properties? It is shown that variations of fatigue properties in the thickness of steel sheets is accessible. An example is given with decarburated and non-decarburated HSLA steel. Specific experiments are chosen to perform differential temperature measurements between a loaded specimen and then without loading. A data-processing technique based on image correlation minimizes artefacts due to the displacement of the specimen. Differential temperature measurements are then compared for both types of samples, showing the consequences of decarburation on the temperature measurements. The heterogeneity of dissipation is evaluated by using a 1D model and last the prediction of the Woehler diagram is performed and compared with fatigue results to validate the method.

6541-52, Session 12

Influence of the mean stress on the thermoelastic coupling

H. Sawadogo, S. Panier, A. Mouftiez, Ecole des Mines de Douai (France)

Lord Kelvin first quantified an analytical linear relationship between the change in temperature and the change in stress: where DT is the cyclic change in temperature, T is the absolute temperature of the specimen, DS is the change in the sum of the principal stress and K is the thermoelastic constant. Thermoelastic stress analysis (TSA) is based on this theory. In recent years, experimental data as well as theoretical formulations have shown a mean stress dependance concerning the thermoelastic constant K. Wong et al. have reformulated the theory and showed that the mean stress dependence of the thermoelastic parameter is fully accounted for by the temperature dependence of the elastic moduli of the material. Under elastic and adiabatic assumptions, K is given by: where Sm is the mean stress.

According to the revised theory, a temperature modulation appears at 2f, even though the stress is a perfect sine function with f frequency. Then, it's easy to show that the second harmonic of Fourier transformation should be a quadratic function of stress amplitude.

Tests were performed on ferritic steel and austenitic steel specimen at different load ratio R (-1, 0.1, 0.3, 0.5). The samples were submitted to a sinusoidally modulated stress. For each, value of the stress amplitude, the specimen were loaded until the mean temperature reached a stabilized level. The specimen surface temperature measurement was performed with a Cedip IR focal plane array camera. At very low levels of stress amplitude, we observed that the second Fourier component is a quadratic function of stress amplitude and multiplicative constant depends of the level of mean stress. For higher levels, non linearity appears and comes from energy dissipation by fatigue damage.

If calibration of the thermoelastic response to mean stress can be successfully implemented, it is feasible to use the relationship to assess the residual stress state of structures.

6541-53, Session 12

Study of the heat generated by a rolling bearing degradation by IR thermography

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Our study deals with the quantification of the energy dissipated by a defect of spalling on the outside ring of a rolling bearing. A previous work showed a correlation between the thermal heating and the vibratory level generated by the progressive appearance of the defect.

First, we propose a numerical model of the heat transfers involved between the rolling elements and the outside border of the bearing cap.

In a second time, we developed an experimental setup constituted by an electric engine, two shaft bearings, a turning axis, a rolling bearing with an internal ring heated by an electric resistance, equipped with a fluxmeter; sensors allow following the distribution of the temperatures on rings. The rolling bearing is accommodated in a bearing cap which allows creating the spalling defect in a progressive way. An infrared camera allows measuring the superficial field of temperature.

Periodic impacts generated by a spalling zone are going to excite the system mechanical structure. Damping effects transform a part of this vibratory energy into heat losses that induce a rise of the ring temperature.

The measurement of the temperature rise and the knowledge of the contact resistances allow estimating the vibratory energy generated by periodic shocks, and thus to estimate the level of degradation of the rolling bearing.

The results obtained in this first step are encouraging. Indeed, the defect generated in the rolling bearing leads to a quantifiable heating of the surface, and the numerical model and the experiments allow quantifying the involved flux.

6541-14, Poster Session

Field test of infrared thermography applied to biogas controlling in landfill sites

F. J. Madruga, J. M. Muñoz, D. A. González, J. I. Tejero, J. M. Lopez-Higuera, J. L. Gil, Univ. de Cantabria (Spain)

The gases accumulated inside the landfill as result of the fermentation of Municipal Solid Waste (MSW) known as biogas, are taking into consideration all possible uses as direct transformation into electricity. The system for collecting, regulating and controlling the biogas must include all the necessary safety features where the biogas leakage presents a high impact. Infrared thermography can be use to detect gas leakages due to the differences in temperature between the gas and the immediate surroundings. This method is able to monitor a wide area of landfill sites, quickly. This technology will not be effective if the differences in temperature are not better than five degrees. This paper describes a field test conducted to study the limitations of the infrared thermography caused by weather conditions and the moment of day or/ and season when the thermal images was captured. Pipelines, borders, cells, covers, slopes and leakage (hot spots) are studied and optimum conditions are defined.

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6542-01, Session 1

Progress with type-II superlattice IR detector arrays

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We report progress in the development of long wavelength IR focal plane arrays built on type-II strained layer superlattice materials. Work at Raytheon Vision Systems and Jet Propulsion Laboratory has led to successful devices with cutoff wavelengths of 10 to 12 µm. Pixels have been formed by both wet and dry etching. Surface passivations include both plasma-deposited silicon dioxide and epitaxially regrown III-V layers. We will present test results on arrays hybridized with indium bump bonding to silicon readout integrated circuits, as well as analyses of current voltage characteristics of individual diodes.

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6542-02, Session 1

Passivation of W-structured type-II superlattice long-wave infrared photodiodes.

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Recently, significant progress has been observed in the performance of discrete, large-diameter (100-400 µm), long-wave infrared (LWIR) photodiodes based on type-II superlattices (T2SLs), as the result of improvements in heterostructure design and growth. To have an impact on LWIR focal plane array (FPA) technology, however, it is also necessary to achieve high performance levels in FPA pixel-sized devices which are much smaller (20-40 µm) and therefore more sensitive to surface effects. Etching to achieve mesa isolation of adjacent photodiodes exposes the diode junction, and introduces surface states that facilitate diode-shunting along the mesa sidewalls. While satisfactory control of surface leakage mechanisms appears to have been achieved in mid-wave infrared (MWIR) T2SLs, as evidenced by the availability of commercially produced high performance MWIR T2SL FPAs, the same cannot be said for LWIR T2SLs. Several groups have approached this problem as strictly a matter of surface treatment, using dielectrics to overcoat and stabilize the chemically treated surfaces, or by epitaxial overgrowth, but with limited success. Here we describe an approach in which the designs of the photodiode superlattice and the overall band-profile are used in addition to surface treatment, to suppress surface leakage currents. In this approach the WSL is used, since the electron effective mass along the growth direction in the WSL is about three times larger than that of a typical T2SL with the same energy gap, resulting in much lower tunneling probability. Also, 15 to 20% of the LWIR WSL is composed of layers with high Al-content, which upon exposure to air form a nonconductive Al2O3 layer that inhibits transport along the surface. Finally, the bandgap of the WSLs are graded to provide a larger energy gap within the depletion region of the photodiode. This effectively increases the tunneling barrier as well as reduces generation and recombination processes that depend on the intrinsic carrier density, which is exponential in the bandgap. We also employ a sulfurization treatment of the surface of the photodiode mesas followed by encapsulation in a dielectric to stabilize performance and protect the devices during subsequent FPA processing steps.

6542-03, Session 1

256 Å~ 256 infrared focal plane array based on type-II InAs/GaSb superlattice with a 12-µm cutoff wavelength

M. Razeghi, P. Delaunay, B. M. Nguyen, D. Hoffman, Northwestern Univ.

We report for the first time the demonstration of a Focal Plane Array (FPA) based on type-II InAs/GaSb superlattice with a cutoff wavelength of 12 µm. The long-wavelength infrared type-II photodetectors were grown on a GaSb substrate using Molecular Beam Epitaxy (MBE). We achieved high differential resistance by increasing the doping of the intrinsic region using Beryllium. At 77 K, photodiodes, with a 12.03 µm cutoff wavelength, exhibited an average quantum efficiency of 30% and an R0A around 15 O.cm(2), resulting in a detectivity of 1.29.10(11) cm.Hz(1/2)/W. A 256x256 array of 25x25µm(2) pixels, hybridized to a Litton CMOS Read Out Integrated Circuit (ROIC), performed thermal imaging up to 144 K.

6542-04, Session 1

MBE grown type-II superlattice photodiodes for LWIR imaging applications

C. J. Hill, J. V. Li, J. M. Mumolo, S. D. Gunapala, Jet Propulsion Lab.; D. R. Rhiger, R. Kvass, S. F. Harris, M. A. Gritz, S. M. Johnson, Raytheon Vision Systems

The closely lattice-match material system of InAs, GaSb, and AlSb, commonly referred to as the 6.1Å material system, has emerged as a fertile ground for the development of new solid-state devices. The flexibility of the system in simultaneously permitting type-I, type-II staggered, and type-II broken-gap band alignments has been the basis for many novel, high-performance heterostructure devices in recent years, including the GaInSb/InAs type-II strained layer superlattice infrared detectors proposed by Smith and Mailhiot in 1987. The type-II superlattice design promises optical properties comparable to HgCdTe, better uniformity, reduced tunneling currents, suppressed Auger recombination, and normal incidence operation. In 1990, Chow and co-workers first reported Ga1-xInxSb/InAs superlattice materials with high structural quality, LWIR photoresponse, and LWIR photoluminescence. More recently, in 1997 researchers from the Fraunhofer Institute demonstrated excellent detectivity (approaching HgCdTe, 8-µm cutoff, 77K) on individual superlattice devices. Here we report on the status of superlattice diodes grown and characterized at the Jet Propulsion Laboratory designed for infrared absorption in the 8-12µm range. Recent devices have produced detectivities as high as 8x1010 Jones with a differential resistance-area product greater than 30 Ohmcm2 at 80K with a long wavelength cutoff of approximately 10.5µm. Imaging results from the first generation of 256x256 LWIR superlattice arrays fabricated at Raytheon Vision Systems on material grown at JPL will also be presented.

6542-05, Session 1

InAs/GaSb type-II short-period superlattices for advanced single and dual-color focal plane arrays

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Bispectral focal plane arrays (FPAs) operating within two separate transmission windows (“dual-color”) using InAs/GaSb type-II short-period superlattices have been developed. Those detectors provide several advantages, e.g., remote temperature measurement, better discrimination between objects and background clutter and are very interesting for missile approach warning systems.

We report on the fabrication and optimization of InAs/GaSb type-II superlattice detectors for single-color and dual-color FPAs in the MWIR (3-5 µm) wavelength region.

Single-color focal plane arrays with 288x384 detector elements and 24 µm pitch have been fabricated with high pixel yield. Camera systems with InAs/GaSb superlattice detectors reveal NETD values of 14 mK at a cut-off wavelength of lc = 5.25 µm for an integration time of 4 msec with F#/2.4 optics.

The bispectral camera system, developed for missile approach warning systems, features simultaneous and spatially coincident detection of both spectral channels on each pixel. The detector consists of two

InAs/GaSb superlattice photodiodes in “back-to-back” configuration, separated by a common ground contact. The detector is grown by molecular beam epitaxy on GaSb substrates. Dual color FPAs with 40 µm pitch and three electrical contacts on each pixel were fabricated in a full wafer process using standard optical lithography.

The 288x384 FPA dual-color InAs/GaSb superlattice camera system shows cutoff wavelengths around 4 µm in the short wavelength part and 5 µm in the long wavelength path, respectively. With F#/2.0 optics and 2.8 ms integration time NETD values < 30 mK have been measured for the short wavelength detector and < 17 mK for the long wavelength detector.

6542-06, Session 1

Dual-color IR detection modules, trends, and applications

M. O. Muenzberg, R. Breiter, W. A. Cabanski, J. C. Wendler, J. Ziegler, AIM Infrarot-Module GmbH (Germany); R. H. Rehm, M. Walther, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

The 3rd generation of infrared (IR) detection modules is expected to provide advanced features like higher resolution 1024x1024 or 1280x720 pixels and/or new functions like multicolor or multi band capability, higher frame rates and better thermal resolution. This paper is intended to present the current status and trends at AIM on antimonide type II superlattices (SL) dual color detection module developments for ground and airborne applications in the high performance range, where rapidly changing scenes - like e.g. in case of missile warning applications for airborne platforms - require temporal signal coincidence with integration times of typically 1ms.

AIM and IAF selected antimonide based type II superlattices (SL) for such kind of applications. The type II SL technology provides - similar to QWIP’s - an accurate engineering of sensitive layers by MBE with very good homogeneity and yield. IAF and AIM last year managed to realize a dual color 384x288 IR module based on this technology. It combines spectral selective detection in the 3 - 4.1 µm wavelength range and 4.1 - 5 µm wavelength range in each pixel with coincident integration in a 384x288x2 format and 40 µm pitch. Excellent thermal resolution with NETD < 17 mK \@ F/2, 2.8 ms for the longer wavelength range (red band) and NETD < 30 mK \@ F/2, 2.8 ms for the shorter wavelength range (blue band) were reported.

In the meantime a square design of 256x256 pixel with a reduced pitch of of 30 µm is in preparation. The fill factor in this design remains despite of the 3 contacts per pixel required for temporal coincidence and eo performance at about 80% . The reduced size of the array enables the use of a smaller dewar with reduced cooling power and significantly reduzed weight and broadens the scope of applications where weight and costs is essential. Design aspects and expected performances are discussed.

6542-07, Session 1

High operating temperature InAs/GaSb type-II strain layer superlattice detectors

J. Rodriguez, E. Plis, S. J. Lee, Y. D. Sharma, R. Dawson, S. Krishna, Univ. of New Mexico

Photodetectors made of type-II GaSb/InAs superlattice are of great interest for mid-infrared (MWIR) and long-wave infrared (LWIR) FPAs fabrication. Recent results have shown it is now a competitive alternative to the well established HgCdTe and InSb technologies, especially for its ability to operate at higher temperature.

Previous results reported by our group have shown a p-i-n detector with a cut-off wavelength at 4.6 µm, with a conversion efficiency of 32 %, and a specific detectivity of 5x1010 Jones at 80 K, under a 300 K 2π field of view illumination. Higher temperature (250-300 K) performances of such a device are limited by the diffusion length of the minority carriers and by the band-offsets at the hetero-interfaces with the wider band-gap contact layers. In this presentation, we report the recent progress made by our group on the optimization of the SL absorber thickness, on the improvement of carrier transport at the interfaces using with the contact layers doped/graded interface and on an electrochemical sulphidization passivation process that we have implemented. We will show how these parameters influence both responsivity and the noise and propose an optimized HOT detector design.

6542-08, Session 1

Air Force Research Laboratory efforts in SLS IR detectors

V. Nathan, Air Force Research Lab.

In this presentation we will review the recent results of R&D in InAs/GaSb Type2 strained layer superlattice (SLS) infrared (IR) detectors funded and /or monitored by Air Force Research Laboratory/VSSS. Specifically we will discuss results of efforts at Northwestern University and MP Technologies to develop high performance SLS IR detectors. We will report the results of independent characterization of SLS IR detectors from two different sources, performed at AFRL/VSSS. We will discuss areas for further research in SLS IR detectors.

6542-09, Session 1

Modeling of type-II superlattice photodiodes

H. Stewart, BAE Systems plc

No abstract available

6542-10, Session 1

Comparison of type-II superlattice and HgCdTe detector technologies

J. Bajaj, D. L. Lee, Teledyne Imaging Sensors; G. J. Sullivan, Teledyne Scientific Co.; E. H. Aifer, Naval Research Lab.; M. Razeghi, Northwestern Univ.

HgCdTe based detector technology currently dominates performance over most of the mid-wave and long-wave infrared spectrum. This technology is relatively mature; current effort is focused on improving uniformity of the performance characteristics, and demonstrating increased Focal Plane Array functionality. Type-II superlattice (InAs-GaSb and related alloys) based detector technology has seen rapid progress over the past few years. The merits of this material system rest on yet-to-be experimentally demonstrated predictions of higher performance and engineering advantages. While no one has demonstrated Type-II superlattice detectors with performance superior to HgCdTe detectors, the difference in performance from the two technologies is rapidly decreasing. In this paper we review the status and highlight relative merits of both both HgCdTe and Type-II superlattice based detector technologies.

6542-11, Session 2

IR material research at the Army Research Laboratory

H. K. Pollehn, Army Research Lab.

Research on Mercury Cadmium Telluride (HgCdTe) and group III-V based infrared materials is being conducted for the development of advanced IR detectors and focal plane arrays. The focus of this research has been in materials for Quantum Well Infrared Photo Detectors (QWIPs), Sb based type II superlattice detectors, Silicon based substrates for HgCdTe detectors and HgCdTe detectors with higher operating temperature.

For the QWIP detectors a corrugated design will improve quantum efficiency and operating temperature. Details of these efforts will be described in separate presentations. For the superlattice detectors focal plane arrays in the MWIR spectral band have been successfully demonstrated and excellent image quality has been obtained. Current efforts are concentrated on achieving high quality materials and passivation techniques for detectors in the LWIR spectral region. For HgCdTe detectors on Si based substrates MWIR detectors have also

been demonstrated with high quality, but for LWIR detector arrays of sufficient low defect densities have not been obtained on a consistent basis. Recent efforts showing very promising results will be discussed. With a novel design for LWIR detectors and innovative annealing techniques Auger suppression has been obtained for temperatures above 130K allowing for higher operating temperatures.

6542-12, Session 3

Advanced HgCdTe technologies in France

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In this paper we present an overview of the very recent developments of the HgCdTe infrared detector technology developed by CEA-LETI and industrialized by Sofradir in France.

Today Sofradir uses in production from more than 15years a very mature, reproducible, well mastered and fully understood, planar n on p ion implanted technology.

This process that allows very high yields to be achieved in all infrared bands from swir to lwir uses the very conventional approach of LPE growth of MCT on lattice-matched CdZnTe substrates. Progress in this field is continuous from 20years and has recently leaded to the fabrication of high performance VLWIR FPA (320x256 with cut off wavelengths as high as 20µm). Moreover, thanks to the design of the epitaxial structure and to the substrate removal step MCT FPAs present the unique features to have a very high quantum efficiency (above 70%) from the cut off wavelength down to the UV. This effect that opens new application fields was recently demonstrated in SWIR 320x256 FPAs with cut off wavelength of 2.5µm.

Above these conventional technologies, the MBE approach is under investigation for several years to prepare both the very large array fabrication and the 3rd generation development.

Very high quality FPAs (1280x1024) with pitches as small as 15µm have already been demonstrated last year using the MBE growth of mwir MCT epilayers on 4 inches germanium substrates, n on p ion implanted photodiodes and the hot welding indium bump hybridization technique. At the same time, with the MBE growth, bicolour and dual band FPAs which uses more complex multi hetero-junctions architectures (both 4 layers npn and 'pseudo planar' structures and extrinsically doped MCT layers) were fabricated with formats of 320x256 and pitches as small as 25µm.

A very new area of development concerns avalanche photodiodes (APD) made with MCT. This semiconductor presents an unique feature among all the over semiconductors. Extremely high avalanche gains can be obtained on n on p photodiodes without absolutely any noise excess (F(K)=1): MCT APDs act as perfect amplifiers. Using MBE grown MCT epitaxial and a suitable design of the structure no noise MCT mwir APDs with gain as high as 5000 could be obtained in our devices. These results open new interesting fields of investigation for low flux applications and fast detectors (including hyper spectral imaging and active imaging).

6542-13, Session 3

1/f noise in HgCdTe infrared gated photodiodes

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Determining the origins of 1/f noise in HgCdTe photodiodes is important in the improvement of focal plane arrays. At higher operating temperatures the dynamic resistance of these photodiodes can be significantly lower than required due to diffusion currents. The dynamic resistance can be improved by operating the photodiode in reverse bias, however photodiodes operating in this mode have large 1/f noise. Understanding the mechanisms of 1/f within the photodiodes is therefore important in improving focal plane array performance.

In this work gated MWIR HgCdTe photodiodes are used to investigate the physical origin of 1/f noise generation. By varying the gate bias the band-bending at the surface can be controlled, thereby affecting the dominant dark current mechanisms. These photodiodes are based on type-conversion using a plasma process as reported previously, which is simpler than traditional ion implantation and ion milling methods.

Fabricated devices have a R0A of mid 10 4 Ocm2 at 77K, and at 2.5V gate bias 5x10 6 Ocm2. At trap-assisted tunnelling (TAT) current dominates in the reverse bias for 77K, and generation-recombination and diffusion current dominates as the temperature increases. 1/f noise is dependent on temperature because of the change in magnitude and components of the dark current with changing temperature. 1/f noise was found to be strongly correlated to TAT current. Reduction of TAT current will result in reduction of 1/f noise and allow for improved photodiode array performance.

6542-14, Session 3

IR-detectors from 0.9 µm to 13 µm spectral range at AIM

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Since 30 years AIM offers high-performance IR-detector modules for defense, security and industrial applications. AIM is a global supplier of HgCdTe-, QWIP- and Type II-SL-FPAs and IDCAs for FLIR systems and seeker heads, mainly in the MWIR (3 - 5 µm) and LWIR (8 - 12 µm) spectral range. During the last years, this bandwidth has been extended to cover the whole IR range from 0.9 µm to 13 µm. This developments have been triggered by an emerging market for remote sensing from space for weather-forecast, climate research, global security surveillance and intelligence. Most importantly, the defense market benefits from such programs. One example is the need of short-wave (0.9 - 2.8 µm) detector arrays for lidar, laser radar, and night glow vision applications, preferably using avalanche photo-diodes (APDs).

We will present our latest results with emphasis in this paper on MCT material advances and new technologies, presenting typical examples for FPAs in SW-, MW-, LW-, and VLW-applications. To mention a few highlights: Yield in defective pixels, clusters and NETD has been significantly increased. During the last years thermal cycle stability especially of large FPAs has been improved by using a matched underfiller between sensor chip and ROIC. Enhanced homogeneity and significantly reduced 1/f-noise has been achieved by optimized processes of the planar array technology, especially for LWIR and VLWIR sensors.

In summary, AIM offers reliable (\>9000 thermal cycles), large (\>27 mm), uniform, low-noise, MCT modules from 0.9 to 13 µm with options for visible sensitivity and avalanche operation mode. In addition AIM's technology roadmap will be presented.

6542-15, Session 3

Pronounced Auger suppression in long-wavelength HgCdTe devices grown by molecular beam epitaxy

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Mercury cadmium telluride (HgCdTe) semiconductors are of great importance to sensing radiation from the near infrared (lamdac ~ 1 microns) to the very long wavelength infrared (lamdac ~ 15 microns). Much of HgCdTe-related research and development work is carried out for cooled operation. Intrinsic carriers play a dominant role specially in the long wavelength (8-12 micron cutoff) material near ambient temperatures due to high thermal generation of carriers, resulting in low minority carrier lifetimes due to Auger recombination processes. Consequently, this low lifetime at high temperatures results in high dark currents and high noise. Cooling is one means of reducing this type of detector noise. The challenge is to design photon detectors to achieve background limited performance (BLIP) at the highest possible operating temperature; with the greatest desire being close to ambient temperature operation. A higher operating temperature would result in several advantages to an infrared imaging system, such as a reduction in power and weight requirements, thus lowering mission costs. The choice of detector architecture determines the type of dark currents that impact detector performance. The dominant intrinsic recombination mechanism in long wavelength-HgCdTe is Auger. The electron initiated Auger-1 process dominates in n-type material, whereas the hole initiated Auger-7 dominates in p-type material. Intrinsic Auger-7 lifetimes are significantly longer than intrinsic Auger-1 ones. Hence, p-type HgCdTe absorber material is preferred for higher operating temperature devices. In recent years, Ashley and Elliott proposed a new class of infrared sensing devices that utilized the phenomena of exclusion and extraction of thermally generated carriers from the active region under reverse bias, thereby further suppressing Auger processes.

We have fabricated large area P+/pi/N+ devices in HgCdTe material with 10 micron cut-off at 78 K by molecular beam epitaxy. A principal challenge was to obtain a low p-type doping level in the pi-region. This paper will discuss a novel approach to obtaining low arsenic doping concentrations and present device results demonstrating Auger suppression at ambient temperatures.

6542-16, Session 3

Affordable high-performance LW IRFPAs made from HgCdTe grown by MOVPE

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This paper describes the fabrication and performance of LW infra-red detectors made from HgCdTe grown by Metal Organic Vapour Phase Epitaxy (MOVPE). The detectors are staring, focal plane arrays consisting of HgCdTe mesa-diode arrays bump bonded to silicon read-out circuits. The HgCdTe structure is grown on GaAs and consists of an absorber layer sandwiched between wider band-gap cladding layers. Device processing is wafer-scale. Wet etching is used to define the mesas and the mesa sidewalls are passivated with inter-diffused CdTe. The GaAs substrate is thinned after bump bonding to minimise the thermal stress on cooling.

There are three important features of the design. Firstly, the doping and thickness of the absorber are chosen to minimise dark currents while maintaining good quantum efficiency. Secondly, the slots defining the mesas penetrate the absorber and therefore prevent electrical cross-talk. Thirdly, thinning the substrate not only solves the problem of thermal mismatch but also minimises optical cross-talk due to reflections. Furthermore, the devices withstand storage at 70°C and temperature cycling between room temperature and 80 K. Typical diode characteristics at 80 K for a cut-off wavelength of 10 µm are an RoA of ~ 200 ohm.cm2 and a quantum efficiency of ~ 70%.

We have made a number of hybrid arrays consisting of 640x512 pixels on a pitch of 24 µm. This paper describes the performance of arrays with cut-off wavelengths in the range 9.4 to 10.3 µm. For example, array 5209-03 with a cut-off wavelength of 9.6 µm and staring for 0.3 ms at a 300 K background in f/4 has a median NETD of 20 mK and 0.6% defective pixels, where a defective pixel is defined as one with NETD \> 60 mK. This paper will include results for a number of arrays, a discussion of the factors controlling defect levels, and LW imagery obtained using the Selex S&AS Sigma camera.

6542-119, Session 3

Development of mid-wave 320 Å~ 256 infrared focal plane array in Korea

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This paper reports the development of mid-wave 320Å~256 HgCdTe IRFPA with 30µm pixel pitch since 2002 in Korea. All key technologies such as HgCdTe photodiode array fabrication process, the design of silicon readout integrated circuit and hybridization process between HgCdTe photodiode array and ROIC including underfill encapsulation process are studied and realized. The fabricated IRFPA shows good electro-optical performances such as operability of ~99%, NETD of ~19mK with good bonding reliability.

6542-17, Session 4

Performance of focal plane arrays for the Photon Counting Arrays (PCAR) program

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The DARPA PCAR program is sponsoring the development of low noise, near infrared (1.5 um wavelength) focal plane arrays (FPAs) for night vision applications. The first phase of this work has produced a collection of 640 x 512 pixel, 20 um pitch FPAs with low noise. The approach was to design four different read out integrated circuits (ROICs), all compatible with the same bump-bonded InGaAs photodiode detector array. Each of the designs took a different approach to achieving low noise. Two of the designs have capacitive transimpedance amplifier (CTIA) pixels, each with a somewhat different amplifier design and with two different sizes of small integration capacitors. The third design is a source follower per detector (SFD) pixel, integrating on the detector capacitance. The fourth design also integrates on the detector capacitance, but uses a moderate gain, in-pixel amplifier to boost the signal level, and also has a differential pixel output. All four designs require off-chip correlated sampling to achieve the desired noise level. The correlated sampling is currently being performed digitally in the data acquisition software. All of the designs are capable of classical correlated double sampling (CDS) where a reference frame representing the signal level early in the integration is subtracted from the final integrated signal frame. Two of the designs are capable of more sophisticated correlated sampling techniques such as “Fowler sampling” and “sampling up the ramp”. Each design is capable of 30 frames per second read out rate, and has a dynamic range of 1000:1 using a rolling, non-snapshot integration. The designs were fabricated in a standard CMOS foundry process, and were bump-bonded to InGaAs detector arrays. All four designs are working without any significant design errors, and are producing low noise imaging, with less than 50 electrons rms noise per pixel after correlated double sampling.

6542-19, Session 4

Ultra-low dark current InGaAs technology for focal plane arrays for low-light level visible-shortwave infrared imaging

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Under the DARPA PCAR program we have investigated technologies to reduce the overall noise level in InGaAs based imagers for identifying a man at 100m under low-light level imaging conditions. We report the results of our controlled experiments comprising of 15 InGaAs wafers that were untilized to investigate lowering dark current in photodiode arrays. As a result of these experiments, we have achieved an ultra low dark current of 2nA/cm2 through technological advances in InGaAs detector design, epitaxial growth, and processing at a temperature of +10C. The InGaAs photodiode array was hybridized to a low noise readout integrated circuit, also developed under this program. The focal plane array (FPA) achieves very high sensitivity in the shortwave infrared bands in addition to the visible response added via a substrate removal process post hybridization. Based on our current room-temperature stabilized SWIR camera platform, these imagers enable a full day-night imaging capability and are responsive to currently fielded covert laser designators, illuminators, and rangefinders. In addition, improved haze penetration in the SWIR compared to the visible provide enhanced clarity in the imagery of a scence. In this paper we show the results of our dark current studies as well as FPA characterization of the camera built under this program.

6542-21, Session 4

Extending the tuning range of SWIR microspectrometers

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We have developed a microspectrometer based on monolithic integration of a Fabry-Pérot optical filter directly with a HgxCd1-xTe-based infrared detector. The tunable Fabry-Pérot is created by a parallel plate MEMS fabricated from two dielectric mirror stacks separated by an initial air gap of 1.4 microns. We have measured linewidths as low as 55 nm, switching times of 40 microsec and a tuning range of 380 nm. However this tuning corresponds to only 42% of the desired tuning range, from 1.6-2.5 microns (900 nm). The tuning range is limited by a process called "snap down" which occurs when the MEMS is drive by a voltage source. It can be shown that for a parallel plate snap down occurs at 1/3 the initial gap; Complete tuning across the IR band requires a physical deflection of at least 60% of the gap. An integrated ASIC would enable the MEMS to be actuated by charge control, which would allow full range tunability. However the added complexity of design, integration and cost makes the additional electronic control unattractive. We have developed a modified actuation scheme which allow at leat 60% tuning of the moveable mirror. Further, the method developed minimizes stress gradients which can lead to substantial bowing of the mirror and subsequently broad optical linewidths. We will compare the results of our current microspectrometer with our new extended tuning designs. These designs are based on Coventorware and analytical mechanical models combined with optical models for the Fabry-Pérot.

6542-22, Session 4

Quantum manipulation of infrared single photons for upconversion detection, polarization encoding, and quantum interface

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Quantum manipulation of infrared single photons may spur many significant applications in ultrasensitive detection, quantum encoding, imaging and ranging. In this report, we will discuss our recent experimental progress in quantum manipulation of infrared single photons, such as frequency-upconversion and polarization stabilization at the single-photon level in the infrared region.

Single-photon counting in infrared region thus far exhibits a very poor performance and sets a troublesome bottleneck for many applications. We demonstrate a robust method to realize a stable and efficient single-photon counting at 1.55 µm by means of sum-frequency mixing with a strong pump in a diode-pumped unidirectional ring laser. As the efficient input pump intensity reaches 35 W, the long-term stable conversion efficiency approaches 96% while the background counts are less than 600Å~103 s-1. Quantum manipulation of infrared single photons can be also used for the development of some intriguing quantum devices, such as tunable quantum interface and tunable single-photon generation.

We demonstrated a feedback control of single-photon polarization that facilitates active long-term polarization stabilization to beat the unpredictable polarization scrambling in long-distance fibers up to 100 km with a long-term stability over 10 hours. Experimental tests of long-term operations in 50, 75 and 100 km fibers demonstrated that such a single-photon polarization control supported stable polarization encoding in long-distance fibers to facilitate stable "one-way" fiber system for polarization-encoded quantum communication, providing quantum bit error rates below the absolute security threshold.

These quantum manipulation techniques can be readily extended to far-infrared single photons to highlight many attractive experiments, such as single-photon control and polarization switches.

6542-23, Session 5

Dual-band infrared imaging analyses for 256 Å~ 256 InAs/GaAs quantum dot infrared photodetector focal plane array

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In this letter, the 30 stacked InAs/GaAs quantum dot infrared photodetector (QDIP) structure was grown by solid-source molecular beam epitaxy technique and demonstrated with dual-band mid- (2.7~5.6um) and long- (7.5~13.5um) wavelength normal-incident detections without grating and passivated process for 256Å~256 FPA. The 256Å~256 QDIP FPA hybridized with snapshot-mode ROIC was mounted in a 68 pin leadless ceramic chip carrier which was put in the testing dewar with IR optical cold spectral filters of the 2.9~5.5um and 6.5~14.5um for the dual-band IR detections, respectively. The testing scheme for thermal imaging uniformity of the InAs/GaAs QDIP focal plane array (FPA) has been proposed and calibrated using a plane-typed blackbody source of a high temperature of 373K and lower ambient temperature for the two-point temperature correction. The averaged of specific detectivity (D*) and operability of the QDIP FPA have reached 1.5X10E10cm-(Hz)1/2/W and 98% at 80K, respectively. The dominant noise equivalent temperature differences (NEDT) of typical figure of merit for QDIP thermal imaging module operated under the temperature of 80K, device biases of -0.7 V and integration time of 32ms with infrared optics and two-point temperature correction are 1.12 (mid-wavelength IR) and 0.11K (long-wavelength IR), respectively. Meanwhile, it is worth to note that these are the first confirmation for dual-band detections of FPA from direct InAs quantum dots matrix embedded in GaAs heterostructure. In the future, the dual-band IR QDIP FPA will become one of the important candidates for hyper-spectral detection and thermal imaging fusion application.

6542-24, Session 5

Electrically controllable multispectral (SWIR/MWIR/LWIR) infrared photodetector

X. Lu, Univ. of Massachusetts/Lowell; M. J. Meisner, Raytheon Missile Systems

We present an electrically-controllable multi-spectral (SWIR/MWIR/LWIR) quantum dot infrared photodetector (QDIP). The QDIP consists of vertically-stacked InAs quantum dots layers with three different capping layers for SWIR, MWIR and LWIR absorption, respectively. The multi-spectral QDOP is capable of simultaneously detecting multi-spectral normal incidence through inter-subband transitions in the three-dimensional (3-D) confined quantum dot nanostructures. The voltage-controllable detection band selection enables real-time system reconfiguration to focus on the band of interest. The vertically-stacked device structure allows easy construction of focal plane arrays (FPA).

6542-25, Session 5

Self-assembled semiconductor quantum dot infrared photodetector operating at room temperature and focal plane array

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Self-assembled semiconductor quantum dots have attracted much attention because of their novel properties and thus possible practical applications including the lasers, detectors and modulators. Especially the photodetectors which have quantum dots in their active region have been developed and show promising performances such as high operation temperature due to three dimensional confinement of the carriers and normal incidence in contrast to the case of quantum well detectors which require special optical coupling schemes. Here, we report our recent results for mid-wavelength infrared quantum dot infrared photodetector grown by low pressure metalorganic chemical vapor deposition. The material system we have investigated consist of

25 period self-assembled InAs quantum dot layers on InAlAs barriers, which are lattice-matched to a InP substrate, covered with InGaAs quantum well layers and InAlAs barriers. This active region was sandwiched by highly doped InP contact layers. The device operates at 4 µm with a peak detectivity of 1x10(11) cmHz(1/2)/W and a quantum efficiency of 43 % at 150 K. The photoresponse can be observed even at room temperature resulting in a peak detectivity of 1x10(8) cmHz(1/2)/W. 256x256 focal plane arrays have been fabricated in this device. Its performance will also be discussed here.

6542-26, Session 6

C-QWIP material design and growth

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Recently, large format and high quantum efficiency corrugated quantum well infrared photodetector (C-QWIP) FPAs have been demonstrated. Since the detector light coupling scheme does not alter the intrinsic absorption spectrum of the material, the QWIPs can now be designed with different bandwidths and line shapes to suit various applications. Meanwhile, the internal optical field distribution of the C-QWIPs is different from that of a grating coupled detector, the material structure thus has to be designed and optimized differently with respect to quantum efficiency, conversion efficiency and operating temperature. In this paper, we will present the material design aspects of the C-QWIP FPAs. Specifically, we will discuss the system requirements for certain applications, the theoretical methods in designing the materials, the material growth techniques, and the comparison between theory and experiment, which are performed on edge coupled detectors and FPA pixels in fan-out circuits. Through this investigation, we established the optimized tuning curve for the C-QWIP material in the 9 microns regime. The corresponding FPA performance will be presented.

6542-27, Session 6

Development of a 1 megapixel far-IR QWIP focal plane array

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In the rapid development of GaAs Quantum Well Infrared Photodetectors (QWIPs) we have fabricated a 1,024 x 1,024 (1K x 1K), 8-12 µm infrared focal plane array (FPA). This focal plane array is a hybrid using an L3 Cincinnati Electronics silicon readout integrated circuit (ROIC) bump bonded to the 1 megapixel GaAs QWIP. This effort was a collaboration of engineers at the Goddard Space Flight Center (GSFC), the Army Research Laboratory (ARL) and L3 Cincinnati Electronics (L3). We have integrated this focal plane into an SE-IR based imaging camera system and performed tests over the 55K-77K temperature range. As in previous developments the ease of fabrication of the GaAs array continues to be a valuable asset. The overall focal plane development costs are currently dominated by the costs associated with the silicon readout/hybridization. The GaAs array fabrication is based on a high yield, well-established GaAs processing capability. The broadband long wavelength response of this array combined with a markedly improved quantum efficiency is of particular value in science applications where spectroscopy is required. One of the features of GaAs QWIP technology is the ability to precisely design and fabricate arrays responsive to a particular IR spectral region but the spectral response is typically only a few tenths of a micrometer wide limiting the spectral information content. By broadening the spectral response of this device the applications for imaging and spectroscopy are substantially increased. In this paper we will present the latest results of our corrugated 1K x 1K, 8-12 µm infrared focal plane array development including fabrication methodology, test data and experiments.

6542-28, Session 6

Small pitch, full-TV format LWIR QWIP FPAs for polarimetric imaging

A. Nedelcu, Alcatel-Thales III-V Lab. (France) and Thales Research & Technology (France); E. M. Costard, P. F. Bois, Thales Research & Technology (France)

Exploitation of infrared polarization signatures can enhance the detection probability of man-made objects, whose surface characteristics carry the stamp of their origin. Using appropriate designs of the optical coupling (e.g. lamellar gratings), Quantum Well Infrared Photodetectors (QWIPs) can be easily turned into polarization sensitive detectors. The polarizer is thus part of the focal plane array (FPA), leading to simpler and robust imaging systems.

In spite of the obvious interest of QWIPs for polarization imaging, little work has been published on this topic [1,2]. Moreover, these works are concerned with large pixel sizes (\> 40 µm), and extrapolation to lower pixel sizes may not be valid.

After demonstrating the building blocks for small pitch polarization sensitive QWIP pixels [3] on one hand and full-TV, regular QWIP LWIR arrays [4] on the other hand, Thales Research and Technology took up the challenge to build a polarization sensitive full-TV, LWIR QWIP array, able to image the intensity as well as the degree of linear polarization in the scene.

In this talk we will present results on the electro-optical performance of individual pixels, with special focus on the spectral responsivity and its dependence on the pixel size. Two different grating orientations have been investigated, at 0° and 45° with respect to the pixel edges, allowing the determination of the first three components of the Stokes vector.

Depending on the advancement of the global project, we will also present results from FPA characterization.

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6542-29, Session 6

Recent advances of QWIP development in Sweden

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The ongoing development of QWIP focal plane arrays at Acreo resulted in the launch of several new formats up to 640 by 512 pixels and introducing major improvements to all products. The achieved performance and imagery will be evaluated. In the light of the development of new formats, the results of hybridization a 640 by 512 detector with 20µm pitch will be discussed. The driving forces behind these improvements have been the demands from industrial applications where the requirements for the operating temperature due to the life time issues are high, as well as space applications where the requirements for quantum efficiency and dark current are extreme. For the latter type of applications a number of QWIPs covering the 4 to 20µm wavelength band have been grown and evaluated. These demands for better performance are met by ongoing increases in light coupling, tuning of the quantum well structures as well as improvement of the epitaxial growth parameters. This has led to FPAs that can operate at 75K and operation close to 80K is within reach. Acreo is also looking at other material systems to fulfill the requirements of next generation photon detectors.

6542-30, Session 6

Toward dual-band megapixel QWIP focal plane arrays

S. D. Gunapala, Jet Propulsion Lab.

Mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) 1024x1024 pixel quantum well infrared photodetector (QWIP) focal planes have been demonstrated with excellent imaging performance. The MWIR QWIP detector array has demonstrated a noise equivalent differential temperature (NE * T) of 17 mK at a 95K operating temperature with f/2.5 optics at 300K background and the LWIR detector array has demonstrated a NE * T of 13 mK at a 70K operating temperature with the same optical and background conditions as the MWIR detector array after the subtraction of system noise. Both MWIR and LWIR focal planes have shown background limited performance (BLIP) at 90K and 70K operating temperatures respectively, with similar optical and background conditions. In addition, we have recently demonstrated MWIR and LWIR pixel co-registered simultaneously readable dualband QWIP focal plane arrays. In this presentation, we will discuss the performance in terms of quantum efficiency, NE * T, uniformity, and operability of these focal plane arrays and the progress of 1024x1024 pixel dualband QWIP focal plane array development work.

6542-31, Session 7

Two color QWIP and extended waveband

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Since 2002, the THALES Group has been manufacturing sensitive arrays using QWIP technology based on AsGa techniques through THALES Research and Technology Laboratory. This QWIP technology allows the realization of large staring arrays for Thermal Imagers (TI) working in the IR band III (8-12 µm).

In the past researchers claimed many advantages of QWIPs. Uniformity was one of these and has been the key parameter for the production start. The 640x512 LWIR FPA at a pitch of 20µm was the demonstration that very high performances could be achieved even with small pixels which opens the field for the realization of usable and affordable megapixel FPAs. Thales has developed for volume manufacture high performance low cost thermal imaging cameras based on the Thales Research Technology (TRT) 3rd generation Gallium Arsenide long wave QWIP array.

Another advantage widely claimed in the past for QWIPs was the so-called band-gap engineering and versatility of the III-V processing allowing the custom design of quantum structure to fulfill the requirements of specific applications like very long wavelength (VLWIR) or multispectral detection. In this presentation, we present the performances of our first 384x288 MWIR / LWIR two color FPA at a pitch of 25 µm, and also the current status of QWIPs for MWIR (< 5µm) and VLWIR (\>15µm) arrays.

6542-32, Session 7

Variable cold stop for matching IR cameras to multiple f-number optics

N. Gat, J. Zhang, M. Li, J. Garman, L. Chen, Opto Knowledge Systems, Inc.; H. Gurrola, United States Army

In recent years range optics operations have experienced increased requirements for IR capabilities, both in the mid-wave and long-wave spectral ranges. Previously, such ranges have worked primarily in the visible, using high speed cinematography. Refractive and reflective telescopes are used in such operation. However, when transitioning operations to the IR, the large investment in optics may become obsolete. Refractive optics designed for the visible spectrum do not work in the IR, and reflective telescopes are not designed to work with IR cameras that feature a cold stop inside the camera dewar.

The reflective telescopes can be recoated for IR service, but in most cases the f/# of these telescopes does not match the f/# (aperture size) of the camera's cold stop. Similarly, the telescope aperture stop does not match the position of the camera cold stop. This mismatch significantly deteriorates the image quality. Moreover, while present day IR cameras feature a fixed aperture (fixed f/#), the range uses multiple telescopes, each with a different f/#. This situation creates major difficulties in transitioning range optics to IR operations, and also adds a high cost in redesign of equipment.

A solution, demonstrated by OKSI and WSMR under the Army SBIR program, was to develop an IR camera with a variable aperture / cold stop. This variable aperture (VariAp(r)) cold stop operates in the vacuum enclosure and is a part of the radiation shield and cooled to cryogenic temperatures. The VariAp can be set to match the f/# of various reflective telescopes allowing the camera to operate with a large variety of optics present in the range inventories. To implement this, a special optical relay assembly was developed that re-images the telescope image plane on to the camera FPA, while forming an aperture stop at the position of the VariAp. The camera also contains a cold filter wheel.

The paper describes the new 1KÅ~1K InSb camera with the VariAp, the relay assembly, and telescope that make up the system. The paper also references the application of the VariAp to Gen-III FLIR systems under development by NVESD. The work described in this paper received the Army's SBIR Quality Award.

6542-33, Session 8

Multi-color IRFPAs made from HgCdTe grown by MOVPE

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This paper describes the design, fabrication and performance of 2-colour and 3-colour infrared detectors made from HgCdTe grown by Metal Organic Vapour Phase Epitaxy (MOVPE). The detectors are staring, focal plane arrays consisting of HgCdTe mesa-diode arrays bump bonded to silicon read-out circuits. Each mesa has one connection to the ROIC and the colours are selected by varying the applied bias.

In a 2-colour n-p-n design the cut-off wavelengths are defined by the compositions of the two n-type absorbers and the doping and composition of the p-type layer are chosen to prevent transistor action. The bias polarity is used to switch the output between colours. This design has been used to make MW/LW detectors with a MW band covering 3 to 5 µm and a LW band covering 5 to 10 µm.

In a 3-colour n-p-n design the cut-off wavelengths are defined by the compositions of the two n-type absorbers and the p-type absorber, which has an intermediate cut-off wavelength. Between the p-type absorber and each n-type absorber there are electronic barriers consisting of wide band-gap material. At low applied bias these barriers prevent photo-electrons generated in the p-type absorber from escaping and the device then gives an output from the n-type absorber that is reverse biased. At high applied bias the electronic barrier is pulled down and the device gives an output which is the sum of the outputs from the p-type absorber and whichever n-type absorber is reversed bias. Thus by varying the polarity and magnitude of the bias it is possible to obtain 3-colours from a 2-terminal device. This design has been used to make SW/MW/MW detectors with cut-off wavelengths of 2.8, 4.0 and 6.3 µm respectively.

6542-34, Session 8

Enhanced numerical analysis of two and three-color HgCdTe detectors

K. Józwikowski, A. Rogalski, Wojskowa Akademia Techniczna (Poland)

The performance of middle wavelength/long wavelength (MW/LW) dual-band and three-band HgCdTe heterostructure photovoltaic detectors are examined theoretically. An enhanced original computer programs are applied to solve the system of non-linear continuity equations for carriers, heat transport and Poisson equations, as well as a set of noise equations to determine performance of devices. All physical quantities

of semiconductor structure are expressed as functions of electrical potential, Fermi quasi-levels and temperature. The noise analysis is based on the set of "noise transport equations" and enables calculations of spatial distribution of spectral intensities of fluctuations of electrical potential and Fermi quasi-levels. In applied method the fluctuations of carrier mobility being the 1/f noise source as well as the fluctuations of g-r terms as a source of Lorentzian (generation-recombination) noise are taking into account. The results of calculations are presented in the form of maps illustrating spatial distributions of current densities, electrical gain, and spectral densities of fluctuations of selected physical quantities in single diode configuration. In addition, the enhanced numerical analysis include misfit dislocations and points defects as an additional sources of thermal generation and recombination, as well as sources of current noise. Photon absorption process includes the dependence of absorption coefficient on Burstein effects as well as interference effects in heterostructure and substrate. In several cases the theoretical predictions are compared with experimental data published in literature.

6542-35, Session 8

Smart IR FPAs developed in QinetiQ

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SMART focal plane arrays have in-pixel signal processing circuits that improve the performance of electro-optical sensors and extend their functionality. This paper describes three types of SMART focal plane array that have been developed at QinetiQ aimed at improved sensitivity, long range object identification and anti-dazzle.

A novel in-pixel adaptive circuit is described which improves sensitivity by removing the background photo-signal. This allows the detector stare time to be increased resulting in lower noise bandwidth and an increase in signal-to-noise ratio.

The second type of SMART focal plane array described in this paper is designed to detect time varying signals generated, for example, by helicopter blades, jet turbine engines and hot exhaust plumes. The detection of temporal signatures enables objects to be identified at significantly longer ranges than conventional focal plane arrays.

On-focal plane dazzle rejection circuits which mimic the processing found within the mammalian retina are the third type of SMART focal plane array described in this paper. In particular, the ability of a retina to share information between pixels can be used to form a spatial filter. The SMART anti-dazzle sensor uses novel analogue pixel to pixel interconnects to form a tuneable spatial filter. The sensor can be configured as a low pass, high pass or band pass filter using externally supplied signal levels. As dazzling radiation contains mainly low spatial frequencies a silicon retina circuit, which passes only high spatial frequencies, will reject the dazzle signal. The remaining high spatial frequencies give an edge-enhanced image of the object.

6542-36, Session 8

Techniques for image preprocessing in variable acuity focal plane arrays

J. T. Caulfield, Cyan Systems

Cyan Systems is developing algorithms for a compact image processor that resides near the FPA Sensor. This compact image processor works to create localized processing suitable for Variable Acuity Sensors, such as the IRFPA fabricated by Nova Sensors.

Cyan Systems will demonstrate the ability to spatially downsample the output bandwidth and detect targets of interest. The algorithm has been developed with the ability for the near FPA electronics to automatically adapt the imaging and detection parameters to extract targets without losing the sensitivity or altering the false alarm or missed detection rate of existing off focal plane processing systems. Advanced FPAs with near FPA algorithms for pre-cueing have the potential to minimize data throughput bottlenecks from very large format IRFPAs of 1024 x 1024 pixels and larger.

Improvements in Acuity processing concepts will be presented to include lower SNR detection and preservation of edges made possible by improvements in the dim target feature extraction. Figure 1. gives an example of spatial downsampling that can be performed on large and small targets in FPA pre-processing techniques.

Figure 1. Demonstration automated region of interest selection using on FPA cues in brightness, contrast and motion to select pixels to transmit and which pixels to aggregate.

These new class of Adaptive FPA systems are not only smart, but are trending towards "cognitive sensors", in that they now have the ability to sense, track, and create a hypothesis of potential threats autonomously. These sensors are therefore capable of autonomous use in surveillance and DOD threat detection scenarios.

An overview of the signal processing algorithms on real VASI MWIR and LWIR FPA sensors in field experiments will be presented.

We will show quantitative data to illustrate the SNR levels and target cueing capabilities and the simultaneous efficiencies capable by not broadcasting off the FPA all of the pixels without target information. Also, will report measured quantitative data on the smart sensor performance such as spatial and temporal processing, pre-processed Signal to Noise, Signal to Clutter, and Probability of Detection Benefits of modern VASI sensors and compare to existing 2nd generation IRFPA Systems.

6542-37, Session 9

Albion: the UK 3rd-generation high-performance thermal imaging program

R. K. McEwen, M. C. Lupton, M. Lawrence, P. Knowles, M. C. Wilson, SELEX Sensors and Airborne Systems Ltd. (United Kingdom); P. N. J. Dennis, N. T. Gordon, D. J. Lees, QinetiQ Ltd. (United Kingdom); J. F. Parsons, Thales Optronics Staines Ltd. (United Kingdom)

The first generation of high performance thermal imaging sensors in the UK was based on two axis opto-mechanical scanning systems and small (4-16 element) arrays of the SPRITE detector, developed during the 1970s. Almost two decades later, a 2nd Generation system, STAIRS C was introduced, based on single axis scanning and a long linear array of approximately 3000 elements. The UK has now begun the industrialisation of 3rd Generation High Performance Thermal Imaging under a programme known as "Albion". Three new high performance cadmium mercury telluride arrays are being manufactured. The CMT material is grown by MOVPE on low cost substrates and bump bonded to the silicon read out circuit (ROIC). To maintain low production costs, all three detectors are designed to fit with existing standard Integrated Detector Cooling Assemblies (IDCAs). The two largest focal planes are conventional devices operating in the MWIR and LWIR spectral bands. A smaller format LWIR device is also described which has a smart ROIC, enabling much longer stare times than are feasible with conventional pixel circuits, thus achieving very high sensitivity. A new reference surface technology for thermal imaging sensors is described, based on Negative Luminescence (NL), which offers several advantages over conventional peltier references, improving the quality of the Non-Uniformity Correction (NUC) algorithms.

6542-38, Session 9

A signal processing core for high-performance thermal imaging

M. Lawrence, S. F. N. Ashley, M. C. Lupton, R. K. McEwen, M. C. Wilson, SELEX Sensors and Airborne Systems Ltd. (United Kingdom)

In order to fully exploit emerging 3rd Generation infrared detector technology, very high performance signal processing electronics are required. This paper describes SELEX Sensors and Airborne System's most recent developments based upon the existing Sensor Integrated Modular Architecture (SiGMA) thermal imager. Recent developments described in this paper include a modular implementation allowing physical separation of the processing core from the detector and proximity electronics; miniaturisation of the processing electronics and the introduction of a solid state micro-scan mechanism which builds upon concepts developed during the company's previous work with cooled and uncooled focal plane arrays. Other areas described are the development of advanced image processing algorithms including non-linear correction for display optimisation. The sensor architecture is initially designed to operate with the SELEX S&AS developed Hawk infrared detector, a medium waveband 640x512 element CMT array on a 16 micron pitch, but from inception has been designed to be compatible with the emerging 3rd Generation FPAs being developed under the Albion programme. The developments described in this paper will enable these 3rd Generation devices to produce real time thermal images with more than 3 megapixel resolution.

6542-39, Session 9

Overview of range gated imaging at FOI

O. K. Steinvall, P. Andersson, M. Emkvist, Swedish Defence Research Agency (Sweden)

This presentation will review some of the work on range gated imaging undertaken at the Swedish Defence Research Agency (FOI). Different kind of systems covering the visible to 1.5 µm region have been studied and image examples from various field campaigns will be given. In parallel we have also investigated some applications for range gated imaging together with performance evaluation from both experiments and theoretical modelling. Example of such applications will be discussed.

6542-40, Session 9

Gated IR imaging with 128 Å~ 128 HgCdTe electron avalanche photodiode FPA

J. D. Beck, M. Woodall, R. E. Scritchfield, L. A. Wood, M. Ohlson, P. Mitra, J. E. Robinson, DRS Infrared Technologies LP

The next generation of IR sensor systems will include active imaging capabilities. One example of such a system is a gated-active/passive system. The gated-active/passive system promises long range target detection and identification. A detector that is capable of both active and passive modes of operation opens up the possibility of a self-aligned system that uses a single focal plane. The detector would need to be sensitive in the 3-5 µm band for passive mode operation. In the active mode the detector would need to be sensitive in eye-safe range, e.g. 1.55 µm, and have internal gain to achieve the required system sensitivity. An avalanche photodiode detector has internal gain, however, until recently, only visible and near IR avalanche diodes were available. A new device has arrived that not only provides state-of-the-art 3-5 µm spectral sensitivity, but also a high performance avalanche photodiode. This new device is the MWIR HgCdTe electron injection avalanche photodiode (e-APD). Gains of greater than 1000 have been measured in MWIR e-APDS with a gain independent excess noise factor of 1.3. This paper reports the application of the mid-wave e-APD for near-IR gated-active/passive imaging. Specifically a 128x128 FPA composed of 40 µm pitch, 5 µm cutoff, APD detectors with a custom readout integrated circuit has been designed and operated in a demonstration system. A median FPA noise equivalent input of 5.5 photons has been measured on a 128x128 MWIR APD at 77 K. High resolution gated imagery out to 9 km is will be shown.

6542-41, Session 9

Performance modeling and simuation of range-gated imaging systems

O. K. Steinvall, T. R. Chevalier, P. Andersson, M. Elmkvist, Swedish Defence Research Agency (Sweden)

Range-gated or burst illumination systems have recently drawn a great deal of attention concerning the use for target classification. The development of eye safe lasers and detectors will make these systems ideal to be combined with thermal imagers for long range targeting at night but also for short range security applications.

This presentation will describe performance modelling and simulation of range gated systems and compare these with experimental data.

6542-42, Session 9

Noiseless very high-gain avalanche photodiodes made with HgCdTe

J. Rothman, G. Perrais, J. P. Baylet, P. Castelein, J. Chamonal, G. L. Destefanis, Commissariat à l'Energie Atomique (France)

HgCdTe Mid-wave infrared pin avalanche photodiodes, APD, have been studied as a function of the temperature and bias, for two type of junction profiles, having different nominal junction width. A gain of 5300 at an inverse bias of 12.5V was demonstrated in the nominally wide junction pin-APD. The nominally narrow pin-APD showed a higher gain at low bias, but the maximum gain was lower due to an earlier onset of excess currents. The gain was measured for temperatures between T=30-150K, and was found to decrease with increasing temperatures, in correlation with the increase in band gap. The useful gain was however reduced at lower temperatures, due to increased excess current at high inverse bias, indicating a tunnel limited origin of the sensitivity limiting excess current.

The noise factor, F, showed on a nearly deterministic multiplication of the carriers, with F=1-1.5 up to gains of 5000.

6542-43, Session 9

TBD

M. D. Jack, Raytheon Vision Systems

No abstract available

6542-146, Session 9

Uncooled or minimally cooled 10-µm photodetectors with subnanosecond response time

A. Piotrowski, K. Klos, W. Gawron, J. Pawluczyk, Z. Orman, J. F. Piotrowski, VIGO System S.A. (Poland)

We report fast and sensitive long (10 µm) wavelength photodetectors operating at near room temperature. The devices are based on HgCdTe multilayer heterostructures grown by MOCVD on

(211) and (111) GaAs substrates. Device-quality heterostructures are obtained without any post growth anneal. The recent improvements of MOCVD growth were: optimized design of the device architecture to increase speed of response, better IMP growth parameters selection taking into account interdiffusion time changes during growth, stoichiometry control during growth by the layer anneal at metal rich vapors during each IMP cycle, precursor delivery to the growth zone monitored with IR gas analyzer, additional metal-rich vapor anneal at the end of growth and passivation of detector structures with wide gap HgCdTe overgrowth deposition. Monolithic optical immersion of the detectors to GaAs microlenses has been applied in purpose to improve performance and reduce RC time constant. The response time of the devices have been characterized using 10µm quantum cascade laser, fast oscilloscope with suitable transimpedance amplifier as a function of detector design, temperature and bias. Detectivity of the best thermoelectrically cooled photodiodes approaches 1e10 Jones at approx. 10 µm wavelength. The response time of small area (<250x250 µm) decreases with reverse bias to response achieving <100 ps at 140mV.

6542-45, Session 10

High frame rate IR imaging using optical readout photomechanical sensor

J. P. Salerno, Agiltron, Inc.

The ability to perform infrared imaging a high frame rates may enhance many diverse applications such as weapons threat detection, industrial processing, vehicle collision avoidance, and fire suppression. High frame rate imaging provides additional data to accomplish automated functions with improved accuracy and fewer errors. We have used a micro-cantilever based 280x240 pixel photomechanical sensor array with an optical readout incorporating visible light cameras for both MW-

and LWIR imaging at rates up to 1000 frames per second. Whereas microbolometers detect thermally induced resistance change, the photomechanical sensor is essentially a transducer that converts the image-induced temperature change into a mechanical deflection of a cantilevered beam. This defection is measured by an optical method and converted into an electronic image. The photomechanical sensor requires no external drive for operation and therefore creates no bottleneck for readout data rate. It operates uncooled at widely varying ambient temperature. The use of off-the-shelf high speed visible light sensors allows for high frame rate imaging with no need for custom electronics or ROIC. Results on detection of rapid occurrence events, such as gun fire and rocket travel, are reported. The influence of detector sensitivity and time constant on the experimental imaging is discussed. Analysis of the comparative frequency response of microbolometers and the photomechanical sensor is presented.

6542-46, Session 10

Uncooled MEMS IR imagers with optical readout

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MEMS thermal transducers offer a promising technological platform for uncooled IR imaging. We report on the fabrication and performance of a 256x256 MEMS IR FPA based on bimaterial microcantilever. The FPA readout is performed using a simple and efficient optical readout scheme. The response time the bimaterial microcantilever was <15 ms and the thermal isolation was calculated to be 4x10-7 W/K. Using these FPAs we obtained IR images of room temperature objects. Additionally, image quality is substantially improved by automatic post-processing of artifacts arising from noise and non-responsive transducers. An iterative adaptive modification of the Curvelet denoising procedure is successfully applied to image output. We will present our results and discuss the factors that determine the ultimate performance of the devices. One of the unique advantages of the present approach is the scalability larger imaging arrays.

6542-47, Session 10

Wavelength-selective infrared detectors based on patterned resistive sheets

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Planar multi-mode thermal detectors have been investigated for use in wavelength-selective long wave infrared (LWIR) focal planes arrays. Design studies have shown that they should be able to produce enough spectral selectivity to allow a three-color system spanning the 7-14 micron band. To achieve a narrowband spectral response with the simplest possible fabrication process, we propose the use of a patterned resistive sheet as the frequency-selective absorber. These patterned resistive sheets are a modified form of classical Salisbury Screens that utilize a resistive absorber layer placed a quarter-wavelength in front of a mirror. In comparison with previously designed planar antenna-coupled microbolometers that consist of both resistive and highly conductive metal strips (acting as antennas), the absorption layer in these structures involves only a single resistive layer with patterned holes. Hence, the fabrication problem is reduced from at least two layers to a single layer. We have developed a modified mode-matching technique to model the electromagnetic response of these patterned resistive sheets to achieve the required narrowband IR response. Since the design space consists of four geometrical parameters and one sheet resistance parameter, the modified mode-matching technique is ideally suited for rapid multi-variate optimization. To verify the results of this design optimization, the spectral response is also calculated using HFSS, an industry standard full-wave finite element method EM solver. The results of these FEM simulations will be compared to those from the mode matching calculations. Finally, experimental results on the narrowband absorption of the patterned resistive sheets in LWIR will be presented.

6542-48, Session 10

Uncooled nanoscale infrared high-speed sensors for missile seeker applications

N. Kislov, Nano CVD Co.; M. Sarehraz, Phoenix International; E. Stefanakos, Univ. of South Florida

Multicolor capabilities, high detectivity, and quick response are highly important for advanced infrared sensor systems. Photodiodes made of narrow-band semiconductors are widely used in such applications. However, the photodiodes require cryogenic temperatures and are expensive. Less expensive uncooled bolometric detectors are less sensitive, significantly slower, and have no multicolor capability. In order to overcome abovementioned obstacles, we have been developing infrared detectors consisting of a dielectric rod antenna (DRA) in conjunction with a nanoscale metal-insulator-metal (MIM) tunnel diode. In these assemblies, the DRA amplifies the incident electromagnetic radiation, and the induced infrared frequency voltage is rectified by the MIM diode connected between the DRA and the ground electrically conductive plate, thus transforming the electromagnetic energy into a useful electrical signal. Because of the antenna's directional selectivity and using MIM diode having the extremely low tunneling time and nanometer size contact area, such a detector can respond at terahertz frequencies at the room temperature. It was shown that DRAs made of high resistivity silicon posses low loss and enhanced gain at long and very long infrared wavelengths. The proposed approach demonstrates the inherent benefits of nanoscale device manufacturing technique that is compatible with the existing CMOS technology, which may lead to the design of low cost sensors and/or sensor arrays for use in military and commercial applications.

6542-144, Session 10

High-sensitivity 25μm and 50μm pitch microcantilever IR imaging arrays

S. R. Hunter, G. S. Maurer, G. Simelgor, S. Radhakrishnan, J. Gray, Multispectral Imaging, Inc.

This paper will report on the development of small pixel pitch infrared FPAs based on the capacitively read bimorph microcantilever sensor technology. The heat sensing bimorph microcantilever structures are fabricated directly onto the CMOS control and amplification electronics to produce a high performance, low cost imager that is compatible with standard silicon IC foundry processing and materials. Positional responsivities of greater than 0.3 μm/K have been modeled and measured for 50 μm pitch pixels, corresponding to a temperature coefficient of capacitance, ?C/C, (equivalent to TCR for microbolometers) above 30%/K. This along with noise capacitances in the sub attofarad range and nominal sensor capacitances of 15 fF, give modeled NEDT < 30 mK for these devices. The measured thermal time constants for these arrays are in the 5 -10 msec range.

At smaller pixel pitches, the positional responsivity (and consequently the NEDT) decreases rapidly with feature size. Modeling the performance of microcantilever based IR sensors with innovative sensor structures and pixel pitches down to 17 μm indicates NEDTs < 20 mK, with thermal time constants in the 5 msec range, are feasible with this technology. Results from detailed thermo-electro-optical modeling of the operation of the 25 μm pitch pixels will be compared with experimental measurements from various test structures and integrated capacitively read single pixel sensors with 25 μm pixel pitch. The most recent infrared sensitivity and other performance measurements from the development of the 50 μm pitch 160 x 120 pixel imaging arrays under development at Multispectral Imaging will also be presented.

6542-54, Session 11

IR focal plane arrays in future systems

A. F. Milton, U.S. Army Night Vision & Electronic Sensors Directorate

No abstract available

6542-49, Session 12

First THz and IR characterization of nanometer scaled antenna coupled InGaAs/InP Schottky diode detectors for room temperature infrared imaging

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Schottky diodes are one of the most widely used devices in the microwave and millimeter wave range and are employed in circuits such as mixers, frequency multipliers, phase shifters and detectors. Due to their ultra fast transport mechanism they are scalable to very high frequencies by reducing their physical contact area. In this paper we describe a novel method of using ultra small Schottky contact diodes as detectors in the MWIR band.

The increased cutoff frequency of the Schottky detector was accomplished by both reducing its capacitance to attofarad range and also by reducing the contact resistance. The Schottky detectors were fabricated on InGaAs/InP substrates with the doping level as high as 1 x 1019 cm-3. A variety of detector sizes were fabricated using nanometer T-gate technology to reduce the path resistance. The typical Schottky detector anode size was 0.1 x 1 µm2. Planar broadband antennas were designed for MWIR wavelengths to couple the radiation into the nanometer size detector. Several different IR antenna designs were evaluated, including complimentary square spirals, bow ties and crossed dipoles.

A 6x7 array of antenna-coupled Schottky detector was characterized at DC, yielding a 20 KΩ zero-bias resistance and a responsivity of 6 A/W for the entire array. The arrays were characterized at visible (0.63 µm), as well as in the IR (3-5µm and 10.6 µm). In addition a THz gas laser was used to characterize the detector array at 2.5 and 4.25 THz. The current results for polarization sensitivity confirm that an antenna-coupled mechanism is responsible for the measured responsivity. The paper will compare the measured results at the various wavelengths and attempt to explain the possible detection mechanisms.

6542-50, Session 12

Non-equilibrium free carriers overcome cooling need in quantum IR detectors

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Thermal noise of quantum IR detectors is defined by the number of thermal carriers with energy higher or equal to the detector's energy threshold. The energy distribution function of these carriers is of Boltzmann-type with a high energy tail dictated solely by the device temperature. Therefore, thermal noise in such detectors can be suppressed only by cooling the device down.

Sirica presents new technology for tunable quantum IR detector that requires no cooling. The detection is based on the response of non-equilibrium free carriers to IR photons. Sirica's IR detector uses pumping light (NIR/Visible) to form a steady-state non-equilibrium distribution (SNED) of free carriers with a narrow high-energy tail (i.e. low effective temperature), which is then used to absorb and detect IR photons. Simulations of the SNED formed in the case where the free carrier's lifetime is shorter than their energy relaxation time is presented, showing that the free carriers' effective temperature, is significantly lower than the device temperature.

Although the total number of carriers in the SNED formed is small, IR photon absorption coefficient in Sirica's detector is very high (equivalent to MCT). This is due to the very high effective cross-section achieved in Sirica's proprietary detector substance. Parameters of this composite structure will be discussed.

6542-51, Session 12

Low-cost far infrared bolometer camera for automotive use

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A new low-cost long-wavelength infrared bolometer camera system is under development. It is designed for use with an automatic vision algorithm system as a sensor to detect vulnerable road users in traffic. Looking 10 m in front of the vehicle it can in case of an unavoidable impact activate a brake assist system or other deployable protection system. To achieve our cost target below €100 for the sensor system we evaluate the required performance and can reduce the sensitivity to 150 mK and pixel resolution to 80 x 30. We address all the main cost drivers as sensor size and production yield along with vacuum packaging and the optical components.

The detector array is based on a new type of high performance thermistor material. Very thin Si/SiGe single crystal multi-layers are grown epitaxially. Due to the resulting valence barriers a high temperature coefficient of resistance is achieved (\>2.3%). Simultaneously, the high quality crystalline material provides very low 1/f-noise characteristics and uniform material properties. The thermistor material is transferred from the original substrate wafer to the read-out circuit using adhesive wafer bonding and subsequent thinning. Bolometer arrays can then be fabricated using industry standard MEMS process and materials. The inherently good detector performance allows us to reduce the vacuum requirement and we can implement wafer level vacuum packaging technology used in established automotive sensor fabrication. The optical design is reduced to a single lens camera. We develop a low cost moulding process using chalcogenide glass (GASIR(r)3) and integrate anti-reflective and anti-erosion properties using diamond like carbon coating.

6542-52, Session 12

Uncooled infrared bolometer arrays operating in a low to medium vacuum atmosphere: performance model and tradeoffs

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Uncooled infrared bolometer arrays for high-volume automotive applications such as pedestrian injury mitigation systems have to fulfil extremely stringent cost and lifetime requirements. Because of the cost aspect, only compact, uncooled infrared sensor arrays such as micro-bolometer arrays fit these requirements. In this paper we discuss design compromises at the sensor and system level and how they relate to the system performance, to cost and to lifetime. We present a calculation model for the noise equivalent temperature difference (NETD) of infrared imaging systems based on uncooled bolometer arrays. The model is validated and benchmarked using published performance data of state-of-the-art uncooled infrared bolometer arrays. The calculation model is used to evaluate possible infrared sensor and system design tradeoffs allowing low-cost infrared systems with improved reliability and lifetime, while still achieving sufficient sensitivity required for pedestrian injury mitigation systems. We propose an approach in which high-performance crystalline semiconductor materials with very low 1/f-noise properties and a moderate temperature coefficient of resistance (TCR) of about 2.5 %/K are used as thermistor material for the bolometers. The resulting increase in performance can be used to operate the bolometers in an atmosphere with reduced vacuum requirements, while still achieving useful NETD levels. The proposed calculation model suggests that a NETD on the order of 150 mK can be reached with uncooled infrared bolometer arrays operating in vacuum pressures of about 1 mbar and above. Such specifications for the bolometer vacuum package dramatically simplifies wafer-level packaging and ease long term reliability issues.

6542-53, Session 12

Performance evaluation and analysis for carbon nano-tube (CNT) based IR detectors

N. Xi, J. Zhang, K. W. C. Lai, Michigan State Univ.

Many theoretical studies have concluded that carbon nanotubes (CNTs) are promising material for the detection of infrared (IR) due to their unique electronic properties, such as he ballistic electronic transport that makes the noise equivalent temperature difference smaller compared to other semi-conducting materials. In order to explore these potentials, a reliable nano manufacturing process has been developed to make single CNT based IR detectors. CNTs are first deposited on the substrate surface and then aligning them using our newly developed Atomic Force Microscopy (AFM)-based nanomanipulation system. This paper will focus on the performance evaluation and analysis for the CNT based IR detectors. By assembling a single carbon nanotube onto a pair of electrodes, two Schottky barriers are formed at the contacts between the carbon nanotube and the two electrodes. The electron-hole pairs generated by photons within the carbon nanotube are separated by an external electric field between the two electrodes. The separated carriers contribute to the current flowing through the carbon nanotube and form photocurrent. By monitoring the photocurrent, the incident infrared can be detected and quantified. Experiments were carried out to exam the photo response of single carbon nanotube based IR detectors. Based on the experimental results, the quantum efficiency, dark current, response time and other infrared detector performance measures have been obtained. The experimental results have demonstrated that single CNT based IR detectors have much lower dark current and faster response time comparing to other infrared materials.

6542-55, Session 13

PIR security sensors: developing the next generation

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

Passive infrared (PIR) security sensors employ decades old pyroelectric technology for short range detection. This ubiquitous technology is a major market which receives little attention in the international IR forum. It is, however, a market ripe for exploitation using alternative sensor technology.

PIR security sensors are essentially hot spot detectors, and have a number of shortcomings, including low sensitivity, low spatial resolution, poor detection range (typically less than 25 metres), ability to detect only moving targets (thus inability to detect developing fires or electrical faults), and poor target recognition. Technology now exists or is under development that can address these limitations.

The challenge for next generation PIR sensors is to adapt more modern technology to this application at competitive cost. Numerous claims to 'low cost' belie the fact that production sensors remain at least 10 times greater than that needed to compete in this market. A major shift in culture is needed, away from the drive for more and smaller pixels and very low NETD, to what is actually needed and can be developed at very low cost.

In this paper a review will be made of various IR technologies, as applied to this application. It will be reasoned that only three competing technologies are likely to be successful in the short term: silicon resistance or diode microbolometers (two options of the former). An update will also be given on the development of amorphous silicon microbolometer security sensor technology employing non-evacuated packaging and plastic optics.

6542-56, Session 13

Infrared sensor module using uncooled 320 Å~ 240/640 Å~ 480 detector

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Versatile uncooled infrared sensor module is designed, which will be used in various kinds of application areas easily. the module is based on an uncooled microbolometer with 23.5 micron pixel pitch, providing 320x240 or 640x480 resolutions. one of the narrowest pitch detector of the commercial base realizes small and light weight, and even less expensive camera module. the paper introduces the features, performance and new functions of the module.

6542-57, Session 13

Toward lower uncooled IR-FPA system integration cost

B. Dupont, ULIS (France)

This paper presents the latest progress at ULIS to reduce infrared focal plane arrays integration cost for camera manufacturers. The inherent wide dispersion of classical uncooled IRFPAs leads to complex compensation electronics, making camera integration difficult and expensive. ULIS low dispersion aSi:H technology already addresses this issue by offering highly uniform uncooled IRFPA leading to wide dynamic, low NETD value and low cost with no extra custom components. ULIS continues his effort towards even lower dispersion. Within this scope, this paper reviews the latest development at ULIS of low dispersion focal plane arrays integrated readout circuits as of FPA-integrated tools helping camera manufacturer to improve image quality.

6542-58, Session 13

New IRCMOS architecture applied to uncooled microbolometers developed at LETI

F. Simoens, M. Tchagaspanian, A. Arnaud, P. Imperinetti, G. Chammings, C. Bour, P. Villard, J. Yon, Commissariat à l'Energie Atomique (France); J. Tissot, ULIS (France)

Thermal imaging market is today more and more attracted by systems with "instant-on" and low power consumption. Therefore the "TECless" operation of uncooled microbolometer detectors, that is where no Peltier module is needed, is the major step to fulfil the market requirement. In order to fulfil this trend , LETI/SLIR is working on a new IRCMOS architecture. This new design is based on a differential reading implemented with current mirrors that simultaneously reduces focal plane temperature sensitivity and simplifies the detector driving. An IRCMOS laboratory model (320 x 240 with a pitch of 25 μm) has been designed, processed, and characterised. This paper presents an overall view of this new design and the preliminary characterization results obtained from this laboratory prototype.

6542-59, Session 13

Uncooled VOx thermal imaging sensors

M. D. Joswick, P. W. Norton, BAE Systems North America

BAE Systems continues to advance the technology, performance, and utility of uncooled microbolometer based imaging systems. We continue to serve the warfighter by developing and dependably producing a family of thermal weapon sights as well as manufacturing the world's longest range uncooled LWIR camera in production, both for the US Army end-user. This paper will also review the latest advancements in microbolometer technology including the performance of the first 17 micrometer pixel pitch focal plane arrays. These arrays will be the building blocks for future imaging systems, enabling high performance in smaller, lighter-weight products, reducing the burden of man-portable camera systems on the soldier.

6542-60, Session 13

Uncooled amorphous silicon 160 x 120 IRFPA with 25-μm pixel-pitch for large volume applications

C. Trouilleau, B. Fieque, J. Tissot, P. Robert, A. Crastes, C. Minassian, O. Legras, ULIS (France); J. Yon, A. Arnaud, Lab. d'Electronique de Technologie de l'Information (France)

The rapid mastering of the 25 μm amorphous silicon technology allowed ULIS to develop two new FPA formats namely 384 x 288 (or 320 x 240) and 160 x 120 with 25 μm pixel-pitch which complete the product range currently available.

In this paper, we focus our attention on the small format 160 x 120 with 25 μm pixel pitch. This detector has conserved all the innovations developed on the full TV format ROIC (detector configuration by serial link, low power consumption or wide electrical dynamic range ...) and offers an advanced, highly reliable, RoHs compliant, TEC-less focal plane array very which is well adapted to thermal imaging. The specific appeal of this unit lies in the miniaturization of the packaging and its extremely light weight. The reduction of the pixel-pitch and the innovative package turn this 160 x 120 pixels array format into a low cost product and therefore well adapted for mass production.

In the last part of the paper, we will look more closely at high electro-optical performances of this TEC-less product 160 x 120; we will insist on the wide thermal dynamic range and the low consumption achieved thanks to the mastering of the amorphous silicon technology coupled with the innovation and care in the ROIC design.

6542-61, Session 13

Design of ADC in 25 μm pixels pitch dedicated for IRFPA image processing at LETI

M. Tchagaspanian, P. Villard, B. Dupont, G. Chammings, J. Martin, C. Chantre, A. Arnaud, J. Yon, F. Simoens, Commissariat à l'Energie Atomique (France); J. Tissot, ULIS (France)

LETI has been involved in IRFPA development since 1978, the design department (LETI/DCIS) has focused its work on new ROIC architecture since many years. The trend is to integrate advanced functions into the CMOS design in the aim of making cost efficient sensors.

The purpose of this paper is to present the latest developments of an Analog to Digital Converter embedded in a 25μm pixel.

The design is driven by several goals. It targets both long integration time and snapshot exposure, 100% of image frame time being available for integration. All pixels are integrating the IR signal at the same time. The IR signal is converted into digital by using an electrical charge counter. High density 130nm CMOS allows to use many digital functions such as counting, memory and addressing.

This new structure has been applied to 25μm pitch bolometer sensors with a dedicated 320 x 240 IRCMOS circuit. Due to smart image processing in the CMOS, the bolometer architecture requirements may become very simple and low cost. The room temperature sensitivity and the DC offset are solved directly in the pixel. This FPA targets low NETD (<50mK), a variation of 80 Kelvin for the FPA temperature, 14 bits output at 50/60Hz video rate.

6542-62, Session 13

Large format and high-sensitivity VOx μ-bolometer detectors

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SCD has established an uncooled detector product line based on the high-end VOx μ-bolometer technology. The first PFA launched was BIRD384, a 384x288 (or 320x240) configurable format with 25μm pitch. Typical NETD values for these FPAs are below 50mK with an F/1 aperture and 60 Hz frame rate.

The product exhibits superior image uniformity stability and reduced power consumption, making it most suitable for a broad range of "high-end" military and commercial applications.

In this paper we report on our progress in development of new products in accordance with SCD's uncooled products roadmap:

1. A sensitive version of BIRD384 with an improved NETD of ~ 30mK \@ F/1, 60Hz frame rate. This performance is achieved by optimizing concurrently the membrane structure, pixel architecture and ROIC electronics.

2. An improved version of BIRD384 ROIC that supports 100/120Hz frame rate.

3. First data of the BIRD640 - a 640x480 array with 25μm pitch and NETD < 50mK \@ F/1, 60Hz frame rate.

6542-63, Session 13

Recent development of ultra-small pixel uncooled focal plane arrays at DRS

C. C. Li, DRS Nytech Imaging Systems; G. D. Skidmore, C. G. Howard, DRS Infrared Technologies LP; E. Clarke, DRS Nytech Imaging Systems; D. Peysha, L. A. Wood, C. J. Han, DRS Infrared Technologies LP

DRS is a major supplier of the 25-micron pixel size 640x480 and 320x240 infrared focal plane arrays and camera products for commercial and military markets. The state-of-the-art 25-micron pixel focal plane arrays currently in production provide excellent performance for soldier thermal weapon sights (TWS), vehicle driver vision enhancers (DVE), and aerial surveillance and industrial thermograph applications. To further improve sensor resolution and reduce the senor system size, weight and cost, it is highly desired to reduce the UFPA pixel size. However, the 17-micron pixel FPA presents significant design and fabrication challenges as compared with that of 25-micron pixel FPAs. The design objectives, engineering trade-offs, and performance goals will be discussed. This paper presents an overview of the 17-micron microblometer uncooled focal plane arrays and sensor electronics production and development activities at DRS. The 17 micron pixel performance data from several initial fabrication lots will be summarized. Relevant 25-micron pixel performance data are provided for comparison. Thermal images and video from the 17-micron pixel 640x480 UFPA will also be presented.

6542-64, Session 13

640 Å~ 512, 17 μm pixel microbolometer and sensor development

T. E. Sessler, D. F. Murphy, Raytheon Vision Systems

No abstract available

6542-65, Session 13

Uncooled polycrystalline PbSe monolithic devices: a real alternative

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Paradoxically more than 50 years after being used in WWII, the polycrystalline PbSe technology has turned today in an emerging technology. The responsible of that is a new method for processing PbSe detectors based on a Physical Vapor Deposition (PVD) technique developed at CIDA. Using this method recently they were processed the first low density 2D PbSe Focal Plane Arrays (FPAs). They were x-y addressed type devices processed on Silicon. Last advances are important but not enough for being considered a mature technology and a real alternative to other uncooled technologies. To reach technical relevance and commercial interest it is mandatory to integrate monolithically the sensors with their corresponding read out electronics. Aiming to process monolithic devices, a proper CMOS read out electronics has been designed and enabled technologies have been developed. In this work the first monolithic device is presented. Even though it is a modest 16x16 FPA with a pitch of 200 * m, it represents an important milestone and allocates the PbSe technology among the major players in the uncooled IR detectors domain. It is a photonic detector suitable for being used as detector in low cost IR imagers sensitive in the MWIR band and with frame rates well above of 300 Hz. The number of applications is therefore huge, some of them specific such as sensor for Active Protection Systems or low cost seekers.

6542-147, Session 13

Solid state optical thermal imagers

M. Wagner, E. Ma, J. Heanue, S. Wu, RedShift Systems Corp.

No abstract available

6542-67, Session 14

A new moldable infrared glass for thermal imaging and low-cost sensing

Y. M. Guimond, Y. Bellec, Umicore IR Glass (France)

Umicore, known for its activities in the infrared materials and molded optics, this year launches a new infrared glass called GASIR (r) 3. This material can be molded using Umicore's proprietary molding technology and allows serving a wide range of new markets. Examples are a new automotive commercial application and sensing applications with their need for very small optics.

Parallel to the materials development, a new coating has been developed by Umicore, that allows the use of GASIR (r) molded optics in extremely harsh environments. The extreme performance of this new type of coating which complies with the toughest military specs will also be described.

6542-68, Session 14

Fabrication and test of compact high-aperture IR telescope lenses for airborne use

T. Weyh, M. Esselbach, S. Franz, S. Belke, J. Taubert, H. Lauth, JENOPTIK Laser, Optik, Systeme GmbH (Germany)

Very long range surveillance and target recognition applications in the infrared spectral range require an optical lens system with large focal length and high numerical aperture optimized for low aberrations and stray light at a working temperature considerably different from the temperature of mounting and adjustment of the system. Additionally, for the airborne use the system shall be rugged, lightweight and compact. These conflicting requirements do not only represent a demanding design task. The much bigger challenges consist in the selection and characterisation of the optical material, in the fabrication and measurement of the particular optical elements, in their integration into the lens system as well as in the characterisation of this lens system and in the verification of its performance parameters. Recent technological approaches developed at JENOPTIK Laser, Optik, Systeme GmbH for the fabrication and the test of such lens systems will be presented in this paper:

- examples of very long range telescope lenses for airborne surveillance,

- optical material selection,

- ultrahigh precision manufacturing and mounting of IR lens elements with up to 200 mm diameter,

- interferometric characterisation of lens elements and systems at 3.39 µm,

- MTF measurements at working temperature.

It will be shown that an iterative combination of manufacturing and measurement techniques is needed for the fabrication of IR lens systems meeting the highest performance requirements.

6542-69, Session 14

The trials (and tribulations) of light-weight UAV optical system design

T. A. Palmer, C. C. Alexay, StingRay Optics, LLC

Increasing demands for thermal imaging systems on unmanned aerial vehicles have lead to a concentrated effort in the design and development of light weight infrared optical systems. Pre-engineered or commercially available infrared lens assemblies are typically unsuitable for such low mass applications. This paper will focus on the challenging aspects and design considerations employed to minimize the weight of the refractive elements as well as the associated opto-mechanical support housings. In particular, consideration will be directed towards the hurdles associated with the manufacture of systems intended to operate in this unique branch of surveillance optics.

6542-70, Session 14

A compact dual-band MWIR + LWIR hyperspectral imaging sensor

T. A. Mitchell, Wavefront Research, Inc.; J. G. Zeibel, U.S. Army Night Vision & Electronic Sensors Directorate

A compact dual-band MWIR + LWIR hyperspectral imaging sensor is described. Utilizing a plane ruled reflectance grating rather than the complex and expensive convex gratings required by conventional Offner relay-based spectrometers, the all-refractive double-pass relay design form renders the spectrometer compact enough to be included within the cryogenic environment of the Dewar. This provides several advantages over other hyperspectral sensors including a 100% cold stop efficiency, greatly reduced thermal self emissions, and lower thermal background radiation. A set of novel cryogenic motorized actuators provide the capability to perform focus and rotational alignment of the slit and grating components of the spectrometer under the cryogenic operating conditions.

6542-71, Session 14

Cumulative gradient-based image sharpness evaluation algorithm for auto-focus control of thermal imagers

A. K. Srivastava, N. Kandpal, Instruments Research and Development Establishment (India)

Acquiring clear and well-focused images through an auto-focusing system is an important task for thermal imaging applications. An auto-focus system is built around an image sharpness evaluation module and a control module. Image sharpness evaluation module provides the required data to the control module for controlling the focus lens assembly to achieve the auto focus functionality. Image sharpness evaluation algorithm is a key aspect in implementing the Auto-focus feature. An Image Sharpness Evaluation algorithm based on cumulative gradient for auto-focus control of thermal imagers is presented in this paper which involves passive auto-focusing approach. The algorithm has been tested on different thermal images under varying thermal contrast and it shows good results with high precision and good discrimination power. The cumulative gradient based algorithm has been compared with other sharpness evaluation methods like standard deviation and absolute central moment which have been used in various auto focus applications. All simulations have been done using MATLAB. The algorithm is computationally simple, effective in finding out the best focused frame, and can be implemented easily on hardware.

6542-72, Session 14

Effective use of computational imaging degrees of freedom in LWIR systems

K. S. Kubala, CDM Optics, Inc.

In the digital camera world, more and more computational resources are being used to improve image quality and performance as the cost of signal processing continues to drop. This trend exists in current night vision systems where advanced algorithms such as multiple band fusion are being implemented. These systems exploit the abundance of signal processing that is now available at a low cost. Modern systems mate the growth of inexpensive signal processing with advances in fabrication techniques that allow for low cost mass produced general aspheric optics. A technology that is enabled by this change in paradigm is Wavefront Coding. Wavefront Coding is a computational

imaging technology in which optics, mechanics, detection and signal processing are jointly optimized, enabling novel LWIR imaging systems to be realized with system performance that is difficult or impossible to obtain in the optical domain alone. This paper will explore the class of LWIR systems that can benefit from Wavefront Coding as well as the class of systems where a traditional solution is more appropriate. In addition, example systems will be presented that provide a solution to some of today's most difficult imaging problems.

6542-73, Session 14

Motheye structured surface fabrication as durable anti-reflection treatment on CdZnTe for space-based LWIR detector devices

N. Agarwal, L. M. Goldman, S. A. Sastri, Surmet Corp.; P. H. Kobrin, Teledyne Scientific Co.

Space based HgCdTe imaging devices, built on CdZnTe substrates, require radiation hardened anti-reflection (AR) treatments in order to withstand the rigors of the space environment. Conventional anti-reflection (AR) coatings provide adequate optical performance but are prone to delamination and degradation due to extreme temperature cycling and irradiation in space. Consequently, there is an intense need for improved AR technology that combines high optical performance with improved durability. Etching physical gradient or motheye structures directly into the CdZnTe eliminates the need to deposit additional layers of different materials onto the substrate, avoiding the possibility of delamination and cross contamination. Motheye AR surfaces, under development at Surmet Corporation, have demonstrated excellent broadband optical performance in the LWIR (11-13 micron) waveband. Surmet's motheye technology involves direct etching of a regular pattern of fine features into the CdZnTe substrate, using standard lithography and dry etching techniques. The results from this ongoing research and development effort will be discussed.

6542-75, Session 15

Microminiature linear split Stirling cryogenic cooler for portable infrared imagers

A. M. Veprik, H. Vilenchik, S. V. Riabzev, N. Pundak, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel)

Novel tactics employed in carrying out military and antiterrorist operations call for the development of a new generation of warfare, among which sophisticated portable infrared (IR) imagers for surveillance, reconnaissance, targeting and navigation play an important role. The superior performance of such imagers relies on novel optronic technologies and maintaining the IR focal plane arrays (FPA) at the cryogenic temperatures.

Traditionally, closed cycle rotary driven Stirling cryogenic engines are used for this purpose. As compared to their off-the-shelf available linear rivals, they are lighter, more compact and normally consume less electrical power.

Recent technological advances in industrial development of high-temperature (100K) IR detectors initialized attempts for developing microminiature cryogenic coolers, both of rotary and linear types. On this occasion, linearly driven cryogenic coolers appear to be more suitable for the above applications. Their known advantages include flexibility in the system design, inherently longer life time, low vibration export and aural stealth. Moreover, recent progress in designing highly efficient "moving magnet" resonant linear drives and accompanied electronics enable further essential reduction of the cooler size, weight and power consumption.

The authors report on the development and project status of a novel Ricor model K527 microminiature split Stirling linear cryogenic cooler designed especially for portable infrared imagers.

6542-76, Session 15

Life testing of Ricor linear cryocooler

I. Nachman, A. M. Veprik, N. Pundak, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel)

Ricor is reporting on the successful completion of the life test program of K529N linear Stirling Cryocooler. In the course of the testing at elevated skin temperature (71C) the cooler accumulated 27,500 running hours. During four years of testing the cooler has performed 7,500 on/off cycles without any visible degradation in performance indices like cold tip temperature, power consumption and cool-down time.

The thorough inspection of critical rubbing surfaces in the "piston - cylinder" and "bushing plunger" pairs revealed no sign of mechanical wear and contamination. It is important to notice that those surfaces had no special coating and no "contactless" precaution was made.

We also experienced no change in leakage rate from the cooler meaning that our metal crash seal technology is quite adequate for long life cryocooler applications.

6542-77, Session 15

Raytheon dual-use cryocooler development

R. C. Hon, C. S. Kirkconnell, Raytheon Space and Airborne Systems; J. Ikegami, South Bay Science and Technology Corp.; M. M. Pillar, Raytheon Space and Airborne Systems

Raytheon initiated development of the Dual-Use Cryocooler (DUC) as a way of bridging the gap between the typical tactical and space cryocooler systems. The stated goal of the program was to produce a cryocooler system with 80% of the typical space system functionality at less than 20% of the typical cost. Initial trade studies led to the decision to use a single-stage pulse tube design due to the inherently lower complexity. The compressor module was to be a dual-opposed, self balanced design, making use of a flexure suspension and clearance gap scheme for extremely long operational lifetimes. The drive electronics were based on a robust tactical design, modified for additional functionality and hardened against radiation typical of the space environment.

Development of the DUC system has progressed substantially over the past two years, including the design, build and testing of a brassboard thermo-mechanical unit (TMU). Early design efforts were undertaken with simplicity as a goal, and as a result the brassboard TMU contained significantly less parts than typical space-level cryocoolers. Build time for the brassboard unit was extremely short, with the compressor being built in a matter of days as opposed to weeks.

The brassboard TMU was subjected to characterization testing in both horizontal and vertical orientations (to address sensitivity of the pulse-tube cold head to gravitational effects), and results from that set of tests have been correlated to the thermodynamic model. Several lessons were learned as the testing and correlation activities progressed, and improvements necessary to meet the intended performance objectives were identified for implementation in the deliverable system.

Significant progress was made in terms of electronics development as well. Existing tactical assets were heavily modified for use with the DUC, including the addition of separate drive circuits for each compressor motor. The operating software was modified to enable features not found in typical tactical systems such as first-order active vibration cancellation. Ultimately, the brassboard electronics set was used to drive passive loads as well as an actual tactical Stirling cryocooler.

This paper discusses the DUC development effort and relevant lessons learned. Test results and their meaning in terms of possible future work will be covered as well.

6542-78, Session 15

Flexure bearing compressor in the one-watt linear interface

I. Rühlich, T. Wiedmann, M. Mai, J. J. Petrie, AIM Infrarot-Module GmbH (Germany)

For high performance IR detectors the split linear cooler is a preferred solution. High reliability, low induced vibration and low audible noise are major benefits of such coolers. Today, most linear coolers are qualified for MTTF of 8,000h or above. It is a strong customer desire to further reduce the maintenance costs on system level with significantly higher cooler lifetime. Increased cooler MTTF figures are also needed for IR applications with high lifetime requirements like missile warning applications, border surveillance or homeland security applications.

AIM developed a moving magnet flexure bearing compressor to meet a MTTF of minimum 20,000h. The compressor has a full flexure bearing support on both sides of the driving mechanism. In the assembly process of the compressor an automated alignment process is used to achieve the necessary accuracy. Thus, side-forces on the pistons are minimized during operation, which significantly reduce the wear-out. In order to reduce the outgassing potential most of the internal junctions are welded and the use of all non-metallic components is minimized.

The outline dimensions comply with the SADA 2 requirements in length and diameter.

The compressor can be combined with different Stirling type coldfingers and also with the AIM Pulse Tube coldfinger, which gives additional lifetime potential up to 50,000h MTTF.

Technical details and performance data of the new compressor will be shown.

6542-79, Session 15

Improvements and extensions in Thales Cryogenics product portfolio

T. Benschop, P. C. Bruins, W. L. van de Groep, Thales Cryogenics B.V. (Netherlands); J. Martin, R. Griot, J. C. Bourdaudhui, Thales Cryogénie SA (France)

Thales Cryogenics is working with large effort on the extension and improvement of its full cryocooler product range. Due to improvements made in the last few years by most cooler manufacturers cryocoolers are - in the defence world - more and more a commodity. However, the requirements under which cryocoolers are used and the demands which users are requesting from a cryocooler such as increased reliability, shorter cooldown times, higher efficiency, lower induced vibrations and decrease in size and mass are still very challenging.

With as basis his wide product portfolio Thales Cryogenics has worked extensively on the extensions and improvement of its RM cooler range and to improve the CDT and robustness of its LSF cooler range for stringent environmental conditions. For both types of coolers also studies have been performed on the actual induced vibrations and on methods to reduce the effect of these induced vibrations at camera level.

This paper presents the latest results of the work performed and explains the gain for the users of cryocoolers.

6542-80, Session 15

Performance testing of a large heat lift 40 to 80K pulse tube cooler for space applications

T. Trollier, J. Tanchon, J. Buquet, A. Ravex, Air Liquide (France); I. Charles, L. Duband, Commissariat à l'Energie Atomique (France); T. Benschop, J. C. Mullié, Thales Cryogenics B.V. (Netherlands); M. Linder, European Space Agency (Netherlands)

A Large heat lift 40 to 80K Pulse Tube Cooler (LPTC) has been designed, manufactured and tested in partnership between AL/DTA, CEA/SBT and THALES Cryogenics BV.

The Engineering Model specification of 2.3 W cooling power at 50 K for 10°C rejection temperature and maximum 160 watts electrical input power has been reached.

The as built Engineering Model weighs 5.13 kg.

The thermal and mechanical performances will be presented and discussed.

This work is funded by the European Space Agency (ESA/ESTEC Contract N°18433/04/NL/AR) in the frame of future Earth Observation instruments development.

6542-83, Session 15

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

A. Ganot, N. Pundak, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel)

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

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

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

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

The authors will describe the various functions and advantages of an integral ("on-board") digital temperature controller that was developed in RICOR Vacuum and Cryogenic Systems

6542-84, Session 15

Cryocooler selection considerations for gamma-ray sensor cooling

N. GurArye, Cryo Solutions Inc.

The prevention of the cross-border trafficking of nuclear material suitable for the fabrication of a nuclear weapon or a "dirty bomb" has become a high priority issue for the USA Department of Homeland Security and other similar organizations world wide.

In order that the flow of commerce is not restricted, rapid and unambiguous detection and identification of radioactivity in freight and in human traffic is vital. The large number of everyday substances and objects in freight which are naturally radioactive mandates the use of "spectroscopic" detectors , capable of accurate identification of the radioactive isotopes present. The fact that the would be terrorist is liekly to understand this and try to "mask" the nuclear signature with shielding or an innocent isotope means that the instruments and systems employed by the authorities must display the best possible "resolution" or "isotope selectivity". The best practical sensor is the cooled high purity Germanium Gamma ray sensor. The ASP Detective Spectroscopic Portal monitor systems developed and manufactured by Ametek Corp (ORTEC) for the screening of persons, cars, cargo, rail each employ several such cryogenically cooled sensors.

The paper presents the main design considerations of cryocooler selection for this application, where outdoor conditions, cooling capacity, reliability and low vibrations signature are the main technical drivers.

6542-85, Session 16

IR detector dewar and cooler assemblies for stringent environmental conditions

X. Breniere, M. Molina, A. Kessler, P. M. Tribolet, Sofradir (France)

Environmental conditions (thermal, vibrations and shocks) are key performance and reliability factors for designing IR detectors. Taking into account these constraints during the IR detector design phase, Sofradir develop specific solutions to harden them with respect to stringent environmental conditions. These solutions concern both the IRFPA and the cryogenics parts and are described in this paper as well as the hardened level reached.

6542-86, Session 16

Optimal snubbers for the system of vibration protection of sensitive electronic and electro-optic instrumentation

A. M. Veprik, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel); S. Djerassi, RAFAEL Armament Development Authority Ltd. (Israel)

Visco-elastic snubbers are the indispensable component of the low-frequency vibration isolation arrangements protecting the sensitive electronic and electro-optic instrumentation from the environmental extremes. Usually, the visco-elastic properties of such a snubber are chosen as to minimise the peak acceleration (forces) developed during the collision while maintaining the peak deflection of the snubber within predefined tolerance.

The author develops the analytical model of the axial collision of the lumped body with the viscoelastic snubber which is thought of as a linear Kelvin-Voight body. The experimental testing supports the theoretical findings. From the simple analysis of collision of the freely moving body with such a single sided snubber follows the existence of the optimal relationship appearing independent of the body mass, pre-impact velocity and allowed deformation of the snubber.

For the more complicated case, where the vibration isolated payload is subjected to the gravity force and base induced shock and collides with the symmetric snubber, the author develops the Matlab-Simulink model. The optimisation procedure evaluates the optimal snubber providing for the minimum of the impact acceleration experienced by the colliding payload while maintaining the deformation of the snubber within predefined tolerance.

6542-88, Session 16

Portable cryogenically cooled infrared imager: how silent it might be?

A. M. Veprik, H. Vilenchik, R. Broyde, N. Pundak, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel); A. Struckhoff, Kollsman, Inc.

For the sake of weight and compactness, the enclosures of the modern portable cryogenically cooled infrared (IR) imagers are made in the form of a light metal (aluminium, magnesium, titanium) thin-walled shell, serving as an optical bench and accommodating telescope, an optical train and Infrared Detector Dewar Cooler Assembly (IDDCA).

Such IDDCA normally rely on the miniature rotary Stirling cryogenic coolers, which are known as powerful sources of wideband vibration export capable of exciting the inherently lightly damped structural resonances in the imager enclosure thus causing their early aural detectability when used in a close proximity to the opponent force. Eventually, the aural inaudibility distance became one of crucial figures of merit along with the overall weight, battery life, imagery quality, etc characterising the portable IR imager.

In the novel approach, the IDDCA is mounted upon the enclosure using the silent pad attenuating vibration export over the typical high frequency range containing its structural resonances. The residual noise radiation from the imager enclosure is then attenuated practically to a background level by minimising its volume velocity; this is achieved by finding the “magic point” and affixing there the optimised lumped mass.

The results of the theoretical prediction are strongly supported by the full scale experimentation. The authors report on successful attempt to developing an inaudible at greater then 10 meters (even during the cool down phase) per MIL-STD-1774D (Level II) IR imager.

6542-89, Session 16

Vibration control of a linear single-piston compressor in a microminiature Stirling cryogenic refrigerator for portable infrared imagers

S. V. Riabzev, A. M. Veprik, H. Vilenchik, N. Pundak, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel)

Modern portable infra-red imagers rely mostly on micro miniature integral Stirling-cycle cryogenic refrigerators driven by rotary compressors. However, a split Stirling refrigerator relying on a linear compressor having inherently longer life, higher reliability and aural stealth might be much more appropriate for using in this type of applications.

The state of the art, low-vibration twin-piston linear compressor is typically counterbalanced through opposite motion of the moving assemblies under the tight supervision of sophisticated DSP-based controller. However, a linear refrigerator with a single piston, passively counterbalanced compressor would have apparently better bulk, weight, price, power consumption and reliability indices, which are so vital in the above portable infra-red imagers. Unfortunately, the industry does not offer yet such a single-piston low-vibration linear refrigerator.

The authors report on the development of a novel Ricor model K527 micro miniature split Stirling linear cryogenic refrigerator designed especially for portable infrared imagers, where for the sake of effective vibration suppression, compactness, weight, price and reliability the “twin-piston” approach is abandoned in a favor of a “single-piston” design.

Different methods of a passive control of the vibration export from the single-piston compressor rely on the optimized combination of undamped dynamic absorber and heat-conductive vibration mounting. The results of the theoretical predictions are strongly supported by full scale experimentation.

6542-90, Session 16

Identification of vibration sources in pulse tube cryogenic refrigerator

S. V. Riabzev, A. M. Veprik, H. Vilenchik, N. Pundak, Ricor-Cryogenic & Vacuum Systems Ltd. (Israel)

As is known, a cold finger of a pulse tube cryogenic refrigerator does not contain moving mechanical components and, therefore, is traditionally thought of as producing low vibration and having extended lifespan. Because of these outstanding features, such cryogenic engines are especially attractive for use in a variety of vibration-sensitive instrumentation, such as IR thermal imagers, scanning electron microscopes, superconductive quantum interference devices, etc. However, even relatively low-level vibration produced by a cold tip of a pulse tube, resulting from oscillation of a gas pressure along with a vibration transmitted from a compressor through a metallic gas transfer tube, may sometimes appear to be excessive for the above vibration-sensitive applications.

By making an extensive use of the finite element analysis supported by the full-scale experimentation, the authors are attempting to identify the sources of vibration occurring in a cold tip of a pulse tube.

6542-91, Session 17

Introduction to infrared in future soldier systems

G. F. Fulop, Maxtech International, Inc.; G. L. Jinks, GLJ Group

A brief overview will be given of the common elements in major Future Soldier Systems and they way in which they rely on infrared sensors.

6542-92, Session 17

Thermal imaging applications for soldier systems

M. A. Ingalls, U.S. Army Night Vision & Electronic Sensors Directorate and DCS Corp.; D. Kitts, U.S. Army Night Vision & Electronic Sensors Directorate

The development of uncooled focal plane array technology has allowed the US Army and its industry partners to create a lighter and longer range set of night vision tools for ground forces. This discussion on thermal imagers for soldier systems will focus on soldier-borne systems and their key attributes, as well as future program goals.

6542-93, Session 17

Digital image fusion systems: color imaging and low-light targets

J. P. Estrera, Northrop Grumman Corp.

This paper presents digital image fusion (enhanced A+B) systems in color imaging and low light target applications. This paper will discuss first the digital sensors that are utilized in the noted image fusion applications which is a 1900x1086 (high definition format) CMOS imager coupled to a Generation III image intensifier for the visible/near infrared (NIR) digital sensor and 320x240 or 640x480 uncooled microbolometer thermal imager for the long wavelength infrared (LWIR) digital sensor. Performance metrics for these digital imaging sensors will be presented. The digital image fusion (enhanced A+B) process will be presented in context of early fused weapon sight system, digital image fused system (DIFS), first digital image fused night vision goggle system, digital enhanced night vision goggle (ENVG), and later long range digitally fused, digital fire control unit (DFCU). Next this paper will discuss the effects of user display color in a dual color digital image fusion system. Dual color image fusion schemes such as Green/Red, Cyan/Yellow, and White/Blue for image intensifier and thermal infrared sensor color representation, respectively, are discussed. Finally, this paper will present digitally fused imagery and image analysis of long distance targets (200 - 1500 meters) in low light from early digital ENVG and present DFCU systems. The result of this image analysis with enhanced A+B digital image fusion systems is that maximum contrast and spatial resolution is achieved in a digital fusion mode as compared to individual sensor modalities in low light, long distance imaging applications.

6542-94, Session 17

Video visor for German army soldier-of-the-future program

J. Fritze, H. Lenz, Carl Zeiss Optronics GmbH (Germany)

The German Soldier-of-the-Future (“Infanterist der Zukunft” - IdZ) program provides three different optronic reconnaissance systems and weapon sights respectively for each infantry squad of ten soldiers. Next to the reconnaissance and targeting device (WBBG) of the squad leader and the weapon sight (WBZG) for the sniper, the so-called “Videovisier” (video visor) will be used as a new type of weapon sight for aiming and combating with the German assault rifles G36 and AG36, with the machine gun MG4 as well as with the bazooka PzF3. The video visor includes an uncooled thermal imager, a day light camera, an eye-safe laser range finder and a digital magnetic compass with inclination sensor. Communication with the soldier-mounted central processing unit and real-time transmission of the video data (e.g. into the helmet mounted display of the soldier) is enabled by a wireless data link. In the presentation the requirements, the philosophy and concept as well as the funktionality of the video visor will be described in detail.

6542-95, Session 17

Long-range thermal weapon sights for the German future infantryman program IdZ

R. Breiter, T. Ihle, K. Mauk, M. Münzberg, W. Rode, AIM Infrarot-Module GmbH (Germany)

In December 2004 AIM started the series production of the HuntIR long range thermal weapon sight. The sight is fielded in the Germany Future Infantryman (IdZ) basic system and since that time in continuous service in various out of area missions with German participation.

For very long identification ranges \>1500m cooled technology still outperforms uncooled sights, even with respect to smaller size and lower weight because the typical F/1 design of uncooled systems overcompensates cooler weight for focal length \>175mm. The HuntIR sight is therefore based on a cooled MWIR detection module for range battlefield surveillance and target engagement. The device specifically is a perfect match to state of the art small arms like 0.50 cal sniper rifles or 40mm automatic grenade launchers (AGL) which provide engagement ranges \>1500m and need an adequate sight performance beyond that.

A recent modification of HuntIR was done to provide a wider field of view for improved situation awareness in urban operations and specifically to allow the engagement of the 40mm AGL in ranges between 200-1400m. The qualification tests of the sight by the German infantry were successfully completed mid 2006.

To match the demand of the follow-up program IdZ-ES additional components have to be integrated. Most important are a laser range finder (LRF), 3 axis digital magnetic compass (DMC) and a wireless data link. LRF and DMC together with a highly sophisticated fire control computer provide improved first round hit probability, the DMC additionally improves the fire control in any case of steep trajectories or for pronounced ballistic trajectories to avoid any need to precisely level the AGL.

This new sight is done under the brand name RangIR. An important additional feature is the interface for air burst ammunition (ABM). The optical distance is measured by the LRF, the fire control computer accurately evaluates the trajectory under the given angle, muzzle velocity, temperature and range conditions to define the time-of-flight. This fully integrated IR fire control system is available mid 2007.

The development phase of the IdZ-ES program is under contract, series deliveries expected in 2009. The RangIR will see some specific modifications for the link and a man machine interface to control the whole IdZ-ES system components ergonomically from the weapon with optimized power supply concepts to minimize the number of batteries, chargers etc.

Besides the IdZ program AIM is working on a day/night weapon sight providing daylight-like imaging quality allowing the feature of identification of persons e.g. in special mission like hostage rescue by special forces. AIM’s MCT 384x288 SWIR detector is used to broaden the HuntIR family with a SWIR version. The details of the required MCT avalanche photodiodes (APD) and capacitive trans-impedance amplifier (CTIA) are presented in a separate paper.

6542-96, Session 17

Surveillance and target acquisition applied to FIST

S. Modica, J. Foley, Thales FIST PCMO (United Kingdom)

The presentation will cover the work carried out in the FIST programme in evaluating the optical / electro-optical sub-systems and the potential infrared components of the system’.

6542-97, Session 17

The Felin combat system improves several essential capabilities

P. Le Sueur, Sagem Defense Securite (France)

The FELIN soldier system provides the infantryman with an integrated system increasing dramatically the soldier capability in any dismounted close combat domains.

Man remains at the centre of the system, which can interface equipments or systems already fielded and future equipments to match any customer's needs. Urban operations are carefully addressed thanks to a versatile and modular solution and a dedicated C4I system.

The Felin combat system improves several essential capabilities as defined by NATO, namely lethality, mobility, C4I, survivability and sustainability.

The modular architecture is ideal for interoperability. The system can be configured for the different missions of the soldiers thanks to a backbone that can be completed with specific equipments according to the roles and the mission profiles of the soldiers.

The development of systems contributing to "Network Centric Warfare" is an important subject for Sagem Défense Sécurité. SITEL is the terminal system that will be installed on army vehicles at the same time, and through which infantrymen will be connected to their higher supervision levels.

The large implementation of the FELIN soldier system in the French Army comes with a networked organisation and a consistent C4I capability.

6542-98, Session 17

Optronics sensors suitable for dismounted soldier

P. Le Sueur, Sagem Defense Securite (France)

The digital Felin system matches very well C4I capability when connected to the Felin sensors familly which by construction have digitalised outputs.

A unique range of day - night observation devices has been developed to taylor the system requirements focusing reduction of weight, volume and input power.

The key design drivers has been 'integration' to get multifunction capabilities with a strong effort on miniaturisation.

All sights provide digital outputs connected to the digital network of the soldier backbone.

The optronics equipments are the eye's extension of the soldier. They must give to the infantryman the superiority in term of observation, as well as target detection, recognition and identification in several environments, in urban combat, country combat, by day and by night.

The very new IR and I(c)˜ technology provides video sensors particularly suitable to these constraints.

More over, their video capability allows direct pictures transmission in and out from the system, in and out from the soldier.

6542-142, Session 17

The handheld multifunctional thermal imager and surveillance instrument of Jena-Optronik within the German project: IDZ-Infanterist der Zukunft

J. Heinrich, Jena-Optronik GmbH (Germany)

Today armed forces of a number of countries develop land warrior integrated, modular combat systems the so called Ground Soldier System. The German version is called "IDZ-Infanterist der Zukunft". This high-technically equipped soldier will have some outstanding capabilities which are based on technical components. One of them will be a handheld multifunctional thermal observation instrument. This light weighted instrument includes a thermal imager which detects an object in 2000m, recognizes it in 1500m and identifies it in 1000m. The IR Image channel can be superposed with the visual daylight image what is taken by an integrated CCD-camera. The image is seen trough a biocular viewer on two Organic Light Emmitting Displays. With the laser range finder which works up to 4000m and the Digital Magnetic Compass it is possible to measure distances and angles and so the own and the target object's positions. This information as well as live time video sequences can be transferred wireless to the soldiers C4I-system.

The instrument is based on the surveillance platform NYXUS which was developed in close collaboration with the German Bundeswehr. The NYXUS includes additionally GPS, goniometer and northfinding gyroscope which makes it a precise and irreplaceable tool for nowadays armed forces.

The producer Jena-Optronik is a specialist of opto-electronic systems and instruments for aerospace and security. The worldwide leading company for sensors of Attitude & Orbit Control Subsystems and Guidance & Navigation Control offers also satellite on-board software solutions, ground satellite data processing and data interpretation. Germany based Jena-Optronik is a subsidiary of the JENOPTIK Group.

6542-99, Session 18

Narrowband infrared emitters for combat ID

M. U. Pralle, I. Puscasu, J. T. Daly, K. Fallon, P. G. Loges, A. C. Greenwald, E. A. Johnson, ICx Ion Optics Inc.

There is a strong desire to create narrowband infrared light sources as personnel beacons for application in infrared Identify Friend or Foe (IFF) systems. This demand has augmented dramatically in recent years with the reports of friendly fire casualties in Afghanistan and Iraq. Ion Optics' photonic crystal enhancedTM (PCETM) infrared emitter technology affords the possibility of creating narrowband IR light sources tuned to specific IR wavebands (near 1-2 microns, mid 3-5 microns, and long 8-12 microns) making it the ideal solution for infrared IFF. This technology is based on a metal coated 2D photonic crystal of air holes in a silicon substrate. Upon thermal excitation the photonic crystal modifies the emitted yielding narrowband IR light with center wavelength commensurate with the periodicity of the lattice. We have integrated this technology with microhotplate MEMS devices to yield 15mW IR light sources in the 3-5 micron waveband with wall plug efficiencies in excess of 10%, 2 orders of magnitude more efficient that conventional IR LEDs. We have further extended this technology into the LWIR with a light source that produces 9 mW of 8-12 micron light at an efficiency of 8%. Viewing distances \>500 meters were observed with fielded camera technologies, ideal for ground to ground troop identification. When grouped into an emitter panel, the viewing distances were extended to 5 miles, ideal for ground to air identification.

6542-100, Session 18

EO system concepts in the littoral

P. B. W. Schwering, TNO (Netherlands)

In recent years, operations executed by naval forces were taking place at many different locations. At present, operations against international terrorism and asymmetric warfare in coastal environments, are of major concern. In these scenarios, the threat caused by pirates on-board of small surface targets, such as jetskis and fast inshore attack crafts, is increasing. In the littoral environment, the understanding of its complexity and the efficient use of the limited reaction time, are essential for successful operations. Present-day electro-optic sensor suites, also incorporating Infrared Search and Track systems, can be used for varying tasks such as detection, classification and identification. By means of passive electro-optic systems, such as infrared and visible light sensors, improved situational awareness can be achieved. For long range capability, elevated sensor masts and flying platforms, are ideally suited for the surveillance task and improve situational awareness. A primary issue is how to incorporate new electro-optic technology and signal processing into the new sensor concepts, to improve system performance. It is essential to derived accurate information from the high spatial-resolution imagery created by the EO sensors. As electro-optic sensors do not have all-weather capability, the performance degradation in adverse scenarios must be understood, in order to support the operational use of adaptive sensor management techniques. In the paper we discuss the approach taken at TNO in the design and assessment of system concepts for future IRST development. An overview of our maritime programme in future IRST and EO system concepts including the signal processing will be presented.

6542-101, Session 19

Pelican: SCD's 640 Å~ 512/15 μm pitch InSb detector

J. O. Schlesinger, Z. Calahorra, E. Uri, T. A. Fishman, I. Shtrichman, E. Sinbar, V. Nahum, E. Kahanov, B. Shlomovich, SemiConductor Devices (Israel); S. Hasson, SemiCondutor Devices (Israel); N. Fishler, D. Chen, T. Markovitz, SemiConductor Devices (Israel)

Over the last decade, SCD has developed and manufactured high quality InSb Focal Plane Arrays (FPAs), that are currently used in different applications worldwide. SCD's production line includes InSb FPAs with mid format (320x256 elements), and large format (640x512 elements), all available in various packaging configurations, including fully integrated Detector-Dewar-Cooler Assemblies (DDCA). Many of SCD's products are fully customized for customers' needs, and are optimized for each application with respect to the weight, power, size, and performance.

In 2006, SCD has added to its broad InSb product portfolio the new "Pelican" detector family. All Pelican detectors include a large format 640Å~512 InSb FPA with 15μm pitch, which is based on the FLIR/Indigo ISC0403 Readout Integrated Circuit (ROIC). Due to its small size, the Pelican FPA fits in any mid format Dewar, enabling upgrading of mid format systems with higher spatial resolution due to its good MTF.

This work presents the high performance of Pelican products. As achieved in all SCD's InSb DDC's, the Pelican detectors demonstrate high uniformity and correctability (residual non uniformity less than 0.05% std/DR) and remarkable operability (typically better than 99.9%). The Pelican FPA can be integrated in various DDCA configurations as per application needs, such as light weight, low power and compact form for hand held imagers, or a rigid configuration for environmentally demanding operating and storage conditions.

6542-103, Session 19

Elta's IRST defense and self-protection system

Z. Schneider, Elta Systems Ltd. (Israel); M. Meidan, A. Lottan, A. Gershikov, S. Schijvarg, Israel Aircraft Industries Ltd. (Israel)

The EL/L-8273/4 is a long range, multi-role, passive multispectral Infrared Serach and Track system for airborne and naval applications. The system is designed to assist tactical operations by supporting the platform's self defense system and by backing up collision avoidance in radio silence navigation. We describe the main features of this new 360 degrees coverage IRST design.

6542-104, Session 19

Artemis: Staring IRST for the FREMM frigate

V. Megaides, C. Grollet, Thales Optronique SA (France)

Dealing with military and asymmetric threats represents a key issue for any military vessel in various environment. In order to support ship's self protection, Thales has design a new generation of naval infrared search and track (IRST) called ARTEMIS. It has been selected to equip Future European Multi Roles Frigates (FREMM).

ARTEMIS is a fully passive infrared surveillance system capable of automatically detecting and tracking both air and surface targets simultaneously. It is able to detect and track manoeuvring and stealthy new threats as well as surface asymmetric threats.

The paper describes technologies than has been introduced in ARTEMIS design (large IR FPA, original optic design, electronic stabilization, dedicated and patented algorithms on COTS processing boards). It describes also the advantages offered by this new concept of electro-optical surveillance with full static sensor heads compare to existing scanning solutions from a technical, operational and logistic point of view.

6542-105, Session 19

Large format staring IR-FPAs for persistent surveillance applications

J. W. Devitt, M. E. Greiner, R. L. Rawe, Jr., D. P. Forrai, P. Henry, L-3 Communications Cincinnati Electronics, Inc.; M. T. Eismann, R. Mack, J. S. Harris, Air Force Research Lab.; J. Dennison, L-3 Communications Cincinnati Electronics, Inc.; C. C. Alexay, StingRay Optics, LLC; S. D. Gaalema, Black Forest Engineering

Ongoing and recent world events highlight the need for 24/7 Persistent Surveillance capabilities. Round the clock reconnaissance is needed over large scale (city sized) area's in order to achieve the required coverage. Two approaches are considered to satisfy these requirements; a 4k x 4k contiguous FPA with 15um pixel pitch fitted into a compact gimbaled arrangement, and a quad mosaic 2560^2 on a fixed platform which (with micro-scanning) could produce a 50Mpixel equivalent IR image. Several key technologies in the large format IR-FPA arena will help satisfy these requirements: detector, optical, and platform level technologies are considered. Methods to flag events in the enormous data stream are also of critical importance and could include spectral, polarimetric, and temporal discrimination techniques.

6542-106, Session 19

Compact modular reconnaissance and targeting platform for various military and security tasks

M. Spieweck, H. Ziegner, H. Flack, Carl Zeiss Optronics GmbH (Germany)

The development of an compact and lightweight stabilized platform for various reconnaissance and targeting tasks is presented. Due to the fast accessibility of almost the entire hemishere, extraordinary stabilisation quality and high-precision measurements of the azimuth and elevation angles, the platform can be adapted for countless land-based and maritime vehicle missions as well as for airborne operations. As the key component of a modular system, it can be equipped with a wide range of electro-optic devices. The standard sensor configuration includes an infrared camera, a TV camera and an eyesafe laser rangefinder. Depending on the desired performance, there are three infrared camera families available at Carl Zeiss Optronics: The so-called UnCooled Modules (compact high-quality microbolometers up to 640x480 pixels), the OPHELIOS (2nd generation LWIR CMT system with a 768x576 resolution) and the ATTICA familiy (MWIR and LWIR FPAs up to 640x512 pixels with additional 2x2 micro-scan). For extreme daylight resolution requirements the platform can be equipped with a HDTV camera. Any alternative or additional components like laser designators or illuminators can be configured on specific customer requirements. Currently, the platform system is prepared for the PUMA which will be the new armored fighting vehicle of the German Army.

6542-107, Session 19

SWAD: small arms fire warning and direction finding system: a passive IR concept

M. Zahler, M. Danino, Elisra Electronic Systems Ltd. (Israel)

Elisra Electronics system introduce a passive IR approach for stationary system providing protection to high value infrastructure and strategic areas by detecting and warnings against fire shot from rifles, carbines, sub-machines and various other small arms - SWAD.

SWAD provides protected surroundings in which it remotely detects small arms fire. Using novel imaging and processing techniques; SWAD precisely locates the flash sources for future counter firing and plots them over an IR imaging display. The system detects multiple small arms/sniper fire sources simultaneously, day and night, at long ranges and with high-precision detection capabilities.

SWAD consists of a set of wide field of view and high frame rate infra-red staring sensor, a processor a commander control unit with a real-time IR imaging display to assist in finding the shooter location in a background of an urban, rural or other areas and a sniper end station

comprises of an electrical Pan and Tilt for cueing a gun and/or a telescope towards the shooter. The system transfers verified targets data to friendly force snipers in real time.

6542-108, Session 19

TANDIR: projectile warning system using uncooled bolometric technology

Z. Horovitz-Limor, M. Zahler, Elisra Electronic Systems Ltd. (Israel)

Following the demand for affordable, various range and light-weight protection against ATGMs', Elisra develops a cost-effective passive IR system for ground vehicles. The system is based on wide FOV uncooled bolometric sensors with full azimuth coverage and a lightweight processing & control unit.

The system design is based on the harsh environmental conditions. The basic algorithm discriminates the target from its clutter and predicts the time to impact (TTI) and the target aiming direction with relation to vehicle.

The current detector format is 320*240 pixels and frame rate is 60 Hz. The digital video output has 14bit resolution & wide dynamic range. Spectral response is on Far Infrared (8-14?).

Future goal is to enhance detection performance by using large format uncooled detector (640X480) with improved sensitivity and higher frame rates (up to 120HZ).

6542-109, Session 19

Anti-tank missile system MILAN: optronic sensors for the new generation firing post MILAN ADT/ER

J. Barth, A. Fendt, H. Kuffner, R. Pröls, R. Rüger, C. Schmid, EADS Lenkflugkoerper GmbH (Germany)

The European anti-tank missile system MILAN has found wide-spread use in numerous countries. Introduced in 1974 it has since undergone several technological upgrades.

We report here on the newly developed firing post MILAN ADT ("Advanced Technology") which improves the MILAN system performance substantially while maintaining all operational features to which MILAN operators are accustomed. An even further advanced version of this firing post is now under development in the frame of a range extension of the missile system dubbed MILAN ADT/ER.

Being a command-to-line-of-sight system, the new MILAN ADT firing post is equipped with a missile tracking sensor which captures the missile´s signature with a wide field-of-view optics and a large CMOS detector covering both gathering and guidance phase. Using adaptive windowing and sub-sampling functions combined with differential imaging modes this sensor tracks the signatures of all MILAN missile types with optimum precision, high resistance against IRCM, and improved signal-to-noise ratio over the entire flight path.

An integrated thermal imager replaces the earlier ancillary TIs, MIRA and MILIS. The TI image is displayed on an internal micromonitor and projected into the eyepiece. Optimum axis harmonization between both missile tracking and sighting channels is ensured by projection of reference marks into each optical sensor path from a common multispectral projector.

An extended range version will also be offered which takes advantage of the missile tracking sensor´s enhanced responsivity and the precision of axis alignment. An integrated color TV sensor substitutes the bulky direct view telescope, andboth TI- TV-sensor will provide two fields-of-view on the internal micromonitor for surveillance and target identification, respectively.

6542-110, Session 19

TED: a novel miniaturized infrared detection and situation awareness system

G. A. Tidhar, R. Manor, Optigo Systems, Ltd. (Israel)

Optigo Systems develops miniaturized, infrared wide field of view detection and situation awareness systems named TED (Transient Event Detector).

The system could be man potable and battery operated for a long operation time. Furthermore, it provides imaging video signals and inertial direction signals.

We present TED architecture and design concepts utilizing advanced signal processing algorithms and unique optics, as well as some possible applications. We provide first demonstrations of system performance in laboratory as well as field conditions.

6542-111, Session 19

Dual-mode seeker with imaging sensor and semi-active laser detector

J. Barth, A. Fendt, R. Florian, W. Kieslich, T. Kuligk, EADS Lenkflugkoerper GmbH (Germany)

When the field of operation of precision strike ground/air-to-ground missiles is extended to beyond-line-of-sight missions autonomous seekers will soon encounter serious difficulties, especially with regard to low signature targets and complex scenarios.

We have investigated dual-mode sensors which are conceived to overcome these specific problems by combining an imaging sensor with a semi-active laser seeker. These sensors offer non-line-of-sight target engagement with high reliability and under operator control using a laser target designator while minimizing the active exposure time for target designation by handing over the tracking process once the passive imaging sensor has locked onto the target.

For this purpose a laboratory demonstrator has been built with a standard TV-sensor and an InGaAs 4-quadrant detector mounted on a 2-axis gimbal system. Both detectors use a common objective; the focussed radiation is divided by a spectral beam splitter.

The signals of the 4-quadrant detector are digitized and subsequently processed by an FPGA. If the pre-programmed laser pulse characteristic is identified the position information is evaluated and the gimbal system activated in order to center the laser spot. Subsequently a tracker locks onto the target signature found in the imaging sensor signal. Once lock-on is confirmed the laser can be turned off automatically.

We present the results of laboratory and field tests obtained with the dual-mode demonstrator. Based on these results we plan to replace the TV-sensor by an uncooled microbolometer detector in the future. The design and expected performance of such a dual-mode sensor will be discussed.

6542-112, Session 19

Track extraction algorithms for rocket motor ejecta

C. L. Edwards, M. P. Mattix, L. M. Howser, L. R. Gauthier, Johns Hopkins Applied Physics Lab.

A Bolometer IR Camera recently captured IR images of motor ejecta or chuff during two rocket booster flight missions. This paper summarizes and compares the chuff tracking algorithms that were used for the two missions. Initial algorithms had very little predictive capability for frame-to-frame object estimation. Improved algorithms leverage many additional physical properties of the chuff to enhance the algorithm's performance in the frame-to-frame association and discrimination of objects. The enhanced algorithms also record statistics of tracked chuff's physical parameters including size, speed, direction, intensity, peak-pixel intensity and position. The developed predictive capability utilizes the statistical history of the chuff tracks to anticipate future chuff location. The pieces of chuff in a new frame are compared to the prediction and statistical track history with tolerances proportional to the track parameter's standard deviation of truncated statistics. Truncated statistics utilize the recent track history's stronger correlation to a chuff's future physical parameters. Chuff satisfying prediction and truncated statistical tolerances are added to the track history. The track's statistical information then updates. This paper discusses the Bolometer IR camera's specifications affect on the algorithm performance, such as pixel fill-factor and its effect on the algorithm performance.

6542-127, Session 19

QWIP compact thermal imager: Catherine-XP and its evolution

O. Cocle, C. Rannou, B. Forestier, P. Jougla, Thales Optronique SA (France); E. M. Costard, P. F. Bois, Thales Research & Technology (France); A. Manissadjian, D. Gohier, Sofradir (France)

Since 2005, The THALES Group is successfully manufacturing TV/4 format QWIP sensitive arrays in high rate production through THALES Research and Technology Laboratory.

Sofradir has entered a full production of its VEGA-LW-RM4 IDDCA using a 25µm pitch, 384x288 QWIP Array which is the core of the very compact QWIP thermal imager CATHERINE-XP.

Serial production of CATHERINE-XP has now started in Thales Optronique in order to meet the delivery schedule of the various programs for which it has been selected. A review of the QWIP Production status, CATHERINE-XP achievements and current programs is presented.

As THALES Optronique has based its today strategy on very compact TI in order to address the largest panel of platforms and applications, THALES Optronique is working in cooperation with Sofradir and TRT on the evolutions of the product to take advantage of the new capabilities offered by QWIP technology like bi-spectral. The achievements of these developments are also presented.

6542-113, Session 20

Fire service and first responder thermal imaging camera (TIC) advances and standards

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Fire Service and First Responder Thermal Imaging Camera (TIC) applications are growing, saving lives and preventing injury and property damage. Firefighters face a wide range of serious hazards. TICs help mitigate the risks by protecting Firefighters and preventing injury, while reducing time spent fighting the fire and resources needed to do so. Most fire safety equipment is covered by performance standards. Fire TICs are not, subject to inadequate operational performance and insufficient user training. Meanwhile, advancements in Fire TICs and lower costs are driving product demand. The need for a Fire TIC Standard was spurred in late 2004 through a Government sponsored Workshop where experts from the First Responder community, component manufacturers, firefighter training, and those doing research on TICs discussed strategies, technologies, procedures, best practices and R&D that could improve Fire TICs. The workshop identified pressing image quality, performance metrics, and standards issues. Durability and ruggedness metrics and standard testing methods were also seen as important, as was TIC training and certification of end-users. A progress report on several efforts in these areas and their impact on the IR sensor industry will be given. This paper is a follow up to the SPIE Orlando 2004 paper on Fire TIC usage (entitled Emergency Responders' Critical Infrared) which explored the technological development of this IR industry segment from the viewpoint of the end user, in light of the studies and reports that had established TICs as a mission critical tool for firefighters.

6542-114, Session 20

Fabry-Pérot MEMS-based integrated microspectrometers spanning the SWIR and MWIR

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Wideband capable microspectrometers enable a broad range of rapidly tunable hyperspectral IR-FPA imagers and spectroscopic analysis systems to be developed. We have developed a microspectrometer based on monolithic integration of a parallel plate MEMS optical filter directly with a HgxCd1-xTe-based infrared detector. The primary technical challenge in achieving the integration of a MEMS Fabry-Pérot filter with the HgxCd1-xTe detector is to keep the processing temperature less than 125°C, as the performance of HgxCd1-xTe based detectors degrades at higher process. In this work measured results and design issues for microspectrometers operating in the 1.5-2.6 microns (SWIR) and the 3-5 microns (MWIR) wavelength range are presented. In the SWIR, measurements indicate linewidths as low as 55 nm, switching times of 40 microsec and a tuning ranges of 380 nm which is limited by parallel-plate snap-down. In the MWIR, linewidths of 210 nm, switching times of 20 microsec and a tuning range of 900 nm have been achieved. The tuning speed is limited by squeezed film damping due to the physically narrow gap (lambda/2) between the Fabry-Pérot mirrors; Nevertheless, switching times are more than suitable for high-speed, full frame rate IR-FPA. Bowing of the moveable Fabry-Pérot mirror due to stress gradients is identified as the dominate source of linewidth broadening. The integration of a MEMS tunable Fabry-Pérot filter capable of continuous tuning within a given band and a HgxCd1-xTe detector capable of being designed for any IR band should enable this microspectrometer to be used in a wide array of low-cost spectroscopic applications.

6542-115, Session 20

The Infrared Cloud Ice Radiometer (IRCIR)

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The Submillimeter-wave and Infrared Ice Cloud Experiment (SIRICE) will provide global measurements of ice water path (IWP - the vertically integrated mass of ice particles per unit area), and weighted mean mass particle diameter (Dme). The SIRICE payload will contain two instruments, the Sub-millimeter/Millimeter (SM4) Radiometer, and the Infrared Cloud Ice Radiometer (IRCIR). IRCIR is a compact, low-cost, multi-spectral, wide field of view pushbroom infrared imaging radiometer. IRCIR will employ four IR sensor assemblies to produce 90° cross-track (contiguous along-track) coverage in three spectral bands with a spatial resolution of 0.6 km at nadir. Each IR sensor assembly consists of an uncooled microbolometer focal plane array (FPA), associated sensor core electronics, a stripe filter fixed at the FPA, and an IR lens assembly. A single scene mirror is used to provide two Earth view angles, as well as calibration views of space and the on-board calibration blackbody. The two Earth view angles will be used for stereo cloud height retrievals.

6542-130, Session 20

First responder homeland disaster protection

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Disasters can be either natural, as seem recently with Hurricane Katrina or man-made, as seen by recent global terrorist activities or even a combination of man-made and natural, involving the ever increasing transportation of Hazardous Materials by land sea and air. Unencumbered operation of critical infrastructure systems, such as oil & gas facilities, nuclear power plants & utility facilities, ports, harbors, borders and transportation systems necessitate a complete, comprehensive, sometimes automated and integrated detection, management and control systems that can provide both owners and First Responders Global Homeland protection against these disasters. Governmental organizations, like Border and Transportation Security, USCG, Office of State & Local Governmental Coordination and Preparedness, Strategic Border Initiative Network, FEMA and DHS, are looking to state, local and municipal organizations including Police, Fire, EMS and private Security to continue to serve as First Responders in disaster situations. First responders such as firefighters, police, EMS and security professionals are all driven to maintain order and protect lives and property. First responders have begun to adopt thermal imaging because of its unsurpassed detection capabilities and situational awareness. They understand that passive long wave thermal imaging systems, whether handheld or fixed/mobile mounted can detect activity 24/7 and in all-weather using high resolution imagery performance, provide high reliability operation and when combined with other sensor wavelengths, using automated video analytics, can reduce both First Responder Fatigue and false alarm resulting in full situational awareness with more efficient and effective (safer) on-scene or remote decision making. Thermal imaging technical advances and applications related to first responders are illustrated through case studies in this paper.

6542-117, Session 21

Recent advances in negative luminescent technologies

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Negative luminescent (NL) devices, which to an IR observer appear colder than they actually are, have a wide range of possible applications, including use as IR sources in gas sensing systems and as thermal radiation shields in IR cameras. A further important use would be a calibration source for IR focal plane arrays where there are many potential advantages over conventional sources, including high speed operation (for multi-point correction) and low power consumption. Such applications produce considerable technological challenges as they require large area uniform devices (\>1cm2) with a large apparent temperature range.

Two of the key technical challenges in developing this type of device are reducing the required drive currents and voltages. In this paper we report on recent progress in fabricating large area (1.5cm Å~ 1.5cm) negative luminescence devices from Hg1-xCdxTe grown on silicon substrates, where we have been investigating the possible use of optical concentrators to reduce the required drive currents, and the use of a segmented device architecture to reduce the required drive voltages.

6542-118, Session 21

Noise characteristics of HDVIP HgCdTe LWIR detectors

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DRS LPE-grown SWIR, MWIR and LWIR HgCdTe material are fabricated in the High-Density Vertically Integrated Photodiode (HDVIP) architecture. Instruments manufactured for certain strategic applications have severe constraints on excess low frequency noise due to the effect the noise has on the image quality with subsequent consequences on the period of calibration. This paper will present data and analysis of excess low frequency noise in LWIR (Cutoff ~ 10.5 um \@ 60 K) HDVIP HgCdTe detectors.

The vehicle for noise measurements is a multiplexed 320 x 6 array of 40 um x 50 um, 10.5 um cutoff, HgCdTe detectors. Noise has been measured on a column of 320 detectors, at 60 K, as a function of frequency under dark and illuminated conditions, at zero and 50 mV reverse bias. Integration time for the measurement was 1.76 ms. Output voltage for the detectors was sampled every 100th frame. 32,768 frames of time series data were collected for a total record length of 98 minutes. Since the total time for collecting the 32,768 time data series points is 98 minutes, the minimum frequency is 170 uHz. At present, time series and Fourier transform data on individual detectors at 50 mV reverse bias in the dark have been studied. Examination of the detector current time series and Fourier transform curves thereof, reveal a variety of interesting characteristics: (i) time series displaying switching between two states characteristic of random telegraph signal (RTS) noise), the noise current power spectrum having Lorentzian type characteristics; (ii) time series data exhibiting slight wave-like characteristics with the noise current power spectrum being 1/f-like at low frequencies; (iii) pronounced wave-like characteristics in the time series with the noise current power spectrum being 1/f^2-like at low frequencies; and (iv) time series having a mean value independent of time with the noise current power spectrum being white. In addition some isolated diodes had characteristics that lay between the four main types outlined above. Time series and noise for other conditions under which data was obtained (zero bias dark, zero bias illuminated, and 50 mV reverse bias illuminated) are to be examined to determine changes in behavior under different operating conditions.

6542-120, Session 21

Spatial resolution of SCD's InSb 2D detector arrays

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The two-dimensional spatial response of a pixel in SCD's back-side illuminated InSb focal plane array (FPA) is directly measured for arrays of small pitch, namely, 30, 20 and 15 μm. The characterization method uses spot-scan measurement and deconvolution algorithm, resulting in the net pixel spatial response. Two independent methods are used to measure the detector spatial response: a) direct spot-scan of a pixel with a focused beam; b) uniform illumination upon back-side evaporated thin gold mask, in which sub-pixel apertures are distributed in precise positions across the array. The experimental results are compared to a numerical 3D simulation with excellent agreement for all pitches. The spatial response is used for calculating the crosstalk and the modulation transfer function (MTF) of the pixel. We find that for all three pixel dimensions, the net spatial response width (FWHM) is equal to the pitch, and the MTF width is inversely proportional to the pitch. Thus, the spatial resolution of the detector improves with decreasing pixel size as expected, and should not limit the overall resolution of an observation system for all the discussed InSb FPA pitch values.

6542-121, Session 21

Sigma-delta column-wise A/D conversion for cooled ROIC

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Designing a digital IR focal plane array (IRFPA) requires to fulfil very stringent requirements in terms of power consumption, silicon area and speed. Among the various ADC architectures, like dual-ramp, successive approximation or over-sampled converters, the best choice strongly depends on the application. We believe that sigma-delta converters, in spite of their quite high power consumption, are a promising solution for high-performance and medium size FPA, e.g. 160x120 or 320x240.

This paper presents the design of a second order sigma-delta (incremental) ADC dedicated to cooled (77°K) FPA applications. System-level simulations used to specify the critical analog blocks are presented along with electrical simulation results. The column ADC including the digital decimation filter has been designed in a standard 0.35μm CMOS process on the basis of a 25 μm pitch and lead to a total length of 3500 μm ("spaghetti ADC"). Based on these simulations, the expected performance is the following: 25 kSamples/s rate, 80 dB Signal-to-Noise Ratio (SNR), 13 bits Effective Number Of Bits (ENOB) and 200 μW power consumption. Test chips including a single ADC have been manufactured end of 2006 and measured. The first results, at 77°K, are presented, along with perspectives and future developments.

6542-122, Session 21

A pixel-level analog to digital conversion circuit based on single-slope integration for infrared FPA applications

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With the development of basic component of infrared focal plane array (IRFPA) readout electronics , the research focus is being diverted increasingly to how to intensify the ability of IRFPA and reduce system complexity. One of the most effective approaches is to integration the analog to digital conversion circuit on readout circuit chip of IRFPA, which originally belongs to signal processing circuits off chip.

This paper discusses a kind of pixel-level analog to digital conversion circuit base on the principle of single slope integration ,which can be used for signal readout and A/D conversion of IRFPA. An 8Å~8 array readout circuit chip with pixel-level A/D conversion base on single slope integration is designed and simulated, which has current input and serial digital output. The chip is produced by the 0.6µm CMOS process. Test results show that the circuit can realize pixel-level A/D conversion, and its resolution reaches 8-bit.

6542-124, Session 21a

Non-uniformity correction results for SOFRADIR infrared 2D staring arrays

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The Non Uniformity Correction (NUC) performance of infrared 2D staring arrays is a key factor to ensure the best IR image quality at the camera level. SOFRADIR has carried on studies to improve both the NUC performance and the correction table stability over the time periods, the readout integrated circuit configuration and the environmental conditions. Indeed, works have been performed on the improvement of HgCdTe wafer layers homogeneity and uniformity for both Liquid Phase Epitaxy (LPE) and Molecular Beam Epitaxy (MBE) growth techniques, on the improvement of the readout circuit linearity and on the optimization of the dewar optical interface. Thanks to these improvements, Sofradir offers to its customers high level NUC performances as well as excellent correction table stability for the short wave, mid wave and long wave infrared bands. Thus, the calibrations constraints are reduced at the camera level and the image quality is optimized over a large operating condition ranges. These results are presented in this paper for different types of IR detectors and different wavebands.

6542-125, Session 21a

Scene-based nonuniformity correction using texture-based adaptive filtering

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The detectors within an infrared focal plane array (FPA) characteristically have responses that vary from detector to detector. It is desirable to remove this “nonuniformity” for improved image quality. Factory calibration is not sufficient since nonuniformity tends to drift over time. Field calibration can be performed using uniform temperature sources but requires briefly obscuring the field-of-view and leads to additional system size and cost. Alternative “scene-based” approaches are able to utilize the normal scene data when performing non-uniformity correction (NUC) and therefore do not require the field-of-view to be obscured. These function well under proper conditions but at times can introduce image artifacts such as “ghosting”. These artifacts generally result when a portion of the scene is not optimal for NUC. The scene-based approach presented in this paper estimates a correction term for each detector using spatial information. In parallel, motion estimation and texture segmentation are used to identify regions in the scene that are suitable for NUC. This information is then employed to adaptively converge to the proper bias term for each detector in the FPA. Results using both synthetic and actual data sets demonstrate the advantages of this approach. Implementation options are also investigated.

6542-126, Session 21a

Nonuniformity correction algorithm based on a noise-cancellation system for infrared focal plane arrays

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In this paper a novel nonuniformity correction method that compensates for the fixed-pattern noise (FPN) in infrared focal-plane array sensors is developed. The proposed NUC method compensates for the additive component of the FPN statistically processing the temporal signal using a noise-cancellation system. The main assumption of the method is that a source of noise correlated to the additive noise of the infrared focal-plane array is available to the system. Using such assumption as well as the read-out imagery, a finite impulse response (FIR) filter is designed and an estimate of the additive noise is synthesized. This estimate is then subtracted to the read-out data in order to produce a filtered version of the corrupted imagery. The performance of the proposed system and its ability to compensate for the FPN are tested with infrared images corrupted by both real and simulated nonuniformity.

6542-145, Session 21a

A resistance non-uniformity correction method using bias heating for resistive type uncooled microbolometer FPAs

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Microbolometer-type uncooled thermal detector focal plane arrays (FPAs) suffer from pixel-to-pixel resistance variation, which is conventionally corrected by applying a specific bias voltage to each detector by the use on-chip DACs. The proposed method in this paper uses the bias heating of the detector where the detector is heated-up for a pre-determined period of time before the read-out phase. Assuming that the detector active material has negative TCR, the detector resistance can only be decreased using bias heating. Due to this, a correction resistance with %5 of the mean detector resistance is embedded into the readout circuit which is used to increase the resistance seen by the readout circuit for the detectors having resistances smaller than the mean value. The proposed method uses only a current source and simple digital blocks for each column, eliminating the need of DACs that occupy large silicon area, contribute to the noise floor of the system, and dissipate large power. The resistance correction resolution of the proposed method is 37.5 Ohm for a 5 MHz digital clock frequency, a 100 kOhm detector resistance, a 1E-9 thermal capacitance, -0.03 %/K TCR, and 25 uA heating current; this correction resolution corresponds to more than 12-bit DAC resolution where a conventional CTIA structure with a 2 V detector bias and a 5 V maximum DAC voltage is used.

6542-66, Poster Session

Pixelwise readout integrated circuits with pixel-level ADC for microbolometers

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Pixelwise integrated circuits involving a pixel-level analog-to-digital converter (ADC) are studied for 320 * 240 microbolometer focal plane arrays (FPAs). It is necessary to use a pixelwise readout architecture for decreasing the thermal noise. However, it is hard to locate a sufficiently large integration capacitor in a pixel of FPAs because of the area limitation. To effectively overcome this problem, a two step integration method is proposed.

First, after integrating the microbolometer current for 32 * s, upper 5bits of the 13bit digital signal are output through a pixel-level ADC. Then, the microbolometer current is integrated during 1ms after the skimming current is corrected using upper 5bits in the field-programmable gate

array (FPGA) and lower 8bits are output through a pixel-level ADC. Finally, upper 5bits and lower 8bits are combined to the digital image signal after the gain and offset correction in digital signal processor (DSP)

Each 2 * 2 pixel shares an readout circuit which has a current-mode background skimming circuit, an operational amplifier (op-Amp), an integration capacitor and a multichannel bit-serial (MCBS) ADC. When the current of a microbolometer is integrated, the integration capacitor is connected between a negative input and an output of the op-Amp. Therefore a capacitive transimpedance amplifier (CTIA) has been employed as the input circuit of the microbolometer. When the output of a microbolometer is converted to digital signal, the Op-Amp is used as a comparator of the MCBS ADC. This readout circuit is designed to achieve 35 * 35 * m2 pixel size in 0.35 * m 2-poly 3-metal CMOS technology. The noise equivalent temperature difference (NETD) of the proposed readout circuit is 60mV, which is a two times smaller NETD because the integration of it is 1ms, which is sixteen times longer than that of the conventional one.

6542-74, Poster Session

Multispectral thermal imaging with interferometers at Brewster angle of incidence

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The optical scheme of a multispectral thermal imager (MSTI) is considered using a staring thermal imager and interferometers established at Brewster angle of incidence to the axis of the sighting device. The calculations of sensitivity, resolving power and other parameters of this device were conducted.

In the MSTI considered the filtration of received radiation is implemented owing to the multi-beam interference of beams (polarized in a plane perpendicular to the plane of incidence) in interferometers positioned at Brewster angle of incidence to the axis of the optical system/ The interferometers were made from flat optically polished laminas from a material with high refractive index, transparent for the filtrated radiation.

As interferometers were placed at the Brewster angle of incidence to the optical axis several important characteristics were obtained:

* The reflection coefficient of beams (polarized in a plane of a perpendicular plane of incidence) increases, and, therefore, the Q-quality and spectral resotution of interferometers also increase;

* There is an increase of the spectral interval between the adjacent pass bands of interferometers, and, therefore, there is a capability of increase of spacing interval between mirrors and Q-factor of interferometers;

* There appears a possibility to avoid negative influence of the parasitic interference between the mirrors of the adjacent interferometers.

To enable the activity of the MSTI in other spectral ranges, the mirrors of interferometers have no reflecting coatings.

The offered MSTI allows:

* To log fast processes, by obtaining in one frame the instantaneous photo with “multi-colored strips”;

* To provide fast switching of operational modes of the device from the mode of multispectral thermal imaging to the mode of “customary” thermal imaging , by turning the polaroid placed in front of the chilled filter of the photodetector;

* To provide functioning in several spectral ranges (i.e. in other orders of the interference) by replacing the chilled band pass filter in front of the photodetector or replacing the chilled filter together with the photodetector.

6542-116, Poster Session

An infrared solution to a national priority NASA ice detection and measurement problem

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NASA has a serious problem with ice that forms on the cryogenic-filled Space Shuttle External Tank (ET) that could endanger the crew and vehicle. This problem has defied resolution in the past. To find a solution, a cooperative agreement was developed between NASA-Kennedy Space Center and the U.S. Army-Tank Automotive Research, Development & Engineering Center. This paper describes the general operating principles, test methodology, and some results for the resultant mobile near-IR ice detection and measurement system developed by MDA of Canada and jointly tested with NASA and the U.S. Army TARDEC. Performance results achieved demonstrate that the pre-launch inspection system has the potential to become a critical tool in addressing NASA’s ice problem.

6542-128, Poster Session

A high fill-factor uncooled infrared detector with thermomechanical bimaterial structure

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By adopting new capacitance reading scheme, a capacitive type uncooled infrared detector structure with high fill-factor and effectively controllable thermal conductance is proposed. Instead of conventional MEMS capacitor structure (i.e. an insulating gap between top and bottom electrodes), a capacitor with a floating electrode and two bottom electrodes has been applied to the infrared detector. Infrared absorber which also acts as floating electrode of the capacitor is connected to the substrate via two bimaterial legs. These legs are consisted of two materials having large difference in thermal expansion coefficient (Al:25ppm/K and SiO2:0.35ppm/K). However, the one end tip of the bimaterial leg does not contain Al and only consist of SiO2, so that the absorber can be separated from the substrate thermally as well as electrically. The capacitance change by the result of infrared absorption is read only through two bottom electrodes which are placed right under the absorber, and also perform as infrared reflectors. The design has advantages of enlarging fill-factor of the infrared detector, effective thermal conductance controlling and high sensitivity to IR. With only small dimensions of SiO2 (5µm x 2µm x 0.1µm), the device can have low thermal conductance of 1.3x10-7W/K, so that the portion of the legs can be reduced in a pixel area. The device has fill-factor of 0.84 and 15.4%/K of sensitivity to infrared rays concerning 5K of temperature difference between the structure and the substrate.

6542-131, Poster Session

Successful MWIR FPA fabrication using gas cluster ion-beam InSb surface finishing

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As the demand for mid wavelength infrared (MWIR) focal plane arrays (FPAs) continues to increase, the quality of both the surface and sub-surface of InSb becomes more stringent. To meet the resolution and sensitivity requirements for high performance mid-wavelength infrared (MWIR) FPA imaging systems in the 1 to 5.4 micron region (77°K), the surface of the material as well as the bulk crystal must be of excellent quality. Chemo-mechanical-polishing has proven to be a qualified and steadfast finishing process for InSb surfaces in the fabrication of IRFPAs. However, a time consuming surface etch of the InSb is universally required at some point in the IRFPA manufacturing process. Gas cluster ion beam processing (GCIB) has been shown to significantly enhance the surface oxide desorption of both GaSb and InSb substrates for MBE growth and provides an alternate surface finish to CMP for InSb based FPA processing. The use of GCIB may preclude the need for surface etching, thus reducing IRFPA processing time and reducing extended chemical cleanup. This study examines the comparison of CMP and NF3/O2 dual energy gas cluster ion beam processing (GCIB) on InSb surfaces and the effect on final IRFPA device performance. Atomic force microscopy (AFM), cross-section transmission electron microscopy (XTEM), and rocking curve x-ray diffraction (XRD) examine the surface and sub-surface InSb integrity. The study shows no difference between CMP and GCIB finished InSb based IRFPA pass rates, opening the possibility for etch step

elimination. DARPA support from contract #W31P4Q-04-C-R001 is gratefully acknowledged.

6542-132, Poster Session

Improved bias equalization method for suppression temperature-induced errors in microbolometer FPA over 20-K substrate temperature change

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Among all uncooled infrared detectors resistive microbolometer focal plane arrays (FPA) are the most perspective for applications not requiring ultimate parameters typical for cryogenic FPAs. Variations in parameters from element to element of microbolometer FPA, mainly in temperature coefficient of resistance, give rise to various temperature dependencies of output signals corresponding to different elements. It in turn gives rise to non-uniformities in response characteristics when temperature of FPA changes and demands its stabilization with accuracy better 0.1 K. Application a non-uniform corrective biases to the individual microbolometers for equalization temperature dependencies of FPA output signals, proposed and realized by Indigo Systems Corporation, allows to reduce requirement to FPA temperature stabilization up to 5 degrees. Further reduction of this requirement up to removal of the thermoelectric cooler from infrared microbolometer systems is in present realized by means additional real-time correction of output signal and/or bias voltages in depending on current temperature.

This paper describes improved bias equalization method for control of microbolometer FPA uniformity at substrate temperature change. This approach uses in general case thermally-shorted and heat-insulated shielded from infrared radiation compensating bolometers instead only thermally-shorted ones and two additional bias impulses to equalization variations in temperature dependencies of dark output signals. It allows to equalize temperature coefficient of resistance not only in sensitive bolometers but also in compensating ones and as result significantly improve equalization quality. Numerical simulation two proposed FPA architectures in compare with Indigo Systems' ones shows that new equalization method allows to control microbolometer array non-uniformity under 50 mK level over 20 K range of substrate temperature. This probably will allows to apply microbolometer FPAs indoors without use the additional measures such as temperature stabilization and real-time correction.

6542-133, Poster Session

A high-SNR readout circuit design for TDI array with adaptive charge capacity control

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Infrared imaging system is a very important instrument in a satellite system and the infrared image getting from the satellite is very useful in weather forecast. Among many information acquired from the satellite infrared image, cloud top temperature (CTT) is important in understanding the phenomena of atmosphere. CTT is much lower than the surface temperature, so the infrared intensity of cloud top is very low. For a low IR radiation, signal current is decreased but total noise is not decreased because shot noise resulting from the detector is decreased proportional to decreased signal but readout noise is the same regardless of the reduced signal. Thus SNR is significantly reduced at low radiation. For this reason, we proposed an adaptive charge capacity control method to measure more exact temperature in the low temperature range. TDI array looks at a fixed scene n times, where n is a TDI depth. From the result of the first integration time for the scene, we can anticipate the intensity of the scene. So, if we change the charge capacity adaptively according to the incoming radiation intensity, we can get increased SNR and enlarged dynamic range. For the low intensity, we integrate the detector current into a small integration capacitor. And for the high intensity, we integrate the detector current into a large integration capacitor. As a result, this adaptive charge capacity control amplifies the low radiation signal without increasing readout noise. Moreover, high radiation signal can be integrated without saturation, so dynamic range is increased. By the simulation it is found that SNR is increased by 13.5dB at 200K and dynamic range is enlarged by 13.3dB.

6542-134, Poster Session

Dim moving target detection based on detection index using local gamma correction and motion information

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Modern Infrared Search and Track (IRST) system is the essential defense technique against an attack of the cruise missiles and the lower infiltration flights. The signature of their threats is typically much less intensive than intensity of cluttered background with noise. This necessitates the development of efficient detection technology for robust and reliable target detection in cluttered background with noise. Conventional studies show that the track-before-detect (TBD) algorithms provide a powerful processing technique for detecting dim moving low observable target under low SNR conditions. However, these algorithms were often extremely sensitive to background or noise and too computationally expensive to be applicable in real situations.

This paper introduces a novel adaptive algorithm for target detection. The algorithm is proposed on the basis of robust and adaptive method that is invariant to the prior uncertainty with respect to statistical properties of cluttered background and noise. The essence of proposed algorithm is to design the detection index over two images obtained by processing the given image through the local gamma correction and the estimation of target motion. And the detection index is obtained by the three factors which calculated relations between two images: correlation rate (CLR), luminance rate (LR), and contrast rate (CTR). Results of simulation show that the proposed algorithm gives an enormous gain compared with the conventional TBD techniques.

6542-135, Poster Session

The geometric design of microbolometer elements for uncooled focal plane arrays

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In this paper we discuss possibilities to improve the geometric design of microbolometer pixels in uncooled focal plane arrays. For cost reduction reasons, the pixel pitch of these microbolometer elements should be reduced as much as possible while keeping the same level of performance. This becomes increasingly difficult once the dimensions of the microbolometer elements reach a critical value of about 25 micrometers, mainly because the available space limits the thermal isolation and the available area for IR absorbtion. For these reasons it is essential to optimise not only the material properties but also the geometric aspects of the microbolometer structure to get the maximum performance for a given size of the elements.

Extending the work of Liddiard [1], in the first part of this paper we discuss the design of the optical cavity, focussing mainly on the influence of the sacrificial layer thickness, which defines the properties of the resulting Fabry Perot resonator. In the second part of this paper we concentrate on the geometry of the absorbing membrane itself and give estimates for optimum film thicknesses and lateral dimensions. Finally, based on the resulting calculated values for the NETD (noise equivalent temperature difference), possibilites to further reduce the size beyond a pixel pitch of 25 micrometers are reviewed.

[1] K. C. Liddiard, Infrared Phys. Vol. 34, No. 4, pp. 379-387 (1993)

6542-136, Poster Session

Uniformity studies of inductively coupled plasma etching in fabrication of HgCdTe detector arrays

R. Bommena, S. Velicu, P. Boieriu, T. S. Lee, C. H. Grein, EPIR Technologies, Inc.; K. K. Tedjojuwono, NASA Langley Research Ctr.

Inductively coupled plasma (ICP) chemistry based on a mixture of CH4, Ar and H2, was investigated for the purpose of delineating HgCdTe mesa structures and vias typically used in the fabrication of high performance infrared photodetector arrays. We report on the ICP etching uniformity results and correlate them with plasma controlling parameters (gas flow rates, total chamber pressure, ICP power, and RF power). The etching rate and surface morphology of In-doped MWIR and LWIR HgCdTe showed distinct dependences on the plasma chemistry, total pressure, and RF power. Contact stylus profilometry and cross-section scanning electron microscopy (SEM) were used to characterize the anisotropy of the etched profiles obtained after various processes. The surface morphology and the uniformity of the etched surfaces were studied by plan view SEM. Atomic force microscopy (AFM) was used to make precise assessments of surface roughness. The electrical characteristics of etched HgCdTe samples were investigated using temperature dependent Hall measurements in van der Pauw contact geometry. We also report the preliminary results of device performance from the photovoltaic detectors fabricated with ICP.

6542-137, Poster Session

Detection of 2,4,6-trinitrotoluene on non-traditional surfaces using fiber optic coupled grazing angle probe: FTIR

S. P. Hernández-Rivera, O. M. Primera-Pedrozo, L. Pacheco-Londoño, N. Rodríguez-Cardona, D. E. Nieves, Univ. de Puerto Rico Mayagüez

With heightened awareness of homeland security issues, the detection of explosives has become a pressing priority. Explosives detection is a very important task for National Security. The formidable task includes development of new probes and methods for detection of concealed threat compounds. Energetic compounds need to be detected on a variety of surfaces. Every surface will interact differently with the target compounds and the degree of adhesion will vary from surface to surface. Fiber Optic Coupled Grazing Angle Infrared Spectroscopy has been used in our research group as a potential technique to develop new methodologies for detection of explosives on surfaces. The technique is remote sensed, in situ and can detect nanograms of the compounds. Sample smearing, direct pipette transfer, thermal inkjet (TIJ) technology, among others are used for transferring the target analyte on the substrates to be used as standards and samples. In this research smearing was used as a sample transfer method. One of the most relevant areas of investigation is to analyze 2,4,6-trinitrotoluene (TNT) on various non traditional surfaces such as plastics and glasses. Another important aspect of the research was to optimize the procedure where more reproducible spectra could be obtained and a better data preprocessing protocol could be achieved. For non traditional surfaces, the analysis can be influenced by the distance between the grazing angle probe and the sample plate. A series of statistical methods can be used for quantification of TNT dissolved in dichloromethane on plastic surfaces. Among these the preferred are integration of band areas and Partial Least Squares (PLS) analysis. Partial least squares (PLS) regression is an extension of the multiple linear regression models. By using peak areas in the range from 1380 to 1273 cm-1, the method was not linear for loading concentration higher than 5.0 µg/cm2. The loading concentration of 0.62 * g/cm2 was considered as limit of quantification and 0.16 * g/cm2 as limit of detection.

In this work the first method for detection and quantification of explosives on plastic surfaces using Fiber Optic Coupled Grazing Angle Probe-FTIR sample and smearing on surface as transfer method was evaluated as a proof of concept experiment. This methodology can also be used on others surfaces such as glass surfaces. The method promises to be an excellent methodology in areas of National Defense and Security for contamination detection. The focal point of the program is detection of explosives such as TNT for Defense and security applications.

6542-138, Poster Session

Short-wave infrared radiometers design and characterizations

G. P. Eppeldauer, H. W. Yoon, National Institute of Standards and Technology

Short wave infrared (SWIR) radiometers have been developed to extend the NIST reference responsivity scales from the silicon wavelength range to 2500 nm. In addition to spectral power responsivity measurements, where 5 mm diameter InGaAs and extended-InGaAs (EIGA) detectors are underfilled by the incident radiation, irradiance responsivity calibrations were needed. Irradiance measuring radiometers are used as reference detectors to calibrate field radiometers in both irradiance and radiance measurement modes. In irradiance mode, smaller detectors with high shunt resistance, such as 1 mm diameter short-wave HgCdTe and EIGA detectors were used. Mechanical, optical, thermal, and electronic design considerations of SWIR radiometers are discussed in this paper. Noise equivalent currents and peak responsivities were measured to evaluate noise equivalent power (NEP).

To convert power responsivity into irradiance responsivity, an integrating sphere diffuser is mounted between a precision input aperture and the detector. For irradiance mode measurements, usually transmitting diffusers are used between the aperture and the detector. All of our SWIR detectors are temperature controlled with 4-stage thermoelectric coolers to obtain high detector shunt resistances. The dissipated heat is removed by either a fan or using circulated water from a fan cooled radiator unit. The detector temperature is stabilized with a temperature controller to about -80 oC using a thermistor sensor. As a result of the short wavelength cut-off and the high detector shunt resistance, the background produced noise could be equalized to the output noise of the detector-preamplifier unit. The shunt resistance dominated resistor noise (at the highest signal-gain selections) was equalized to the low 1/f noise (from the selected operational amplifiers) at the output of the preamplifier. The operational amplifiers with high open-loop gain and large unity-gain bandwidth were selected to perform low uncertainty current-to-voltage conversion even at high signal gains and frequencies. The signal (chopping) frequencies were tuned to the elbow of the 1/f noise spectrum. Optimization of the preamplifier gain characteristics was necessary to measure chopped radiation with high sensitivity and low measurement uncertainty. Typically, the photocurrent-to-voltage conversion uncertainty is 0.02 % (k=2). The responsivity calibration results are reported at DC (zero Hz). To obtain exact decade ratios for the different signal gain selections at a given (other than DC) signal frequency, the frequency dependent gain (responsivity) curves were measured and then corrections were applied based on the measured data.

6542-139, Poster Session

Characterization of layer of Tetryl, TNB, and HMX using grazing angle-FTIR

S. P. Hernández-Rivera, A. Santiago-Morales, L. Pacheco-Londoño, O. M. Primera-Pedrozo, Univ. de Puerto Rico Mayagüez

Grazing angle Fourier transform infrared (FT-IR) spectroscopy has been used for characterization of the distribution and form of layers of some explosive. Among the explosives tested were trinitrobenzene (TNB), HMX and Tetryl. The thickness of the layers deposited was measured and verified by visible region ellipsometry. Various solvents were used to generate the films on stainless steel slides and on silicon single crystals (110). Isopropyl alcohol was the preferred solvent because it produced more homogeneous mass distributions of target explosives on the substrates. The film thickness, analyte distribution and the relation of thickness to infrared absorption/reflection response of these explosives were compared with those previously reported for TNT, 2,4-DNT and RDX. This comparison was used for described the general optical behavior of the explosives studied

6542-140, Poster Session

The uncooled microbolometer trade-off: a new figure of merit for uncooled IR FPA

A. Crastes, J. Tissot, ULIS (France)

NETD is often the only available parameter to characterize uncooled FPAs. However NETD is strongly dependant on thermal time constant. Therefore, this paper deals with the important parameters like MTF, fill factor and thermal time constant, to compare microbolometer devices and proposes a figure of merit taking into account thermal sensitivity as well as imager characterization. For example, a FPA with a NETD around 10 mK and thermal time constant around 40 ms is obviously not compliant with a 100 Hz frame rate and has to be compared with a 40 mK, 10ms component.

The important point is to define the right figure of merit (FOM) to compare different FPAs and to make the best choice for a given application. A dynamic approach is therefore proposed to be as close as possible to the "real life" and compared to the static approach generally used in simulation software.

6542-141, Poster Session

Dual-band camera system with advanced image processing capability

O. Schreer, M. López Sáenz, C. Peppermueller, U. Schmidt, IRCAM GmbH (Germany)

A dual-band IR camera system based on a dual-band QWIP focal plane array in 384x288x2 format was developed. The camera delivers exactly pixel-registered simultaneously acquired images and exhibits an excellent NETD of <30 mK at an integration time of less than 10 ms. It is equipped with industry standard Camera Link and Gigabit Ethernet data interface and is connected to and operated from a personal computer.

The camera is equipped with a special dual-band, dual-field-of-view lens (14.6 degree and 2.8 degree diagonal FOV). Radiometric calibration was performed for real quantitative comparison of MWIR and LWIR radiant power.

The system uses special software to extract and visualize the - often quite small - differences of MWIR and LWIR images. The software corrects and processes the images and permits to overlay them with complementary colors such that differences become apparent and can easily be perceived.

As a special feature, the system has advanced software for real-time image processing of dynamic scenes. It has an image stabilization feature which compensates for the movement of the camera sensor relative to the scene observed. It also has a powerful image registration capability for automatic stitching of live images to create large mosaic images.

The camera system was tested with different scenes and under different weather conditions. It delivers large-format sharp images which reveal a lot of details which would not be perceptible with a single-band IR camera. It permits to identify materials (e.g. glass, asphalt, slate, etc.), to distinguish sun reflections from hot objects and to visualize hot exhaust gases.

6542-148, Poster Session

Singlemode step-index and microstructured fibers for the middle infrared

L. N. Butvina, O. V. Sereda, E. M. Dianov, General Physics Institute (Russia); N. V. Lichkova, V. N. Zagorodnev, Institute of Microelectronics Technology (Russia)

We report the design, fabrication and optical characterization of a step index singlemode and singlemode microstructured crystalline optical fibers from silver halide. Step-index singlemode was extruded from a preform with an inserted rod of higher refractive index and had core diameter about 38 μm. The microstructured fiber was extruded from a preform with 18 inserted rods of lower refractive index that form two ring structure in a hexagonal pattern. The fiber core size was approximately 79 μm. Both experimental and theoretical evidences are presented to establish that the fibers are singlemode at wavelength 10.6 μm. The near field and far field mode distributions showed no evidence of the structures associated with higher-order modes. Optical losses measured by cut-back method were ~ 1-2 dB/m . Silver halide crystals have the wide transmission range of wavelengths 2-20 μm. Singlemode fibers for the middle infrared may be applied in infrared systems for heterodyne detecting in IR countermeasure systems and IR stimulation. There is also a promising possibility of application of microstructured crystalline fibers as effective modal wavefront filters with broadband single-mode behavior in 4 - 20 μm .

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6543-01, Session 1

Simulation of passive and active infrared images using the SE-WORKBENCH

J. Latger, T. Cathala, N. Douchin, OKTAL Synthetic Environment (France); A. Y. Le Goff, DGA/DCE/CELAR (France)

The SE-WORKBENCH workshop, also called CHORALE (French acceptation for "simulated Optronic Acoustic Radar battlefield") is used by the French DGA to perform multi-sensors simulations. CHORALE enables the user to create virtual and realistic multi spectral 3D scenes, and then generate the physical signal received by a sensor, typically an IR sensor.

Taking advantage of developments made in the frame of Radar simulation, CHORALE is currently enhanced with new functionalities in order to tackle the "active" problem, involving new generation infrared sensors such as laser.

This article aims at presenting the technical challenges for simulating both classical passive IR imagery of a full terrain and active imagery especially on targets.

Authors will insist on duality and differences concerning in particular monochromatic/coherent waves versus incoherent waves, active domain versus passive domain, BRDF modeling, influence of roughness surface on BRDF expression, influence of phase in the combination of waves, polarization effects, Doppler effects.

SE-WORKBENCH workshop implements the "Photon Map" original method, which enables to treat the "global illumination" paradigm, consisting of multi reflections ray tracing effects combined with Monte-Carlo ray scattering. This approach will be assessed in the frame of coherent illumination by laser systems.

The atmosphere propagation accurate dependence on wavelength constraint will be studied.

Special requirements for advanced systems such as flash laser systems, heterodyne infrared detectors or hyperspectral imagery will be analyzed, from the point of view of research simulation.

Finally, modeling issues of the degradations introduced by atmospheric turbulence will be discussed, merging 3D and 2D MTF effects.

6543-02, Session 1

Modeling and analysis of ship surface BRDF

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

Modeling the bi-directional reflectance distribution function or BRDF of a ship surface is an integral part of any infrared ship signature model. The ship surface BRDF within ShipIR is based on the Sandford-Robertson (1965) model with a discrete assumption for lobe-width and solar-glint. The sea surface reflectance model within ShipIR is based on a sea roughness probability density function or PDF as formulated by Cox and Munk (1954) but uses a more refined integral approach, as outlined by Mermelstein et al. (1994), to compute the solar-glint and non-glint reflections of the sea and sky. A similar roughness model was proposed by Ward (1992) to characterize the BRDF properties of a typical surface paint based on isotropic and anisotropic assumptions of surface roughness. This paper compares the two surface roughness models to show that BRDF (sr-1) is not an ideal parameter for the calculation of a micro-faceted surface reflectance. Simulated examples and actual IR measurements of a ship are used to demonstrate how the ShipIR sea surface reflectance model can be used to accurately model the solar reflections off a micro-faceted ship surface.

6543-03, Session 1

Cameo-SIM reflections from exact surfaces

A. A. Mitchell, J. Brewster, A. W. Haynes, Defence Science and Technology Lab. (United Kingdom)

No abstract available

6543-04, Session 1

Measured and modeled temperatures for the CUBI test body

A. Malaplate, A. Schwarz, M. Kremer, Forschungsfesellschaft für Angewandte Naturwissenschaften e.V. (Germany)

The actual status of the FOM CUBI will be presented. First outdoor temperature measurements with thermocouples had been performed and the environmental conditions were measured with the FOM weather station. The FOM Background Model was applied to the given situation and CUBI wall temperatures were simulated. This model will be explained and measured temperature values will be compared to modelled values.

6543-05, Session 2

Measurement of soot particles in different combustion processes and their contribution to the IR emission of these processes

A. D. Devir, A. B. Lessin, Institute for Advanced Research and Development (Israel)

No abstract available

6543-06, Session 2

Computer-aided camouflage assessment in real time

T. Muller, M. Müller, Fraunhofer-Institut für Informations- und Datenverarbeitung (Germany)

No abstract available

6543-07, Session 2

A new instrument for measuring optical transmission in the atmosphere

T. A. Kaurila, The Finnish Defence Forces (Finland)

It is an important task to measure optical transmission of the atmosphere when testing performance of electro-optical systems such as thermal imagers. Only by knowing atmospheric transmission precisely enough, we will be able to eliminate effects of the atmosphere on test results. For this reason a new instrument that measures optical transmission in the atmosphere has been constructed. The transmissometer consists of a transmitter-receiver unit, a reflector and control software. The instrument measures atmospheric transmission at wavelength of 1 µm and 8-12 µm by comparing the intensity of the beam propagating through the atmosphere and the reference beam inside the transmitter-receiver unit. Calibration is carried out by the aid of a visibility meter and a special calibration algorithm. An important criterion for the design was to create an instrument which could be used flexibly in field measurements. This paper describes the construction of the transmissometer, its operation principles and calibration procedure. Moreover, the measured performance of the transmissometer based on field tests is discussed. According to first measurements the transmissometer fulfills the requirement

specifications. Total measuring accuracy of the transmissometer is typically between 10 and 20 %.

6543-08, Session 2

Modeling night sky radiance for night vision systems

J. M. Cathcart, T. L. Haran, J. C. James, W. Robinson, T. Wasilewski, L. West, D. Roberts, K. Lyons, Georgia Institute of Technology

In this paper we present the results of our research efforts to develop a digital signature model for prediction of night sky radiance levels. The motivation for this model arose from a need for analysis tools to support the design and evaluation of future military night vision systems. Based on this requirement, this research focused primarily on radiance computations for the visible to shortwave infrared spectral region. The model predicts expected irradiance levels for tactical operations in a variety of scenarios spanning urban to rural conditions and for various night sky conditions, e.g., , full moon, cloudy sky conditions, etc.. The model employs a group of submodels to calculate contributions to the total radiance level from a variety of sources. These source functions include contributions from both extraterrestrial sources (e.g., moon light, starlight, zodiacal light, etc.) and terrestrial sources (e.g., night glow, light pollution, atmosphere, etc.). A discussion of the signature modeling approach, the underlying physical basis for each source, and results from the radiance computations will be presented.

6543-09, Session 3

An engineer's approach to system performance

G. C. Holst, JCD Publishing

No abstract available

6543-10, Session 3

Range performance benefit of contrast enhancement

R. H. Vollmerhausen, EO Consultant; V. A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate

This paper discusses the range-performance benefit of image processing techniques like linear deconvolution and local area contrast enhancement. These techniques correct for diffraction blur and other factors that degrade the high-frequency content of imagery. In some cases, the target acquisition range of state-of-the-art thermal imagers is increased by 70 per cent. However, the effectiveness of image processing depends on the signal to noise and sampling properties of the imager. This paper discusses the theory and limitations of image restoration and contrast enhancement techniques.

6543-11, Session 3

NVThermIP versus TOD: matching the target acquisition range criteria

P. Bijl, M. A. Hogervorst, J. Beintema, A. Toet, TNO Human Factors (Netherlands)

Traditionally, assessment and prediction of Target Acquisition (TA) performance with EO or IR systems is limited to static imaging. However, recent developments in sensor technology (e.g. micro-scan) and image enhancement techniques (e.g. Super Resolution and Scene-Based Non-Uniformity Correction) are based on motion. Hence, there is an increasing need for methods to quantify the operational effectiveness of dynamic imaging. Until now, empirical dynamic TA field data is lacking and all estimates of image enhancement effectiveness are either based on TA model calculations or on measurements using abstract test targets (e.g. the TOD triangle test pattern). In this study, we recorded static and dynamic IR imagery of small hand-held military and civilian objects at a range of distances, and applied several types of signal processing techniques to the imagery. In an observer experiment, we determined identification performance as a function of target range for static, dynamic and enhanced imagery. The results are in close agreement with the TOD data collected in earlier studies. In conclusion, the data support the TOD as an end-to-end measure that quantifies dynamic image quality. In addition, the data set may be used to validate or improve dynamic imaging performance predictions of current TA models.

6543-12, Session 3

Avoiding and mitigating cell imbalance in tank identification perception tests

R. K. Moore, E. L. Jacobs, C. E. Halford, The Univ. of Memphis

Corrections are given for cell imbalance in the design and analysis of twelve-target tracked vehicle identification perception tests. Such tests are an important tool in the development of the NVESD model of human observer performance that is used in NVThermIP to compare electro-optical systems. It is shown that the partitions of the twelve-target set that have been previously used in perception experiments exhibit a statistically significant amount of cell imbalance according to observer results. Results from perception testing are used to determine the relative difficulty of identifying different images in the set. A program is presented to partition the twelve target set into lists that are balanced according to the collected observer data. This will allow perception test designers to decrease the possibility that cell imbalance will corrupt their test results. The relative difficulty of image subsets is shown to be related to the best-fit V50 values for the subsets. The results of past perception experiments are adjusted to account for cell imbalance using the subset V50 terms. The adjusted results are shown to better follow the TTP model for observer performance. When the proper conditions are met, the correlation to the model increases and the mean squared error decreases.

6543-13, Session 3

Superresolution reconstruction and local area processing performance

G. C. Holst, JCD Publishing; E. Cloud, H. C. Lee, T. L. P. Olson, D. Mansville, J. Puritz, DRS Technologies, Inc.

No abstract available

6543-14, Session 4

Direct-view optics model for facial recognition

R. G. Driggers, U.S. Army Night Vision & Electronic Sensors Directorate

Direct view optics is a class of sensors to include the human eye and the human eye coupled to rifle scopes, spotter scopes, binoculars, and telescopes. The target acquisition model for direct view optics is based on the contrast threshold function of the eye with a modification for the optics modulation transfer function (MTF) and the optics magnification. In this research, we extend this model for the application of facial identification. The model is described and is compared to field performance results for three different direct view optical configurations.

6543-15, Session 4

The effects of spatial band-limited noise on human performance for tank identification

S. M. Salem, R. K. Moore, The Univ. of Memphis; P. Bijl, M. A. Hogervorst, TNO Human Factors (Netherlands); C. E. Halford, The Univ. of Memphis

A twelve-alternative forced choice tank identification perception test shows the effects of spatially band-limited noise on observer performance. Previously, Bijl showed that the contrast threshold of a target image with bandlimited noise is a function of noise spatial frequency. He used the method of adjustment to find the contrast thresholds for each noise frequency band. A noise band exists in which the target contrast threshold reaches a peak relative to the threshold for higher or lower noise frequencies. Bijl also showed that the peak of this

noise band shifts as high frequency information is removed from the target images. To further establish these results, we will perform a forced-choice experiment. Our experiment consists of three parts. First, NVESD twelve-target infrared tracked vehicle image set identification. Second, an MRTD bar-pattern experiment. Third, a Triangle Orientation Discrimination experiment. Sixteen noise bands will be tested along with three blur levels and nine contrast levels. Finally, we will compare the TTPF human observer model predictions for performance in the presence of band-limited noise with these experimental results.

6543-16, Session 4

Temporal/spatial tracking requirements for tracking humans

A. L. Robinson, The Univ. of Memphis; B. S. Miller, S. K. Moyer, C. Ra, U.S. Army Night Vision & Electronic Sensors Directorate

This paper details the development, experimentation, collected data and the results of research designed to gain an understanding of the temporal and spatial image collection guidelines for tracking humans. More specifically, a quantitative understanding of the relationship between human observer performance and the spatial and temporal resolution is sought. Performance is measured as a function of the number of video frames per second, imager spatial resolution and the ability of the observer to accurately determine the destination of a moving human target. The research is restricted to data and imagery collected from altitudes typical of modern low to mid altitude persistent surveillance platforms using a wide field of view. The ability of the human observer to perform an unaided track of a human target was determined by their completion of carefully designed perception experiments. In these experiments, the observers were presented with simulated imagery from Night Visions EOSim urban terrain simulator. The details of the simulated targets and backgrounds, the design of the experiments and their associated results are included in this treatment. Applicable conclusions are drawn and ideas for further experimentation and research are provided.

6543-17, Session 4

An image sharpness metric for image processing applications using feedback

E. P. Lam, Thales Raytheon Systems

Some image processing techniques require input images to be adequate in image quality in order to be used. Image quality metrics are needed to determine whether an input image can be used. One form of image quality is sharpness. The image sharpness metric is based on a observation of image edges. The described approach is a reference metric, meaning that the quality measure is a relative score dependent on image frames. This metric is designed for evaluation of input images that are obtained from a relatively same observation angle.

We used the image edges because they are greatly affected by image corruption, such as motion blur and video deinterlacing artifacts. Edges are extracted to create edge maps. The edge pixels from the edge maps are summed, which is called the score. Lower scores correspond to the sharper images. The scores are directly related to the number of edge pixels. In relatively unsharp image, the number of edge pixels are increased, because of motion blur, and focus blur. We found that the metric corresponds well with subjective testing and is therefore suitable for quick qualitative characterization of sharpness.

It was discovered that the size of the filter is important for evaluating the quality of the deinterlaced frame. If deinterlaced frame consists of N fields at fields, then the filter size must be at least N+1. For example, if there are even and odd fields (N=2), then the filter size must be at least 3. The reasoning for filter size is that the filter needs to span enough video lines to properly evaluate interlace jitter. In the even and odd field video system, the filter must span the deinterlaced output's two even lines and one odd line, or vice versa.

This metric is used in a system loop where feedback (the described metric) is used to evaluate quality for real-time image processing applications. Because time critical restrictions are in placed, one must also consider the filter size and filter implementation as well. The larger the filter size, the higher the number of floating point multiplications. Therefore, the implementation can involve the use of simple additions and bit shifts for multiplications of numbers in powers of two to reduce floating point operations. Even with the implementation in integer mathematics, the filter size criteria still needs to be met. Since the quality metric is a relative metric, a human in the loop is needed to threshold frames that are unacceptable. The human in the loop chooses the initial threshold. From the initial point the metric is compared with the threshold, which automatically determines if an input image is acceptable or not for use in an image processing application. In this paper, we present a metric that evaluates image sharpness.

6543-18, Session 4

Sine wave contrast target for direct view optics field performance measurements

K. A. Krapels, Office of Naval Research; R. G. Driggers, U.S. Army Night Vision & Electronic Sensors Directorate

A new target and test methodology has been developed and used to determine the field performance of observers through direct view optics (such as binoculars, spotting scopes and rifle combat optics). The target is based on varying levels of contrast modulated sinsoidally. The test is an adaptation of the TOD method used by TNO FEL to test FLIRs. The contrast tragets can be oriented in four directions, enabled a four alternative fixed choice perception experiment. The results are related to the Contrast Threshold Function (CTF) used in NVESD's imaging sensor performance models.

6543-55, Session 4

Third-generation FLIR simulation at NVESD

B. S. Miller, U.S. Army Night Vision & Electronic Sensors Directorate

Third generation FLIR sensors, comprised of 2-D focal plane arrays with simultaneous LWIR/MWIR detection capability, are to be fielded in the near future and are expected to play an important role in future Army sensor applications. NVESD has an effort underway to produce a simulation package that will bring Third Generation FLIR sensor performance to training and wargaming applications. This simulation product provides a wide variety of targets and backgrounds, both rural and urban, for different seasons, times of day, and atmospheric conditions and is built on the existing NVESD LWIR simulation package named EOSim. A sensor effects package, which is part of the simulation, uses standard NVTherm sensor decks to accurately simulate the noise, diffraction, resolution, and other design features of individual sensors. The architecture of the simulation and the key Third Generation FLIR characteristics incorporated are discussed in detail.

6543-56, Poster Session

Guidance on Methods and Parameters for Army Target Acquisition Models

B. P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate

No abstract available

6543-19, Session 5

Electronic zoom and its application in sampled IR systems

S. D. Burks, U.S. Army Night Vision & Electronic Sensors Directorate

Thermal model predictions based on the Johnson Criteria state that if a particular imaging system has an electronic zoom (E-zoom), then range performance for that system will always increase. While there are tactical scenarios where E-zoom will help, our study shows that E-zoom does not always aid in range performance in the classical target acquisition paradigm. A discussion is given as to why this is likely to be true, along with E-zoom case studies and potential uses for it in a tactical theatre.

6543-20, Session 5

Finding a fusion metric that best reflects human observer preference

R. K. Moore, C. L. Howell, E. L. Jacobs, C. E. Halford, The Univ. of Memphis

A perception test determined which of several image fusion metrics best predicts relative observer preference. Many fusion techniques and fusion metrics have been proposed, but there is a need to relate them to a human observer's measure of image quality. LWIR and MWIR images were fused using techniques based on the DWT, the shift-invariant DWT, Gabor filters, pixel averaging, and principal component analysis. Two different sets of fused images were generated from urban scenes. The quality of the fused images was then measured using the mutual information metric, fusion quality index, edge-dependent fusion quality index, weighted-fusion quality index, and the mean-squared errors between the fused and source images. A paired-comparison perception test determined how observers rated the relative quality of the fused images. The observers based their decisions on the noticeable presence or absence of information, blur, and distortion in the images. The observer preferences were then correlated with the fusion metric outputs to see which metric best represents observer preference. The results of the paired comparison test show that the mutual information metric most consistently correlates well with the measured observer preferences.

6543-21, Session 5

The impact of atmospheric path radiance on MWIR and LWIR sensor performance

V. A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate; C. E. Halford, The Univ. of Memphis; T. Maurer, U.S. Army Night Vision & Electronic Sensors Directorate

Atmospheric path radiance between scene and sensor occurs in both the MWIR and LWIR as a consequence of thermal radiation by the gases and other constituents in the atmosphere and scattering of other thermal sources. In thermal IR imagery, it can reduce the apparent contrast of targets at long range. For ground based imaging sensors, this effect occurs primarily in the wide field of view (WFOV) where the sensor gain and level are determined by the contrast of closer targets and backgrounds. In WFOV imagery, as the ground approaches the horizon, high path radiance adds into the average flux of the signal and masks distant targets in the detection process. However, in the narrow FOV, an apparent target-to-background contrast reduction is less likely to occur in the identification (ID) process since in the NFOV the target and background will be at about the same range and thus have the same path radiance. The gain and level of the sensor can be adjusted such that path radiance in both target and background is subtracted from the image. This paper examines the potential impact of path radiance on notional dual band thermal imaging systems (3rd Gen FLIR), both phenomenological and sensor performance, using MODTRAN and NVThermIP.

6543-22, Session 5

A new optical flow estimation method in joint EO/IR visual surveillance

H. Man, J. Wang, R. Martini, Stevens Institute of Technology; R. J. Holt, Queensborough Community College/CUNY; R. Netravali, I. Mukherjee, Stevens Institute of Technology

Electro-Optical (EO) and Infra-Red (IR) sensors have been jointly deployed in many surveillance systems. In this work we study the special characteristics of optical flow in IR imagery, and introduce an optical flow estimation method using co-registered EO and IR image frames. The basic optical flow calculation is based on the combined local and global (CLG) method (Bruhn, Weickert and Schnorr, 2002), which seeks solutions that simultaneously satisfy a local averaged brightness consistency constraint and a global flow smooth constraint. While CLG method can be directly applied to IR image frames, the estimated optical flow fields usually manifest high level of random motions caused by thermal noise. Furthermore, IR sensors operating at different wavelengths, e.g. meddle-wave infrared (MWIR) and long-wave infrared (LWIR), may yield inconsistent motions in optical flow estimation. Because of the availability of both EO and IR sensors in many practical scenarios, we propose to estimate optical flow jointly using both EO and IR image frames. This method is able to take advantage of the complementary information offered by these two imaging modalities. The joint optical flow calculation fuses the motion fields from EO and IR images using a non-linear spatial correlation model which aligns the estimated motions based on neighbor activities. Experiments performed on the OTCBVS dataset and the Stevens dataset demonstrated that the proposed approach can effectively eliminate many unimportant motions, such as moving shadows and object reflections etc, and significantly reduce erroneous motions, such as sensor noise. The full description of the proposed method and the complete experimental results will be presented in the final paper.

6543-23, Session 5

Effects of scene-based nonuniformity correction algorithms on observer performance

S. M. Salem, C. E. Halford, The Univ. of Memphis

In this paper we will present the effects of image degradations caused by scene-based nonuniformity correction techniques on observer performance. Focal plane arrays suffer from fixed pattern noise. Algorithms attempting to correct this noise are either reference based or scene based. Reference based methods produce radiometrically correct outputs, but require halting the camera's operation. Scene-based techniques, by contrast, can be incorporated into the data capturing process, either with a software or a hardware implementation. Scene based algorithms are therefore gaining popularity over reference based ones. Scene based algorithms suffer from an inherent loss of information caused by the assumptions the algorithm is built on. For example, predicting a pixel value by averaging neighboring pixels is equivalent to low-pass filtering. Image degradation become more prominent if the assumptions are not met. For example, an algorithm that requires camera motion will not perform well if the camera is still for extended periods of time. In this paper we will establish the effects of three different scenarios on observer performance. First, the algorithm assumptions degrade image information that may be important. Second, the algorithm assumptions are not strictly met. Third, the algorithm assumptions are completely violated. For every scenario observer performance will be recorded hereby establishing a relationship between observer performance and algorithm behavior.

6543-24, Session 6

Correlation between human observer performance and the number of spatial, thermal, and total cues in LWIR imagery

M. A. Brickell, The Univ. of Memphis; T. C. Edwards, U.S. Army Redstone Technical Test Ctr.; C. E. Halford, The Univ. of Memphis; K. M. Dennen, ERC, Inc.

A human perception test has been conducted to determine the correlation between observer response and the number of thermal, spatial, and total cues in an image. Our experiment used the NVESD 12 target long-wave infrared tracked vehicle image set. Various levels of Gaussian blur were applied to twelve aspects of the twelve targets in order to reduce both the number of resolvable cycles and the number of visible thermal and spatial cues. We then counted every observable thermal and spatial cue in each of the processed images. A thermal cue was defined as either a hot spot or a cool spot. Typically, hot spots are produced by a vehicle's engine or exhaust. Cool spots are features such as air intakes and trim vanes. Spatial cues included characteristics such as barrel length, turret size, turret shape, number of wheels, and cupola location. The results of a 12 alternative forced choice identification perception test were analyzed to determine the correlation between probability of identification and the number of thermal, spatial, and total cues. The results show that spatial cues are favored over thermal cues.

6543-25, Session 6

Silhouette and background information analysis

M. N. Moore, J. D. O'Connor, U.S. Army Night Vision & Electronic Sensors Directorate

Perception testing was performed to determine the amount of information that could be obtained from a target's silhouette. Experiments were performed using original imagery, silhouette imagery, background imagery, and target imagery. The original imagery consisted of both the original background and target signatures. The silhouette imagery was comprised of a uniform background with a temperature approximately equal to the average background temperature and a uniform target with a temperature equal to the root sum of squares delta T. The background imagery included the original background signature with a uniform target having a temperature equal to the root sum of squares delta T. The target imagery consisted of the original target signature with a uniform background having a temperature equal to the average background temperature. An 8 target set was used with varying levels of Gaussian blur and down sampling rates applied to each target. All targets were viewed at 3 different aspects and in the infrared (IR) spectra. Observer results show higher target identification scores for silhouette imagery, at higher blur levels, than original imagery. However, target identification (ID) scores were significantly lower for background imagery than original imagery. Target identification results for target imagery exhibited better scores than the original imagery.

6543-26, Session 6

Quantitative analysis of infrared contrast enhancement algorithms

S. Weith-Glushko, C. Salvaggio, Rochester Institute of Technology

Dynamic range reduction and contrast enhancement are two image processing methods that are required when developing thermal camera systems. The two methods must be performed in such a way that the high dynamic range imagery output from today's sensors are compressed in a pleasing way for display on lower dynamic range monitors. This research examines a quantitative analysis of infrared contrast enhancement algorithms found in literature and developed by the author. Four algorithms were studied, three of which were found in literature and one developed by the author: tail-less plateau equalization (TPE), adaptive plateau equalization (APE), the method according to Aare Mallo (MEAM), and infrared multi-scale retinex (IMSR). TPE and APE are histogram based methods, requiring the calculation of the distribution of digital counts within an image. MEAM and IMSR are frequency based methods, methods which operate on input imagery that has been split into imagery containing differing spatial frequency content. After a rate of growth analysis and psychophysical trial was performed, histogram based methods for infrared contrast enhancement was found to be the best in deference to frequency based methods. Since then, further research has been performed to develop frequency based contrast enhancement algorithms.

6543-27, Session 6

Active imaging system performance model for target acquisition

R. L. Espinola, U.S. Army Night Vision & Electronic Sensors Directorate; E. L. Jacobs, C. E. Halford, The Univ. of Memphis; D. H. Tofsted, Army Research Lab.

The U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate has developed a laser-range-gated imaging system performance model for the detection, recognition, and identification of vehicle targets. The model is based on the established US Army RDECOM CERDEC NVESD sensor performance models of the human system response through an imaging system. The Java-based model, called NVLRG, accounts for the effect of active illumination, atmospheric attenuation, and turbulence effects relevant to LRG imagers, such as speckle and scintillation, and for the critical sensor and display components. This model can be used to assess the performance of recently proposed active SWIR systems through various trade studies. This paper will describe the NVLRG model in detail, discuss the validation of recent model components, present initial trade study results, and outline plans to validate and calibrate the end-to-end model with field data through human perception testing.

6543-28, Session 7

Modeling the blur associated with vibration and motion

R. H. Vollmerhausen, EO Consultant; V. A. Hodgkin, J. P. Reynolds, S. D. Burks, U.S. Army Night Vision & Electronic Sensors Directorate

Scene to sensor motion causes blur in the image. Motion is caused by line-of-sight (LOS) vibration and by translation of the scene relative to the imager. Current models provide a Gaussian pre-filter to model performance degradation due to vibration. However, neither realistic vibrations nor constant translation of the imager LOS is modeled. This paper describes the Modulation Transfer Functions (MTF) associated with LOS vibration. The blurs associated with target-to-imager motion are also discussed. The ability of the eye to track a moving object is discussed, and a unified model of the effect of vibration and motion on target acquisition is provided.

6543-29, Session 7

An evaluation of fusion algorithms using image metrics and human identification performance

C. L. Howell, C. E. Halford, The Univ. of Memphis; S. D. Burks, U.S. Army Night Vision & Electronic Sensors Directorate; R. K. Moore, The Univ. of Memphis

The performance of image fusion algorithms are evaluated using image quality metrics and human identification performance. Image Intensified and LWIR images are used as the inputs to the fusion algorithms. The test subjects are tasked to discriminate between a variety of handheld objects in both the original and fused images. The metrics used for evaluation are mutual information, fusion quality index, weighted fusion quality index, and edge dependent fusion quality index. The fusion algorithms under consideration include Peter Burt's Laplacian, Toet's Ratio of Low Pass also known as contrast ratio, superposition, Waxman's opponent processing, and multi-scale fusion. The fusion algorithms are ranked according to human identification performance. These results are then compared to the ranking of the fusion techniques according to the fusion metrics. The results of the perception test will indicate which fusion technique yielded the greatest observer performance. It will then be determined which measure of fusion quality best correlates with observer performance.

6543-30, Session 7

EO/IR sensor model for evaluating SWIR, MWIR, and LWIR system performance

A. K. Sood, Magnolia Optical Technologies, Inc.; R. A. Richwine, K. S. Freyvogel, The Pennsylvania State Univ.; R. S. Balcerak, Defense Advanced Research Projects Agency

In this paper, we will discuss the capabilities of a EO/IR Sensor Model developed to provide a robust means for comparative assessments of infrared FPA's and sensors operating in the infrared spectral bands that coincide with the atmospheric windows - SW1 (1.0-1.8?), SW2 (2-2.5?), MW (3-5?), and LW (8-12?). The applications of interest include thermal imaging, threat warning, missile interception, UGV and UAV surveillance, and mine detection.

As a true imaging model it also functions as an assessment tool for single-band imagery and for multi-color imagery. The detector model characterizes, InGaAs, InSb, HgCdTe, QWIP, Germanium and Microbolometer Sensors. The model places the specified FPA into an optical system, evaluates system performance (NEI, NETD, MRTD, and SNR) and creates two-point corrected imagery complete with 3D noise image effects. This model has been exercised here as a predictive tool for the performance of state-of-the-art detector arrays in optical systems in the five spectral bands (atmospheric windows) from the SW

to the LW (1.0-1.8, 2.0-2.5, 3.4-4.2, 4.5-5.0 and 8-12µ). Results of the analysis will be presented for various targets for each of the focal plane technologies for a variety of missions.

6543-31, Session 7

Modeling the effects of high contrast and saturated images on target acquisition performance

B. P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate

Most sensors allow the user to adjust a parameter that will modify the displayed scene contrasts; this process is typically referred to as gain. This process is accounted for in the current US Army thermal target acquisition model (NVThermIP) by a parameter called scene contrast temperature. By changing the scene contrast temperature input, the system gain can be modified to reflect varying contrast levels. In this paper, the results for two experiments dealing with task difficulty for several gain levels are reviewed. Strategies for optimizing the scene contrast temperature based upon scene dynamics are presented. Using these strategies, the scene contrast temperature parameter can be scaled for search and identification tasks to provide a more accurate representation of field performance of thermal imagers. Conclusions regarding the validity of the TTP metric in this regime are then discussed.

6543-32, Session 7

Error metric for superresolution enhanced IR passive ranging

J. H. Cha, U.S. Army Night Vision & Electronic Sensors Directorate

Assessment of resolution enhancement effect on disparity estimation provides valuable insights on design and feasibility of advanced stereo vision systems. Application of such enhancement to stereo analysis for visible band cameras has shown promising results in the past. It further needs to be expanded to infrared band for a day/night operational capability, and in particular the performance of uncooled infrared sensors needs to be quantified. In this report, the resolution enhancement effect on disparity estimation is examined empirically using an uncooled low resolution infrared camera, and the results are analyzed with respect to the high resolution cameras. Currently available resolution enhancement algorithms including Maximum A Posteriori (MAP)-based and Markov Chain Monte Carlo (MCMC)-based algorithm are utilized, and the variance of disparity estimate is examined as a function of algorithm parameters, target-to-background temperature difference, 3D Noise, and baseline distance. A metric is applied to evaluate the disparity estimation results, and an empirical model for the performance gain is designed.

6543-33, Session 7

Field performance of sensors using superresolution

J. D. Fanning, U.S. Army Night Vision & Electronic Sensors Directorate

Superresolution processing is currently being used to improve the performance of infrared imagers through the removal of aliasing and the reduction of fixed-pattern noise. The performance improvement of superresolution has not been previously tested on military targets. This paper presents the results of human perception experiments to determine field performance on the NVESD standard eight military target set. These experiments test and compare human performance of both still images and movie clips, each generated with and without superresolution processing. The measured identification range performance is compared to modeled range performance of the system in each case.

6543-34, Session 8

Real-time image processing and fusion for a new high-speed dual-band infrared camera

M. Müller, Fraunhofer- Institut für Informations- und Datenverarbeitung (Germany); O. Schreer, M. López Sáenz, IRCAM GmbH (Germany)

A dual-band infrared camera system based on a dual-band quantum well infrared photodetector (QWIP) has been developed for acquiring images from both the mid-wavelength (MWIR) and long-wavelength (LWIR) infrared spectral band. The system delivers exactly pixel-registered simultaneously acquired images. It has the advantage that appropriate signal and image processing permit to exploit differences in the characteristics of those bands. Thus, the camera reveals more information than a single-band camera. It helps distinguishing between targets and decoys and has the ability to defeat many IR countermeasures such as smoke, camouflage and flares. Furthermore the system permits to identify materials (e.g. glass, asphalt, slate, etc.), to distinguish sun reflections from hot objects and to visualize hot exhaust gases.

Furthermore, dedicated software for processing and exploitation in real-time extends the application domain of the camera system. One component corrects the images and allows for overlays with complementary colors such that differences become apparent. Another software component aims at a robust estimation of transformation parameters of consecutive images in the image stream for image registration purposes. This feature stabilizes the images also under rugged conditions and it allows for the automatic stitching of the image stream to construct large mosaic images. Mosaic images facilitate the inspection of large objects and scenarios and create a better overview for human observers. In addition, image based MTI (moving target indication) also for the case of a moving camera is under development. This component aims at surveillance applications and could also be used for camouflage assessment of moving targets.

6543-35, Session 8

Broad-band optical test bench (OPTISHOP) to measure MTF and transmittance of visible and IR optical components

D. Cabib, A. Rahav, T. Barak, CI Systems (Israel) Ltd. (Israel)

CI Systems has developed a new cost effective and modular Optical Test Bench to measure MTF and transmittance of optical components in the Visible/Near Infrared (0.4-1.7 microns) and infrared (3 to 12 microns) spectral ranges.

The optical design concept of the system allows the user to switch from MTF (on- and off-axis) to lens transmittance measurements, without need of optical alignment by the user. In addition, broad band sources are used, so that these optical properties can be measured in the whole relevant wavelength range of the components to be tested.

Other lens measurements such as effective focal length, back focal length, distortion and field curvature can be made.

The system is based on the standard and proven CTS (Collimator Test System) product line of CI, which is made of reflective optics for wide wavelength coverage, and it is ruggedly built for use in the laboratory, production line or maintenance depot. An advantage of the CTS configuration is that the source-collimator assembly is enclosed in a robust mechanical envelope, which prevents accidental misalignements and breakage, optical misalignments due to environment temperature drifts, soiling of the optics, and easier system transportation.

The system will be described, including calibration and validation techniques.

6543-36, Session 8

Detector spatial response testing of LWIR FPAs

K. A. Lindahl, W. Burmester, K. Whiteaker, E. E. Penniman, P. B. Johnson, R. Banks, Ball Aerospace & Technologies Corp.

The spatial response of IR FPA is an important attribute of image quality. A novel test system for determining detector MTF has been developed for use on LWIR FPAs. Total system MTF is measured through movement of the spot across the FPA, with centroiding techniques applied to account for any FPA non-uniformity. Optics MTF is measured by moving the optical relay through focus with the manipulator and applying phase retrieval methods. The Optics MTF is then removed from the measured system MTR to produce the detector MTF. The technique has been applied to large area LWIR FPAs, and result are compared to theoretical predictions.

The system consists of a fast F/1 Optical Relay designed to image a pinhole illuminated by a blackbody onto a focal plane array (FPA). The F/1 Optical Relay is composed of a three reflective elements which include two Off Axis Parabolas (OAP's) and a fold mirror. The optical relay has been designed with diffraction limited performance and aligned using cryogenic double pass interferometer tests. Measured Zernike Coefficients verified relay performance enabling cryogenic operation at 77K in vacuum dewar over a the wavelength range of 3µm to 15µm. Movement of the imaged spot across the FPA is achieved by moving the optical relay with a three axis vacuum manipulator. The precision manipulator has 0.0001 inch least count and 0.00005 inch repeatability, enabling very accurate and repeatable placement of the imaged spot on the FPA surface.

6543-37, Session 8

Automated testing of ultraviolet, visible, and infrared sensors using shared optics

J. A. Mazzetta, S. D. Scopatz, Electro Optical Industries, Inc.

Complex systems ranging from unmanned vehicles to night vision goggles rely on a various spectral regions to achieve the demanding imaging performance they require. The lines between infrared, visible, and ultraviolet are quickly blurring as multi-sensor systems become more sophisticated and image fusion becomes commonplace.

Typically sensor testing requires hardware and software exclusively designed for the spectral region of interest. Thus a system with ultraviolet through infrared imaging capabilities could require up to three separate test benches for sensor characterization. This not only drives up the cost of testing but also leads to a discontinuity of methods and possibly skewed results.

This paper will discuss hardware and software developed by the authors that utilize identical test methods and shared optics to complete infrared, visible, and ultraviolet sensor performance analysis. Challenges encompassing multiple source switching, splitting, and combining will be addressed along with decisions related to specifying optics and targets of sufficient quality and construction to provide performance to cover the full spectral region. Test methodology controlled by a single software suite will be summarized including modulation transfer function, signal to noise ratio, uniformity, focus, distortion, intrascene dynamic range, and sensitivity. Examples of results obtained by these test systems will be presented.

6543-39, Session 9

An advance in infrared lens characterization: measurement of the lens modulation transfer function using common undersampled IR systems

C. A. Nichols, StingRay Optics, LLC; P. T. Bryant, Left Coast Consulting; C. C. Alexay, StingRay Optics, LLC

The modulation transfer function (MTF) measurement has been a staple of optics testing for many years. Obtaining a highly accurate measurement of the MTF of a lens, however, has always been a challenge for a number of reasons. Traditional MTF tests give a measure of overall system performance, not individual parts such as the lens. Also, the theoretical performance of the optics generally outstrips FPA/camera performance by a wide margin. This typically requires intricate hardware setups to quantify lens performance, such as specialized single-detector systems. These systems, however, are very difficult to use, have few other applications, and are quite expensive.

This paper will describe an improved technique for measuring optical quality of infrared systems, as well as preliminary research regarding individual component (i.e. - lens) MTF. In particular, the methodology presented will expand upon the traditional "tilted slit" technique and demonstrate an improved test capability for characterization of MTF and other optical UUT performance parameters. We will describe a methodology which uses Gaussian energy profiling and novel collection optics to deliver an MTF measurement capability with resolution and usability superior to that of single point measurement techniques. The paper will also discuss the optical system requirements and mathematical algorithms required to provide a fast, accurate, and high-resolution FFT/MTF capability, and support for a range of other optical UUT characterization modes.

6543-40, Session 9

Radiometric calibration of infrared target projector systems in uncontrolled environments

G. P. Matis, Santa Barbara Infrared, Inc.

The radiometric calibration of an infrared target projection system is vital for performing minimum resolvable temperature difference and other tests fundamental for assessing infrared imager performance. The calibration and use of an infrared target projector outside of a controlled laboratory setting can be challenging due to changing background or indirect radiative flux. We report on the radiometric calibration of multiple emissive and reflective target projection systems using the SBIR RAD9000 spectral radiometer. Radiometric accuracy of and the difficulties encountered in the calibration and use of an infrared target projection system in an uncontrolled environment will also be discussed

6543-41, Session 9

New radiometers for NIST: traceable calibrations of pW infrared signals

S. I. Woods, T. M. Jung, Jung Research and Development Corp.; A. C. Carter, R. U. Datla, National Institute of Standards and Technology

Abstract: The Low Background Infrared (LBIR) facility at the National Institute of Standards and Technology (NIST) is developing two infrared radiometers designed to provide infrared radiation calibrations at power levels down to 1 pW with accuracy on the order of 0.1%. Each instrument will have a noise floor of ~1 fW and they will be used together to disseminate new low power calibrations to the LBIR customer base. The first radiometer is a BIB (Blocked Impurity Band device) trap detector, made from two Si:As BIB devices mounted in a trapping configuration. A prototype BIB trap has been designed to have a flat spectral response in the frequency range 6-26 µm with external quantum efficiency \> 85%. The final version of this BIB trap will employ specially engineered BIB detectors that will enable the trap to achieve an external quantum efficiency \> 99% over the 4-28 µm spectral range. The second radiometer is an ACR (Absolute Cryogenic Radiometer) controlled using a SQUID-based (Superconducting Quantum Interference Device) high resolution thermometer, allowing broadband fW sensitivity and better than 99.93% absorption. Design details and some preliminary results for the two radiometers will be discussed, as well as techniques for verifying the accuracy of the BIB trap using the ACR.

6543-44, Session 9

Characterization of a C-QWIP LWIR camera

D. P. Forrai, M. D. Sempsrott, R. C. Fischer, L-3 Communications Cincinnati Electronics, Inc.; K. Choi, Army Research Lab.; J. W. Devitt, L-3 Communications Cincinnati Electronics, Inc.

Large format corrugated quantum well infrared photodetector (C-QWIP) focal plane arrays (FPAs) have been developed over the past two years. The results of this development have demonstrated the potential for this technology to satisfy requirements for very large format high performance long-wave infrared (LWIR) imaging systems. One particular C-QWIP design has focused on developing an FPA that operates in the 8 to 10 µm spectrum with integration times in the millisecond regime when used against warm backgrounds. This FPA is very suitable for many LWIR applications and has been integrated into a camera system. The specifications of that camera are described in this paper. The characterization of this camera system includes standard electro-optical tests and compares the results of those tests to theoretical models for the FPA. This paper concludes by describing the ongoing effort to tailor the system specifically for the C-QWIP. This includes design features of the read-out integrated circuit (ROIC), dewar-cooler design and interfacing electronics, and video processing. This thorough characterization of the camera has demonstrated the utility of the C-QWIP FPA for LWIR imaging and has established a path forward to further improve the performance of imaging systems implementing this technology.

6543-45, Session 9

A very near-infrared tactical testbed

R. Sanderson, J. F. McCalmont, Air Force Research Lab.; J. B. Montgomery, M&M Aviation; R. Johnson, MacAulay-Brown, Inc.; D. McDermott, Air Force Research Lab.

A new tactical airborne multicolor missile warning testbed was developed and fielded as part of an Air Force Research Laboratory (AFRL) initiative focusing on clutter and missile signature measurements for algorithm development. Multicolor discrimination is one of the most effective ways of improving the performance of infrared missile warning sensors, particularly for heavy clutter situations. Its utility has been demonstrated in multiple fielded sensors. Traditionally, multicolor discrimination has been performed in the mid-infrared, 3-5 ?m band, where the molecular emission of CO and CO2 characteristic of a combustion process is readily distinguished from the continuum of a black body radiator. Current infrared warning sensor development is focused on VNIR staring mosaic detector arrays that provide similar spectral discrimination in different bands to provide a cost effective and mechanically simpler system. This, in turn, has required that multicolor clutter data be collected for both analysis and algorithm development.

The developed sensor test bed is a multi-camera system 1004x1004 FPA coupled with optimized filters integrated with the optics. The collection portion includes a ruggedized field-programmable gate array processor coupled with with an integrated controller/tracker and fast disk array capable of real-time processing and collection of up to 60 full frames per second. This configuration allowed the collection and real-time processing of temporally correlated, radiometrically calibrated data in multiple spectral bands that was then compared to background and target imagery taken previously.

6543-46, Session 9

Design of a compact all-refractive double-pass MWIR + LWIR hyperspectral imager

T. A. Mitchell, Wavefront Research, Inc.; J. G. Zeibel, U.S. Army Night Vision & Electronic Sensors Directorate

Broad spectral band hyperspectral imagers typically make use of all-reflective optics in order to avoid the effects of chromatic aberrations. Unfortunately, the convex gratings typically required by these systems can be complex and costly to fabricate, particularly for use in the MWIR and LWIR bands. As an alternative, an all-refractive double-pass relay design form utilizing a plane reflectance grating is described which provides several advantages, including the inclusion of the spectrometer within the cryogenic environment of the Dewar. Topics discussed include the correction of chromatic aberrations with regards to axial color and spectral distortions, modeling of cryogenic operation with room-temperature fabrication and testing, focus and rotational alignment of the slit and grating components of the spectrometer, and stray light and thermal background radiation analyses.

6543-47, Session 9

Real-time processing of low-SNR at high-rate FPA data

M. K. Rafailov, Booz Allen Hamilton Inc.

Recursive Adaptive Frame Integration of Limited Data offers a way to satisfy both major requirements of advanced FPA video-processing - it may handle relatively low SNR along with high data rate and providing in the same time satisfactory high probability of target detection. The technique uses two adaptive thresholds -one is tuned for optimum probability of detection, the other - to manage required false alarm rate, and with integration process placed right between those two thresholds. This configuration allows a non-linear integration process that, along with Signal-to-Noise Ratio (SNR) gain and data reduction provides system designers more capability where cost, weight, or power considerations limit system data rate, processing, or memory. Adding the third threshold can transform a system with Recursive Adaptive Frame Integration into real time operational system. However, performance of Recursive Adaptive Frame Integration of Limited Data may fall short when single-frame SNR is really low. In this paper the Recursive Adaptive Frame Integration of Limited Data is presented in form of multiple parallel recursive integration that is when combined with other elements of FPA video processing - correlation filtering, adaptive offset correction and gain term control. Such an approach can help to manage required probability of detection with reduced data rate when single frame SNR is quite low and to manage real time operation as well.

6543-48, Session 9

Laser dazzling of focal plane array cameras

R. H. M. A. Schleijpen, J. C. van den Heuvel, TNO (Netherlands)

Laser countermeasures against Infrared focal plane array cameras aim to saturate the full image. This paper will discuss optical mechanisms causing area saturation of focal plane arrays by lasers, such as diffraction, multiple reflections and optical scatter. Also electronic mechanisms contribution to area saturation will be addressed.

Experimental results of MWIR laser saturation as a function of laser power are compared with theoretical models. An empirical method for estimating the size of the saturated area in the camera image will be presented.

Base on this empirical method a technique has been developed to generate synthetically partially saturated images for varying laser irradiance levels on the camera. The effects for the observer will be discussed.

6543-52, Poster Session

FMRI for functional localization and task difficulty assessment during visual search

T. J. Meitzler, U.S. Army Tank-automotive and Armaments Command; J. Hirsch, Columbia Univ. Medical School; M. E. Bienkowski, E. Sohn, U.S. Army Tank-automotive and Armaments Command

Past and present U.S. Army computational vision models used to determine the difficulty of the visual detection of camouflaged military vehicles are limited in the sense that they do not encompass any part of the brain outside the retina and visual cortex. Preliminary experiments are done in TARDEC's Visual Perception Laboratory (VPL) and Columbia University's functional MRI Research Center. Functional Magnetic Resonance Imaging (fMRI) employs magnetic fields to measure the blood oxygen level dependent (BOLD) effect in the human brain. It is intended to use fMRI activities as a surrogate marker for the probability of detection (Pd) for ground vehicles. The authors compare the VPL photosimulation values to fMRI data through statistical parametric mapping (SPM). The objective is to obtain the raw data to construct more representative models of human vision and decision. Preliminary results in the fMRI facility indicate a decreasing linear relationship between vehicle probability of detection and distance and an increase in search time versus distance, which similar to what is obtained in the VPL.

6543-53, Poster Session

Multimodal human verification using stereo-based 3D face inforamtion, IR, and speech

C. Park, Chung-Ang Univ. (South Korea)

Human biometric characteristics are unique, so it can hardly be duplicated [1], [2]. Such information includes; facial, speech, hands, body, and gesture to name a few. Face detection and recognition techniques are proven to be more popular than other biometric features based on efficiency and convenience [3], [4]. It can also use a low-cost personal computer (PC) camera instead of expensive equipments, and require minimal user interface. Face authentication has become a potential a research field related to face recognition. Face recognition differs from face authentication because the former has to determine the identity of an object, while the latter needs to verify the claimed identity of a user. Speech [5] is one of the basic communications, which is better than other methods in the sense of efficiency and convenience. Each a single biometric information, however, has its own limitation. For this reason, we propose a multimodal biometric verification method to reduce false acceptance rate (FAR) and false rejection rate (FRR) in real-time.

In this paper, we propose a personal verification method using both face and speech to improve the rate of single biometric verification. False acceptance rate (FAR) and false rejection rate (FRR) have been a fundamental bottleneck of real-time personal verification. The proposed multimodal biometric method is to improve both verification rate and reliability in real-time by overcoming technical limitations of single biometric verification methods. The proposed method uses principal component analysis (PCA) for face recognition and hidden markov model (HMM) for speech recognition based on stereo vision and infrared system. It also uses fuzzy logic for the final decision of personal verification. Fig. 1 shows the result of registered personal verification. Based on experimental results, the proposed system can reduce FAR down to 0.0001%, which provides that the proposed method overcomes the limitation of single biometric system and provides stable personal verification in real-time.

6543-54, Poster Session

Navy and Marine Corps utility of the 2 - 2.3 micron waveband

J. C. Wilson, U.S. Navy Reserve

We investigate the use of the 2 - 2.3 micron waveband for Navy & Marine Corps Fleet/Force Protection. This waveband, despite having good atmospheric transmission, is not commonly used by the military compared to the SWIR and MWIR bands. Following review of atmospheric transmission, natural and artificial illumination, material emissivities and available detectors for this waveband, we present performance comparisons with SWIR and MWIR for imaging scenarios.

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6544-01, Session 1

Spectral radiant emission of dynamic resistive arrays

A. G. Hayes, A. Puryear, J. M. Swenson, MIT Lincoln Lab.

A persistent question in the infrared projection community has been the spectral characteristics of resistive array emission. This paper describes the results of a comprehensive study performed on two resistive array technologies; the Nuclear Optical Dynamic Display System (NODDS) and the Santa Barbara Infrared (SBIR) Mirage and LFRA product lines. A Fourier Transform Interferometer (FTIR)-based radiometer was used to measure the spectral radiant emission of both resistive array technologies at multiple drive levels and substrate temperatures. An infrared microscope was used in conjunction with a reflectance FTIR spectrometer to study the NODDS array unit cell in detail. Application of the results to two-color scene projection and cross spectral non-uniformity correction is discussed.

6544-02, Session 1

Resistor array infrared projector non-uniformity correction: search for performance improvement II

L. Swierkowski, R. A. Joyce, O. M. Williams, Defence Science and Technology Organisation (Australia)

Nonuniformity correction (NUC) has arguably been the most challenging activity that has occupied the minds of resistor array infrared projector researchers over much of the past decade. Progress has been relatively slow due to the conglomeration of effects that tend to contaminate the nonuniformity measurement procedure. Together, temporal noise, camera nonuniformities, camera drift, the large dynamic range, optical distortion, mapping and registration errors, Moiré fringes and sub-pixel effects all conspire to make projector NUC difficult.

Fortunately, there appears to be light at the end of the tunnel, with the camera-associated problems now largely tamed. Indeed, the remaining problems in the above list - all associated with the sampling of the projected scene - now determine the challenge. In this paper we describe our efforts to lower the defences of this next-lower level of NUC-complicating effects. In particular, we emphasize the importance of application of a precise mapping and registration algorithm together with projection techniques that serve to separate the residual nonuniformity, Moiré fringe and sub-pixel effects. Results from our latest NUC procedures are presented, all leading towards our goal of achieving high fidelity NUCs suitable for satisfying the demanding requirements of both low dynamic range thermal imager simulation applications and high dynamic range missile simulation applications.

6544-03, Session 1

LFRA: developments in large-format resistive arrays and advanced IRSP system technologies

J. B. James, J. LaVeigne, G. P. Matis, J. Oleson, Santa Barbara Infrared, Inc.; J. M. Lannon, Research Triangle Institute; S. Solomon, Acumen Scientific; P. T. Bryant, Left Coast Consulting

SBIR's Large Format Resistive Array (LFRA) IRSP system is now in production, with six (6) systems delivered to date. Each LFRA system has demonstrated greater than 700 K MWIR apparent temperature, with a 10-90% radiance rise time of less than 9 ms. To minimize thermal time constant, future emitter pixel designs will allow LFRA to offer the same maximum apparent temperature while providing a rise time of less than 5 ms. All LFRA systems delivered to date have exhibited pixel operability of at least 99.8%, thereby meeting customer requirements with significant margin.

In addition to describing deliverable system performance, this paper will discuss recent system-level developments such as static windowing with increased frame update rate, real-time convolution for simulation of atmospheric and optical effects, and translation/rotation processing (TRP) for compensation of latency between the scene generation host and the IRSP. Subcomponent-level improvements will also be discussed, particularly those related to emitter design/layout and processing.

6544-04, Session 1

OASIS: cryogenically optimized resistive arrays and IRSP subsystems for space-background IR simulation

J. B. James, J. LaVeigne, G. P. Matis, Santa Barbara Infrared, Inc.; J. M. Lannon, A. Huffman, Research Triangle Institute; R. Stockbridge, B. Goldsmith, Air Force Research Lab.; S. Solomon, Acumen Scientific; P. T. Bryant, Left Coast Consulting

SBIR has completed the development of the first lot of OASIS emitter arrays and custom packaging for cryogenic IR scene projection applications. OASIS performance requirements include a maximum MWIR apparent temperature of greater than 600 K, with 10-90% radiance rise time of less than 6.5 ms. Four (4) arrays have been packaged, integrated, tested and delivered.

This paper will report on the first measurements taken of the OASIS resistive emitter arrays at both ambient and cryogenic temperatures. This paper will also provide a discussion of the OASIS cryogenic projector/electronics module (Cryo-PEM) design. We will also describe the novel thermal design employed within the array package and Cryo-PEM assemblies, which allows OASIS to produce radiometrically accurate imagery with reduced thermal lag/gradient artifacts compared to legacy Honeywell cryogenic IRSP assemblies. As OASIS supports both analog and digital input, we will discuss the differences between the two modes in terms of system integration, support electronics and overall array performance.

6544-05, Session 1

NIST traceable infrared test chamber calibrations using the BXR and MDXR

A. C. Carter, R. U. Datla, T. M. Jung, National Institute of Standards and Technology; A. W. Smith, J. A. Fedchak, S. I. Woods, Jung Research and Development Corp.

The Low Background Infrared (LBIR) facility at the National Institute of Standards and Technology (NIST) is responsible for the development of infrared transfer radiometers for the purpose of providing irradiance calibrations to medium and low-background test chambers that are used to calibrate remote sensors. The first generation transfer radiometer, the BXR, is a filter based radiometer that uses an As doped Si BIB detector, and can currently measure in-band irradiances as low as to 10 fW/cm2 with a 1% Type A standard deviation. The current set of filters allow for measurements from 2 micrometer to 15 micrometer in wavelength with bandpasses that range from 2% to 6 %. The BXR has evaluated over 5 chambers and the performance of these chambers will be discussed to a limited extent to demonstrate the range of performance achieved by a variety of infrared calibration chambers in existence. The second generation transfer radiometer, the MDXR, is in the final stages of development. The MDXR will have all the functionality of the BXR, but will also have a resident Absolute Cryogenic Radiometer (ACR) for self calibration, a cryogenic Fourier Transform Spectrometer (FTS) for high resolution spectral capability, and a resident blackbody for reference purposes. The MDXR performance specifications will be discussed and test results will be presented to the extent that they are available.

Conf. 6544: Technologies for Synthetic Environments: Hardware-in-the-Loop Testing XII

6544-06, Session 1

LWIR autoNUC performance issues for resistor arrays

J. R. Lippert, Dynetics, Inc.

Substantial Non-Uniformity Correction (NUC) efforts have been conducted on Suspended-Bridge Resistor Arrays in the MWIR regime, such that attaining 1% non-uniformity, or better, is readily achievable. However, using array performance data collected in the MWIR to generate the NUC coefficients and then projecting images seen with an LWIR camera/sensor has not resulted in the expected comparable level of NUC desired. A new AutoNUC system for LWIR characterization of resistor arrays will be described with unique obstacles and performance issues specific to that waveband regime addressed. The rationale and benefits from a scenario dependent NUCing technique will be discussed.

This work was sponsored by the Johns Hopkins University - Applied Physics Lab. We also want to acknowledge and thank the Army MRDEC for providing a "workhorse" Honeywell 512x512 resistor array for use during this effort.

6544-07, Session 2

Air Force Electronic Warfare Evaluation Simulator (AFEWES) infrared test and evaluation capabilities

H. D. Jackson II, T. L. Blair, B. A. Ensor, U.S. Air Force

The Air Force Electronic Warfare Evaluation Simulator (AFEWES) Infrared Countermeasures (IRCM) test facility currently has the ability to simulate a complete IRCM test environment, including IR missiles in flight, aircraft in flight, and various IR

countermeasures including maneuvers, point-source flares and lamp- and LASER-based jammer systems. The simulations of IR missiles in flight include missile seeker hardware mounted on a six degree-of-freedom flight simulation table. This paper will focus on recent developments and upgrades to the AFEWES IR capability. In particular, current developments in IR scene generation/projection and efforts to optically combining the IR image produced by a resistive array with existing foreground lamp sources.

6544-08, Session 2

Application of scene projection technologies for sensor calibration, characterization, and HWIL testing in the AEDC cryo vacuum space simulation chambers

H. S. Lowry, D. H. Crider, R. A. Nicholson, M. Breeden, U.S. Air Force

The space simulation chambers at The Arnold Engineering Development Center (AEDC) have been engaged in space sensor characterization, calibration, and mission simulation testing on space-based, interceptor, and air-borne sensors for more than three decades. Recently, this capability has been extended to include HWIL testing using the integration of high-fidelity complex scene projection technologies into the low cryo-vacuum (~20 K) environment. The 7V Chamber provided calibration and high-fidelity mission simulation for infrared seekers and sensors, while the 10V Chamber is a similar chamber that has been upgraded to perform real-time mission simulation. The latest scene simulation and projection technologies must be pursued to ensure that the desired target temperatures and ranges can be accomplished such that sensor mission performance can be evaluated. These technologies include multiple-band source subsystems and special spectral tailoring methods, as well as comprehensive analysis and optical properties measurements of the components involved. The implementation of such techniques in the AEDC 7V and 10V space sensor test facilities will be discussed in this paper, as well as recent test results.

6544-09, Session 2

Implementation of a hardware-in-the-loop evaluation facility for student test and evaluation

S. B. Mobley, G. Ballard, U.S. Army Aviation and Missile Command; R. N. Brindley, J. P. Gareri, Simulation Technologies, Inc.

Hardware-in-the-Loop (HWIL) test facilities offer the highest degree of system functional verification and performance evaluation outside of the target system's actual operational environment. The design and analysis of HWIL simulators involves the coordinated efforts of numerous engineering fields, whose professionals possess the technical expertise, analytical skills, and insight regarding cross-discipline collaborative relationships which foster successful simulation development. As system complexity continues to increase, and as programmatic requirements allow for shorter simulation development schedules, the existing knowledge base associated with legacy simulation development will play a key role in the preparation, readiness, and efficiency of future HWIL engineering professionals. As a result, it is crucial that basic HWIL methods and concepts be documented in a formal, academic sense, and that realistic test facilities are made available to allow potential HWIL engineering students the ability to become acclimated to basic HWIL components and design considerations.

To address this need, the United States Army Space and Missile Defense Command (SMDC), in coordination with the Auburn University Department of Aerospace Engineering, has funded an initiative to perform initial development of a graduate-level HWIL simulation course structure, including the provision of a functioning HWIL simulation facility located at the university. This facility, modeled after a conceptual tactical missile system, will possess the major elements of a HWIL simulation including a Six-Degree-of-Freedom simulation of the missile body dynamics, an EO sensor implementation, a flight motion simulator (FMS), a scene generation system, and an in-band image projection system. Architectural implementations and distributed simulation elements will be modeled after existing U.S. Army missile simulation concepts. In concert with this activity, an HWIL academic concept associated with student participation across all engineering disciplines will developed through the Auburn University engineering department, with HWIL facility development and subject matter expert (SME) interaction provided by the U.S. Army Missile Research, Development, and Engineering Center. This paper describes the incremental approach in the development of the HWIL facility, and the associated academic objectives associated with student-centered simulation development and analysis.

6544-21, Session 2

Hybrid Infrared Scene Projector (HIRSP): a high dynamic range infrared scene projector

T. M. Cantey, D. B. Beasley, B. M. Robinson, C. B. Naumann, Optical Sciences Corp.; H. J. Kim, J. A. Buford, Jr., U.S. Army Aviation and Missile Research, Development and Engineering Ctr.

No abstract available

6544-10, Session 3

Improving the fidelity of hydraulic flight motion simulators

M. L. Avory, R. L. Schneider, Ideal Aerosmith, Inc.

Because they are capable of subjecting massive payloads to the high accelerations that typical HWIL simulation scenarios require, it is commonly accepted in the industry that hydraulically-driven flight motion simulators (FMS) offer outstanding dynamic performance. However, the small-signal performance of a hydraulic FMS does not traditionally match that of its electro-mechanical counterparts. This paper presents design improvements in the direct-drive hydraulic servo, which result in improved accuracy and extended bandwidth, hence closing the performance gap with electro-mechanical servos. The

paper shows a new design concept as it applies to a 3-axis motion simulator test bed. It also demonstrates system performance improvements through mathematical simulation and actual hardware tests.

6544-11, Session 3

Graphics Processing Unit (GPU) real-time infrared scene generation

C. L. Christie, E. Gouthas, O. M. Williams, Defence Science and Technology Organisation (Australia)

The widespread availability of low cost programmable Graphics Processing Units (GPUs) has revolutionised real-time infrared scene generation. No longer is it necessary to have access to a high-end specialist graphics computer. Instead, all that is needed is a standard PC equipped with a GPU-based graphics card, the latter being programmed through a standard Application Interface (OpenGL or DirectX) used in conjunction with a GPU shader language such as Cg.

GPU infrared scene generation is now under routine use within the DSTO real-time infrared scene projection facility and is being continually developed as the need for greater scene complexity increases. In this paper we describe our VIRScene infrared scene generation tool together with its VIRPaint and VIRParticle counterparts, the latter having been developed respectively for easy application of vertex radiances to wireframe models and for generating particle-based objects such as plumes and flares. We highlight the underlying features of the GPU that have been exploited to ensure high vertex and fragment throughputs and summarise the techniques that have allowed quite complex scenes to be generated in real-time. Infrared radiometry is also addressed and we show that apparent temperatures above background ranging from a few tens of mK to the sun's temperature can be accommodated without renormalisation, in spite of the limitation arising from the GPU internal use of 16 bit floating point numbers. The overall scene generation capability is assessed in terms of both radiometric fidelity and the trade-off between scene complexity and frame rate.

6544-12, Session 3

Flight motion simulators for the advanced multispectral sensor test acceptance resource (AMSTAR)

M. H. Swamp, Acutronic USA, Inc.; K. G. LeSueur, U.S. Army Redstone Technical Test Ctr.

Design requirements for two flight motion simulation facilities are discussed. One facility is used for subsystem seeker-level tests. The other facility is intended for testing the all-up round. Flight simulator design challenges include the requirement for testing at elevated (+120 degress C)and depressed (-65 degrees C)temperatures, as well as special translation and rotation features for loading/unloading the unit under test (UUT), and providing multiple operating positions of the simulator. High-fidelity dynamic response is required, to allow simulation transparency. Simulator test results are presented.

6544-13, Session 3

COTS PC-based real-time scene generation for IR and SAL sensors

J. A. Buford, Jr., U.S. Army Aviation and Missile Research, Development and Engineering Ctr.

AMRDEC has successfully tested hardware and software for Real-Time Scene Generation for IR and SAL Sensors on COTS PC based hardware and video cards. AMRDEC personnel worked with nVidia and Concurrent Computer Corporation to develop a Scene Generation system capable of frame rates of at least 120Hz while frame locked to an external source (such as a missile seeker) with no dropped frames. Latency measurements and image validation were performed using COTS and in-house developed hardware and software. Software for the Scene Generation system was developed using OpenSceneGraph.

6544-15, Session 4

Versatile plasma display technology for UV-visible scene projector

R. P. Ginn, Acumen Scientific; P. R. Mackin, Air Force Research Lab.; J. G. Eden, S. Park, Univ. of Illinois at Urbana-Champaign; C. Wedding, Imaging Systems Technology, Inc.

No abstract available

6544-16, Session 4

Really high-temperature emitter pixels

S. L. Solomon, Acumen Scientific

Acumen Scientific is working on a phase 2 SBIR program to develop material sets with the goal of increasing the operating temperatures of resistive emitter pixels by up to a factor of 3. A variety of pixel designs have been fabricated and test results are presented for emissive and dynamic pixel performance, material stability, reliability and device physics (the fun stuff). Blanket thin films have been deposited by different techniques and annealed in order to identify the most promising fabrication technology for resistive emitter pixels.

6544-17, Session 4

Is there life after thermal emitters?

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

The world of infrared (IR) emitting devices operating in the 3-5 and 8-12 mkm wavelength bands is divided into two camps: thermal emitters and photonic devices. For the last two decades these devices have been increasingly popular because of possible military and commercial applications. Whereas the market of thermal emitters has plateaued, photonic devices have evolved significantly due to recently developed efficient diode lasers, conventional LEDs, and devices based on transparency modulation technique.

In this report, we examine whether photonic IR emitters are able to compete with advanced thermal microemitter technology in testing and stimulating IR sensors, including forward-looking IR missile warning systems, IR search-and-track devices, and missile seekers. We consider fundamentals, technology, and parameters of photonic devices as well as their pros and cons in respect to thermal emitters. In particular, we show that photonic devices can from platform for next generation of multi-spectral and hyper-spectral dynamic scene simulation devices operating inside the two IR band mentioned with high spectral output density and able to simulate dynamically cold scenes (without cryogenic cooling) and low observable with very high frame rate.

6544-18, Session 4

Advances in 3D integration of heterogeneous materials and technologies

D. Temple, J. M. Lannon, D. M. Malta, RTI International; J. E. Robinson, P. R. Coffman, T. B. Welch, M. R. Skokan, DRS Infrared Technologies LP; A. J. Moll, W. B. Knowlton, Boise State Univ.

Military applications demand more and more complex, multifunctional microsystems with performance characteristics which can only be achieved by using best-of-breed materials and device technologies for the microsystem components. Three-dimensional (3-D) integration of separate, individually complete device layers provides a way to build complex microsystems without compromising the system performance and fabrication yield. In the 3-D integration approach, each device layer is fabricated separately using optimized materials and processes. The layers are stacked and interconnected through area array vertical interconnects with lengths on the order of just tens of microns. This paper will review recent advances in development of 3-D integration technologies with focus on those which enable integration of heterogeneous materials (e.g. MCT FPAs with silicon ROICs) or heterogeneous fabrication processes (e.g. resistive IR emitters with RIICs).

6544-19, Session 4

Design and fabrication of 64 x 64 MWIR LED array for high-temperature target simulation

N. C. Das, Army Research Lab.; J. Kramer, F. Kimilev, Univ. of Delaware

Passive IR imaging and IR detector arrays for seekers now play a very important role in missile defense operations and systems as well as for other DOD applications. The seeker testing requires large 2D array, high frame rate and large dynamic range IR sources. Several IR sources have been integrated into the hardware in the loop (HWIL) facility in the past, including a scanning laser array, resistive array and digital micro mirror devices (DMD) [1]. In an earlier paper [2] we have shown that MWIR LED array with inter-band cascade (IC) structure has emission power equivalent to apparent black body temperature of 650 K and 1050 K when operated at room and liquid nitrogen temperatures respectively. In this paper we present the design and fabrication procedure for large format 64x64 MWIR LED array with peak emission at 3.8 micron. The IC LED structure was grown by molecular beam epitaxy on a p- and n-type GaSb substrate.

The ASIC is 9.5mm square with a 68x68 array of unit cell drivers that was fabricated in the 130nm IBM 8HP SiGe process. The unit cells were designed to source up to 100mA to the LED, be individually addressable, and have analog drive and memory that can operate at a 1 kHz array refresh rate. Each unit cell contains a CMOS logic switch, a capacitor and a SiGe HBT driver. The switch is controlled by row and column select lines, which when activated charges the capacitor. The voltage stored on the capacitor controls the output current from the driver to the LED. The cells have a 120 micron pitch. With a current density of 5 mA/mm for the copper interconnect, at most 10% of the LEDs can be driven at the full 100mA drive current.

The LED array fabrication process starts with Ti/Au anode metal contact deposition, followed by LED mesa etching by ICP dry etching technique. Silicon nitride is deposited by PECVD technique following which contact windows are opened and Ti/Au metal layers are deposited for both top and bottom contacts. The wafer is diced and flip chip mounted on to a CMOS driver circuits. The results of individual LED pixel as well as array performance will be presented in full paper.

6544-20, Session 4

Fiber optic source projector

L. B. Shaw, Naval Research Lab.

No abstract available

6544-22, Session 4

Multicolor IR emissive pixels

J. M. Lannon, S. Grego, RTI International; S. L. Solomon, Acumen Scientific

We have investigated multiple methods for generating multi-color emission for IR scene projector applications. The baseline requirements we employed for evaluating the different approaches were the ability to simulate color temperatures in the range 300-3000 K, minimum radiance levels consistent with existing IR sensor requirements, 200 Hz frame rates and manufacturability. The analysis led us to downselect two independent approaches that are capable of meeting HWIL multicolor requirements. We describe and discuss each of the approaches, their expected performance as well as their limitations.

Conf. 6545: Window and Dome Technologies and Materials X

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6545-01, Session 1

History of the development of hot-pressed and chemical-vapor-deposited zinc sulfide and zinc selenide in the United States

D. C. Harris, Naval Air Warfare Ctr.

This paper traces the history of U. S. development of zinc sulfide and zinc selenide as infrared-transmitting window and dome materials from Kodak in the 1950s and 1960s through Raytheon in the 1970s and 1980s to CVD, Inc. in the 1980s and II-VI in the 1990s.

6545-02, Session 1

International development of chemical vapor deposited zinc sulfide

J. McCloy, Raytheon Missile Systems

The materials community realized that Zinc sulfide (ZnS) was an important optical material for infrared windows over forty years ago. Chemical vapor deposition (CVD) quickly became the method of choice for producing large ZnS windows and domes. In addition to the development initiated in the United States, several international efforts for understanding the processing and properties of CVD ZnS are notable. This paper summarizes the published history of non-U.S. CVD ZnS development including the significant efforts in the United Kingdom, the former Soviet Union, Israel, China, and Japan.

6545-03, Session 1

Optical properties of epitaxial single-crystal chemical-vapor-deposited diamond

G. Turri, Y. Chen, M. A. Bass, College of Optics & Photonics/Univ. of Central Florida; D. Orchard, QinetiQ Ltd. (United Kingdom); J. E. Butler, S. Magana, T. Feygelson, D. Thiel, K. Fourspring, Naval Research Lab.; J. M. Pentony, S. Hawkins, M. Baronowski, R. V. Dewees, M. D. Seltzer, A. Guenthner, D. C. Harris, Naval Air Warfare Ctr.

Epitaxial single-crystal chemical-vapor-deposited diamond was obtained from Element Six Ltd. (Ascot, UK) and from Apollo Diamond (Boston, MA). Both companies provided 5 x 5 mm squares with thicknesses ranging from 0.5 to 1.5 mm. In addition, Element Six provided 10-mm-diameter disks with a thickness of 1.0 mm. The absorptance of all specimens at 1064 nm was measured by laser calorimetry, with good agreement between independent measurements at the University of Central Florida and at QinetiQ. Loss of polarization at 1064 nm and total integrated forward scatter at 1150 nm are also reported.

6545-04, Session 1

Spectral characterization of diffractively structured GaAs using the ARISTMS

M. Wilson, P. Coulter, MilSys Technologies LLC

Diffractively structured GaAs was spectrally characterized using the Automated Rasterable Integrated Spectrometric and Total Integrated Scatter Measurement Systems (ARISTMS) for optical performance. Characterization was executed within the IR from 1 to 10 microns as a function of angle of incidence and spot size. Test articles were 100mm diameter GaAs wafers patterned on one side only. Results of the development effort are presented against the modeled data for the patterned structure. Diffractively structured IR materials potentially offer improved yields and performance matching or exceeding conventional anti-reflective coatings while increasing the field-of-regard of the IR window material.

6545-05, Session 2

Amorphous materials molded IR lens progress report

R. A. Hilton, Sr., J. McCord, R. Timm, Amorphous Materials Inc.

Amorphous Materials began in 2000 a joint program with Lockheed Martin in Orlando to develop molding technology required to produce infrared lenses from chalcogenide glasses. Preliminary results were reported at this SPIE meeting by Amy Graham1 in 2003. The program ended in 2004. Since that time, AMI has concentrated on improving results from two low softening glasses, Amtir 4&5. Both glasses have been fully characterized and Antireflection coatings have been developed for each. Expansion into a larger building has provided room for five production molding units. A large up to date coating unit has been acquired and is in operation. A Zygo unit is now used to evaluate molding results. Lenses have been molded from both glasses and also from arsenic trisulfide glass. Sizes have ranged from 8 to 136 mm in diameter. Recent results will be presented.

1. Amy Graham, Richard A. LeBlanc, Ray Hilton Sr.
SPIE 5078-26 (2003)

6545-06, Session 2

Fluorinated silicate glass for conventional and holographic optical elements

L. B. Glebov, College of Optics & Photonics/Univ. of Central Florida

This presentation is a survey of results of a long-term research at the laboratory of photoinduced processes at CREOL/UCF. A highly homogeneous and transparent sodium-zinc-aluminum-silicate glass doped with fluorine and bromine was developed. Glass is transparent from 220 to 2700 nm. It is a crown-type optical glass having refractive index at 587.5 nm nd=1.4959 and Abbe number υd=59.2. This glass shows low dependence of refractive index on temperature dn/dt<10-6 1/deg. Absorption coefficient in the near IR region is about 10-4 cm-1. Glass can withstand multi-kilowatt laser beams. Nonlinear refractive index is the same as for fused silica. Laser damage threshold for 8 ns is about 40 /cm2. This glass becomes a photosensitive one by doping with silver and cerium. It demonstrates refractive index decrement after exposure to UV radiation followed by thermal development is used for phase volume hologram recording. Spatial modulation of refractive index resulted from precipitation of nano-crystalline phase of sodium fluoride. The main mechanism of refractive index decrement is a photoelastic effect resulted from strong tensions generated in both crystalline and vitreous phases because of strong difference in their coefficients of thermal expansion. Volume Bragg gratings recorded in this glass, show extremely narrow spectral and angular selectivity and have low losses combined with high tolerance to laser radiation. These gratings possess a unique ability to produce laser beam transformations directly in angular space. This feature paves a way to creation of high power lasers with stable narrow emission spectra and diffraction limited divergence.

6545-07, Session 2

Development of a laser glass for the National Ignition Facility

J. S. Hayden, SCHOTT North America, Inc.; J. H. Campbell, S. A. Payne, Lawrence Livermore National Lab.

We review the development of a new glass formulation and manufacturing technology for a neodymium doped phosphate based laser glass used in the National Ignition Facility (NIF). The glass development process built on both accumulated experience and the utilization of glass science principles, and the resultant new glass offered superior laser properties in combination with improvements in physical properties to enhance manufacturing yield. Essentially in

parallel, to meet both the schedule and cost targets of the NIF, a continuous melting production line was also conceived, designed and operated. Prior to 1997, phosphate laser glasses were manufactured by a discontinuous pot process with limited production rate and associated high costs. The continuous melting process met several technical challenges, including producing glass with low residual water content and absence of inclusions which become damage sites when used in the NIF laser system.

6545-09, Session 3

Nano-composite optical ceramics for infrared windows and domes

T. S. Stefanik, R. Gentilman, P. K. Hogan, Raytheon Co.

Currently available IR transparent materials typically exhibit a trade-off between optical performance and mechanical strength. For instance, sapphire domes are very strong, but lack full transparency throughout the 3-5 micron mid-wave IR band. Yttria is fully transparent from 3-5 microns, but lacks sufficient strength, hardness, and thermal shock resistance for the most demanding aero-thermal applications. Missile system designers must limit system performance in order to accommodate the shortcomings of available window and dome materials. Recent work in the area of nanocomposite ceramics may produce new materials that exhibit both excellent optical transparency and high strength, opening the door to improved missile performance. The requirements for optical nanocomposite ceramics will be presented and recent work in producing such materials will be discussed.

6545-10, Session 3

Optical nano-composites with novel architecture

D. Routkevitch, R. Wind, Synkera Technologies, Inc.; S. M. George, Univ. of Colorado/Boulder; E. Mirowski, C. Kostelecky, Synkera Technologies, Inc.

This talk will overview the results of the development of a new nanostructured ceramic composite with innovative architecture. Main objective of this effort is to achieve mechanical and thermal properties exceeding that of sapphire, while retaining optical performance comparable to sapphire. The composite incorporates a self-organized nanoporous ceramic matrix reinforced with nanostructured ceramic of different composition. The intrinsic features of the proposed composite allow the retention of sub-50 nm grain size. Processes used in composite synthesis allow precision control of the composite structure and chemical composition, enabling advanced engineering of composite properties and performance. Results indicate that composites synthesized to date have promising properties, and that removing residual absorption by OH bond is the key issue in achieving desired optical performance. Several processing routes that have been identified to address this challenge will be discussed.

6545-11, Session 3

Fine-grain polycrystalline yttria for IR applications

M. T. Koslowske, M. R. Pascucci, M. V. Parish, CeraNova Corp.; W. H. Rhodes, Rhodes Consulting

Cubic polycrystalline yttria has been made transparent in the visible by eliminating porosity and second phases while consolidating to full density. While this has been accomplished previously resulting in large grain microstructures, renewed interest in this material for infrared domes and windows centers on improved mechanical properties for increased thermal shock resistance. Reducing the grain size and improving the surface finish are two possible approaches to improving the strength and reliability of this material. Efforts to produce fine grain (< 10 μm), dense and transparent yttria will be described. Optical and microstructural properties of resulting materials will be presented.

6545-12, Session 3

Polycrystalline alumina for aerodynamic IR domes

M. V. Parish, M. T. Koslowske, M. R. Pascucci, CeraNova Corp.; W. H. Rhodes, Rhodes Consulting

CeraNova's transparent polycrystalline alumina has sub-micron grain size (500-700nm) and high transmittance in the mid-wave infrared (\>85% in the 3-5 μm MWIR region). 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 which are readily fabricated by powder processing. Both hemispheric and ogive domes have been successfully molded and densified to transparency. Results of optical, mechanical, thermal shock, and rain impact testing will be presented.

6545-13, Session 3

Polycrystalline yttrium aluminum garnet (YAG) for IR transparent missile domes and windows

J. C. Huie, Raytheon Co.; C. B. Dudding, J. McCloy, Raytheon Missile Systems

Ceramic YAG is being considered as an attractive material candidate for IR transparent missile domes and reconnaissance windows, due to its superior optical clarity and mechanical properties compared to the incumbent material choice. YAG possesses a very uniform index of refraction with minimal variation. Its fracture strength, hardness, and toughness also rank high among various other optically transparent materials and can be optimized further through grain size minimization. Ceramic YAG has been in development for several years at Raytheon Advanced Materials Laboratory for laser gain and IR transparency applications. Recent advances in optical loss characterization and optimization, scale-up efforts, and the fabrication of non-planar geometries, such as hemispherical domes, will be presented.

6545-49, Session 3

Optically transparent polycrystalline Al2O3 window and dome produced by spark plasma sintering

D. Jiang, D. M. Hulbert, U. Anselmi-Tamburini, Univ. of California/Davis; D. P. Land, Univ. of California/Irvine; T. C. Ng, A. Muhkerjee, Univ. of California/Davis

Spark plasmas sintering(SPS) method was used to produce transparent alumina and proved to be a cost-effective method due to short processing cycle. It was found that realtively slower heating rate and longer sintering time lead to higher IR transmittance. The transmittance varies with grain size, on the other hand, even with similar grain size the transmittance varied with SPS sintering parameters. Annealing in air at 1250?C for 24h significanly increased IR transmission. A maximum transmittance of 85% has been successfully sintered at 1300?C for 5min. The present results are not consistent with Raleigh-Gans-Debye scattering model that predicts that the transmittance increases with decreasing the grain size. The residual stress in the alumina grains may be a fator influencing the optical transmission among other factors such as stoichiometry, grain boundary, and nanoporosity.

Utilizing SPS, transparent polycrystalline alumina dome has been successfully produced by combining sintering and forming into one step in minutes instead of hours when using conventional methods. This is a near-net-shape forming method such that minor amount of machining or polishing is needed. Obviously, the overall cost for making a shaped part by using this method is drastically decreased. The present forming method provides unprecedented opportunity to make optically transparent dome at much lower cost.

6545-15, Session 4

Optical properties of Nd-doped and undoped polycrystalline YAG

M. E. Thomas, Johns Hopkins Applied Physics Lab.; J. C. Huie, Raytheon Co.

Good optical quality polycrystalline yttrium aluminum garnet (YAG) is now available. The optical properties of pure polycrystalline YAG and 1% Nd doped polycrystalline YAG are reported from the midwave infrared through the visible. The absorption and scatter properties are represented in terms of standard models.

6545-16, Session 4

Water impact experiments on infrared transparent materials

R. M. Sullivan, Naval Air Systems Command

No abstract available

6545-17, Session 4

Determination of hydrometeor deformations during supersonic encounter with a missile

R. K. Frazer, R. P. Roger, H. N. Oguz, Johns Hopkins Applied Physics Lab.; W. F. Adler, Aquila Lab., LLC; B. E. Moylan, U.S. Army Aviation and Missile Research, Development and Engineering Ctr.

A physics-based method is described for reliably predicting the deformation of hydrometeors from first principles during encounters with supersonic vehicles. The results provided are for spherical water drops, but the significance of this method is its ability to describe the deformation of water drops with arbitrary, asymmetric initial shapes as well as other classes of hydrometeors. Prior analyses developed for this problem area are restricted to spherical water drops.

The results obtained from this method, currently being developed, are essential for evaluating the initial conditions for numerical models of the damage missile airframes experience when deformed rain drops reach a location on the surface of the vehicle. Forward looking sensor windows are particular locations of concern. Previous work has shown that the shape of a rain drop at impact with the missile airframe is an important factor in the extent of the subsequent damage. Therefore, this methodology facilitates the prediction of the damage potential for a wide range flight and weather conditions. A spherical drop subject to a normal shock will be considered to illustrate the general approach. The results from the calculations compare favorably with the drop deformations observed during passage through the oblique bow shock for a streamlined missile at Mach 5.

6545-18, Session 4

BRDF and BSDF models for diffuse surface and bulk scatter from transparent windows

M. E. Thomas, D. D. Duncan, Johns Hopkins Applied Physics Lab.

A novel approach based on the generalized Van Cittert-Zernike theorem is used to characterize the scatter properties of window materials and coated surfaces. The scattered light is categorized based on the level of coherence of the scattered light. A closed form model is applied to a wide range of illumination frequencies and material types. Diffuse scattered light is represented in a straightforward manner. Comparisons between measurements and model fits will be presented.

6545-19, Session 4

Application of nondestructive optical techniques in the detection of surface and subsurface defects in sapphire

I. Akwani, D. L. Hibbard, Exotic Electro-Optics, Inc.

Advancements in optical manufacturing and testing technologies for sapphire material are required to support the increasing use of large aperture sapphire panels as windscreens for various electro-optical system applications. It is well known that the grinding and polishing operations employed to create optical surfaces leads to the introduction of surface stress and sub-surface damage which can affect critical opto-mechanical performance characteristics such as strength and durability. Traditional methods for measuring these defects are destructive and, therefore, unsuitable as in-process, high volume inspection tools. Work is presently underway at Exotic Electro-Optics to investigate a number of non-destructive techniques for characterization of post-fabrication stress and sub-surface damage in a-plane sapphire. The ultimate goal is an in-line, non-destructive methodology capable of monitoring the stress/strength level directly in production panels on the shop floor. Raman spectroscopy and laser polarimetry have shown promise in quantifying surface and bulk stress, respectively. Preliminary experimental results using these techniques have shown that stress and sub-surface damage may be non-destructively measured and are dependent on the specific fabrication process steps used. This report will also include a comparison of the results of non-destructive testing to the results of an established destructive technique to provide a measure of correlation.

6545-20, Session 4

Characterization AFB(r) sapphire single crystal composites for infrared windows

H. Lee, H. E. Meissner, Onyx Optics Inc.

Next-generation weapons platforms may require sapphire windows of about 30"x30". Since these sizes exceed what can be manufactured directly, a concept is proposed and experimental data are furnished on the viability of increasing the dimensions by Adhesive-Free Bonding (AFB(r)) by their edges of smaller starting components in this report. The bonding scheme has been evaluated for single crystal sapphire but is expected to also describe other IR window materials.

The bonding mechanism is explained with existing Van der Waals theory of attractive forces and confirmed experimentally by applying bending plate theory. The gap at the interface between two components is deduced from the measured roughness of the polished surfaces that are brought into optical contact and subsequently heat treated, and is estimated to be about 2 Å rms. Stress relief at AFB(r) interfaces has been established. Experimental data and flexural strength determined by four-point bending at various environmental and thermal conditions will be reported and interpreted for AFB(r) composite specimens and equivalently prepared blank samples under standardized testing conditions. The transmitted wavefronts through the AFB(r) composite of various configurations are measured interferometrically without and with applied loads. Critical requirements for precision fabrication of composite AFB(r) sapphire windows are addressed.

6545-21, Session 4

Simulation and experimental results of sub-aperture transmitted wavefront measurements of a window using a time-delayed source

M. B. Dubin, Breault Research Organization, Inc.; W. P. Kuhn, William P. Kuhn, Ph.D., LLC

It is often desirable to measure an optical component whose aperture exceeds the capacity of the measurement device. However, stitching of sub-aperture measurement data into a single measurement of an optical component is a challenging problem since mechanical motions of the test component relative to the reference surface of an interferometer can not be made with interferometric accuracy. Even more challenging than the need to compensate for rigid body motion between the sub-aperture measurements is the need to account for imperfections in the reference surface itself.

In this paper we show, both in simulation and experimentally, how the use of a time-delayed source (TDS) simplifies the stitching of transmitted wavefront measurements from domes and windows. This is accomplished by making it possible to obtain phase-shifted

interferometric measurements using only the light reflected by two surfaces from a dome or window without the use of a reference surface.

6545-22, Session 5

Non-contact aspheric, deep parabolic, ogive measurement system

D. E. Mohring, M. J. Bechtold, J. Meisenzahl, OptiPro Systems

OptiPro Systems is developing a non-contact measurement system using state of the art motion control and calibration techniques while minimizing the axes of motion during measurement and integrating a high accuracy non-contact probe.

The implementation of precision bearings for linear and rotary motion is crucial for system repeatability and a variety of methods are explored. The goal is to precisely scan concave and convex surfaces of aspheric, deep parabolic and ogive shapes. The metrology system will use computer controlled slicing techniques to create a single line scan and a complete topographical surface map of the surface form and also take surface roughness measurements above 30nm. Analysis of the motion and calibration process with resultant measurements and error budgets will be presented.

6545-23, Session 5

Transmitted wavefront metrology of hemispheric domes using a scanning low-coherence dual-interferometry (SLCDI)

D. W. Diehl, C. Cotton, C. J. Ditchman, ASE Optics, Inc.

Modern missile domes are up to 7 inches in diameter, subtending an angular aperture of 2 pi steradians. Quantifying the transmitted wavefront of these domes is critical for quality control, but such optics are difficult or impossible to measure using conventional interferometric techniques. To address this issue, we have developed a non-contact measurement process that uses a technology similar to optical coherence tomography (OCT) to map the optical thickness of a hemispheric dome over its full aperture. The technique has been termed Scanning Low Coherence Dual Interferometry (SLCDI), and has the unique ability to measure the optical thickness of component layers within a multilayer dome. In this paper we demonstrate that SLCDI yields results comparable to those from a Zygo interferometer within the limits of the Zygo's field of view. We also show that SLCDI is capable of measuring decentration errors between the interior and exterior surfaces, which a standard interferometer may mistake for tip/tilt or defocus in the reference wavefront. From this we conclude that SLCDI is a promising new tool for measuring the quality of hemispheric domes.

6545-24, Session 5

Time-delayed source and interferometric measurement of domes and windows

W. P. Kuhn, William P. Kuhn, Ph.D., LLC; M. B. Dubin, Breault Research Organization, Inc.

Measurement of the transmitted wavefront of domes and windows is a long-standing problem. The use of a modern phase-shifting interferometer is problematic because of interference between the interferometer's reference surface and multiple reflections from the dome. One may use a large return sphere and measure the interference cavity without the dome present and again with the dome present. The difference between the two measurements is measure of the transmitted wavefront of the dome. Even so, the long coherence length of the source results in many extraneous fringe patterns. Windows may be tested similarly with the use of a collimated source and return flat.

In this paper we present a method of measuring the wavefront of a dome or window using a time-delayed source (TDS). A single interference pattern due only to interference from the two surfaces of a dome or window may be produced through the use of a short coherence length source and proper setting of the TDS time-delay. Standard phase shifting algorithms may be used to measure the transmitted wavefront of a dome or window in a single measurement while errors from multiple path reflections are eliminated. Since most of the interferometer is common-path, environmental sensitivity is reduced and alignment is straightforward. Finally, since there is no reference surface, stitching of sub-aperture measurements is simplified.

6545-25, Session 5

Laser-assisted pre-finishing of optical ceramic materials

J. C. Rozzi, O. H. Clavier, Creare Inc.

At Creare, we are developing a laser-assisted, pre-finishing system that enables the single-point diamond turning of super-hard ceramics into hemispheres, ogives, and other shapes that are ready for final optical finishing. Currently, super-hard ceramic materials cannot be affordably processed due to the low material removal rates and the high amount of sub-surface damage associated with current processes. Our innovation uses a low-power, far-infrared laser to heat, but not ablate, a thin layer of material prior to its removal. By heating the ceramic material, plastic-like deformation at the cutting edge is fostered by high-temperature dislocation motion. In doing so, the cutting forces are reduced which enables attendant reductions in tool wear, surface and sub-surface damage, and processing time. Our paper will summarize the development of our innovation, describe the process, discuss the machine tool, and review the latest results including assessments of surface quality, subsurface damage, cutting force measurements, and part strength.

6545-26, Session 5

Developments in the finishing of domes and conformal optics

A. B. Shorey, W. Kordonski, J. Tracy, M. Tricard, QED Technologies Inc.

The final finish and characterization of windows and domes presents a number of difficult challenges. Furthermore, there is a desire to incorporate conformal shapes into next generation imaging and surveillance systems to provide significant advantages in overall component performance. Unfortunately, their constantly changing curvature and steep slopes make fabrication of such shapes incompatible with most conventional polishing and metrology solutions. Two novel types of polishing technology, Magnetorheological Finishing (MRF(r)) and Magnetorheological Jet (MR Jet(tm)), along with metrology provided by the Sub-aperture Stitching Interferometer (SSI(r)) have several unique attributes that give them advantages in enhancing fabrication hemispherical domes and even conformal shapes.

The advantages that MRF brings to the precision finishing of a wide range of shapes such as flats, spheres (including hemispheres), cylinders, aspheres and even freeform optics, has been well documented. The recently developed MR Jet process provides additional benefits, particularly in the finishing the inside of steep concave domes and other irregular shapes. Combining these technologies with metrology techniques, such as the SSI, provides a solution for finishing current and future windows and domes. Recent exciting developments in the finishing of such shapes with these technologies will be presented. These include new advances such as the ability to use the SSI to characterize a range of shapes such as domes and aspheres, as well as progress in using MRF and MR Jet for finishing conventional and conformal windows and domes.

6545-27, Session 5

Contact mechanics models and algorithms for dome polishing with UltraForm finishing (UFF)

C. Bouvier, S. M. Gracewski, S. J. Burns, Univ. of Rochester

UltraForm Finishing (UFF) is a new deterministic subaperture computer numerically controlled (CNC) polisher developed by OptiPro Systems (Ontario, NY) with the University of Rochester. UFF is designed, 1) to be compliant to reduce surface roughness and to remove mid-spatial frequency surface errors, especially cutter marks, 2) to be deterministic to preserve or correct the form of the part and, 3) to polish deep domes made of tough, hard materials like aluminum oxynitride, ALON, or polycrystalline alumina, PCA. Because UFF uses compliant tools with large contact patches, the depth of removal is prescribed by adjusting the tool crossfeed velocity. The equations for the depth of removal as the tool traverses an axisymmetric part were derived for flats and spheres. The form correction problem consists in solving these equations by adjusting the tool crossfeed velocity to achieve a desired removal profile. The solution must satisfy constraints on the tool velocity and acceleration. Solutions are achieved by treating the problem as a constrained optimization after writing the depth of removal equations in matrix form for flats, spheres and aspheres. The solutions were validated experimentally by comparing predicted and actual removal profiles. The removal function or footprint of the tool, used to express the depth of removal, is evaluated by making a removal spot for one set of process parameters. Its variations, as a function of the process parameters, are predicted by using Hertz contact theory and the Preston equation. To prevent tool-part collisions and to analyze part and spot measurements, algorithms were developed for the tool path and evaluation of metrology inputs.

6545-28, Session 5

Improving surface figure and microroughness of IR materials and diamond turned surfaces with Magneto-Rheological Finishing (MRF(r))

C. Supranowitz, C. Hall, P. Dumas, B. Hallock, QED Technologies Inc.

Optics manufactured for infrared (IR) applications are commonly produced using single point diamond turning (SPDT). SPDT can efficiently produce spherical and aspheric surfaces with microroughness and figure error that is often acceptable for use in this region of the spectrum. The tool marks left by the diamond turning process cause high surface microroughness that can degrade performance when used in the visible region of the spectrum. For multispectral and high precision IR applications, surface figure may also need to be improved beyond the capabilities of the SPDT process. Magneto-Rheological finishing (MRF(r)) is a deterministic, sub-aperture polishing technology that has proven to be very successful at simultaneously improving both surface microroughness and surface figure on spherical, aspheric, and most recently, freeform surfaces. MRF has been used on many diamond turned IR materials to significantly reduce surface microroughness from tens of nanometers to below 1 nm. MRF has also been used to successfully correct figure error on several IR materials that are not diamond turnable.

This paper will show that the combination of SPDT and MRF technologies enable the manufacture of high precision surfaces on a variety of materials including calcium fluoride, silicon, and nickel-plated aluminum. Results will be presented for microroughness reduction and surface figure improvement, as well as for smoothing of diamond turning marks on an off-axis part. Figure correction results using MRF will also be presented for several other IR materials including sapphire, germanium, AMTIR, zinc sulfide, and polycrystalline alumina (PCA).

6545-29, Session 6

High-durability antireflection coatings for silicon and multispectral ZnS

S. Joseph, O. Marcovitch, Y. Yadin, D. Klaiman, N. Koren, H. Zipin, RAFAEL Armament Development Authority Ltd. (Israel)

In the current complex battle field, military platforms are required to operate on land, at sea and in the air in all weather conditions both day and night. In order to achieve such capabilities, advanced electro-optical systems are being constantly developed and improved. These systems such as missile seeker heads, reconnaissance and target acquisition pods and tracking, monitoring and alert systems have external optical components (window or dome) which must remain operational even at extreme environmental conditions. Depending on the intended use of the system, there are a few choices of window and dome materials. Amongst the more common materials one can point out Sapphire, CVD-ZnS, multi-spectral ZnS, Germanium and Silicon. Other materials such as Spinel, ALON and Yittria may also be considered.

To improve performance of such systems, radiation at any relevant wavelength must be permitted to pass through the window or dome. Most infra-red materials have high indices of refraction and therefore they reflect a large part of radiation. To minimize the reflection and increase the transmission, anti-reflection (AR) coatings are the most common choice. Since these systems operate at different environments and weather conditions, the coatings must be made durable to withstand these extreme conditions. In cases where the window or dome is made of relatively soft materials such as multi-spectral ZnS, the coating may also serve as protection for the window or dome.

In this work, several anti reflection coatings have been designed and manufactured for 3-5µm on Silicon. The coating materials used were chosen to be either oxides or fluorides which are known to have high durability. Ellipsometry measurements were used to characterize the materials and the measured optical constants were used for the coating design. The effects of the deposition conditions on the optical constants of the deposited thin films and durability of the coatings will be discussed. The coatings were tested according to MIL-STD-810E and were also subjected to rain erosion tests at the University of Dayton Research Institute (UDRI) whirling arm apparatus in which one of the coatings showed no rain drop impact damage at all.

Results of a multi-spectral anti-reflection coating on multi-spectral ZnS will also be discussed. An attempt has been made to utilize a coating that will on one hand serve as a protective coating to reduce rain erosion damage and on the other hand to prolong the use of multi-spectral ZnS components in a naval environment.

6545-30, Session 6

Durable optical coatings for windows and domes

L. M. Goldman, S. K. Jha, S. A. Sastri, Surmet Corp.; J. C. Kirsch, U.S. Army Research, Development and Engineering Command; R. Raman, R. Cooke, N. Gunda, Surmet Corp.

Durable optical coatings for improved environmental resistance and optical transmission of high speed missile windows and domes are being evaluated at Surmet Corporation. The coatings are used to protect high-speed missile windows and domes from the environmental loads during flight. Surmet's proprietary process is an innovative vacuum vapor deposition process which is capable of high rate of deposition on substrates with complex 3-D geometries. The ease of manipulating the process variables, make Surmet's process suitable for the deposition of substantially thick films (up to 30 * m) with precisely controlled chemistry. Initial work has shown encouraging results, and the optimization of the coating for this application is under way. Coated coupons with varying coating thickness on a variety of substrates such as ALON, Spinel, Silicon wafer, ZnS and were fabricated and used for the study. This paper will present and discuss the results of the coating deposition and characterization (physical, mechanical and optical properties) as a basis for evaluating their suitability for high speed missile windows application.

6545-31, Session 6

iDLC: hardcoat for GASIR and other IR materials

K. A. Rogers, Umicore Coating Services (United Kingdom); Y. M. Guimond, Umicore IR Glass (France); J. Ward, Umicore Coating Services (United Kingdom)

An novel IR transmissive hard coating that offers protection to harsh environmental conditions on GASIR(r) and other IR materials for thermal imaging and sensing applications.

iDLC has been developed to maximise both spectral and environmental performance for GASIR(r). This coating can be applied to the outside surface of moulded optics and windows and offers high spectral efficiencies from 2.0microns to 15microns.

The ability to deposit a multi-layer structure allows broad band high efficiency anti-reflection coatings.Compared to conventional DLC,this coating offers significantly less absorption, lower reflection,thus

allowing higher transmission over a wider spectral band.

Tests have shown that the coating offers exceptional resistance to abrasion,salt spray and humidity on both GASIR(r) and Germanium.

The process used to manufacture iDLC has been configured for production volumes and offers a process for a wide range of applications on IR electro-optic materials.

6545-32, Session 6

Eclipse IR-TEC: IR transparent conductive coating

H. Demiryont, Eclipse Energy Systems, Inc.

This paper presents an innovative IR transparent conductive coating. The coating is a vacuum deposited thin film system which is nearly 90% transparent in the 1.3 to 27 micron spectral region, having 2.5 ohms/sqr sheet resistance and -35 dB of the shielding effectiveness in the 0.1 to 100GHz frequency region. The spectral transparency of the Eclipse IR-TEC samples was evaluated on ZnS substrates and electrochromic variable emissivity control, ECD-VE, systems. Eclipse IR-TEC was used as a watch-port electrode for the ECD-VE system to observe the emissivity modulations. Films deposited on ZnS substrates were optically tailored to reach 80% transmittance in the mid IR region. The shielding effectiveness of the transparent conductive samples evaluated on 10"X10" substrates exhibit -35dB value in the 4 to 16GHz region.

6545-33, Session 6

The effects of mesh voids on the insertion loss of metallic mesh coatings

J. I. Halman, K. A. Ramsey, S. Rodenbaugh, Battelle Memorial Institute

Metallic mesh thin film coatings have been used for many years to provide electromagnetic interference (EMI) shielding on infrared windows and domes. During the fabrication of these micron-sized mesh patterns, mesh voids or holes in the mesh pattern occasionally occur. Holes in the mesh degrade the EMI shielding or insertion loss of the mesh coating. In the past we have shown that a small number of 1 mm voids do not degrade the insertion loss significantly for 20 dB insertion loss mesh-coatings. In this paper, we will examine the number and size of mesh voids that can be tolerated without degrading the EMI shielding properties of 25 to 30 dB insertion loss mesh-coatings. We will measure the insertion loss of several typical metallic-mesh coatings with and without voids and compare the results with a simple insertion loss model

6545-34, Session 6

Update on the development of high-performance antireflecting surface relief microstructures

D. S. Hobbs, B. D. MacLeod, J. R. Riccobono, TelAztec LLC

Microstructures built into the surfaces of an optic or window, have been shown to suppress the reflection of broad-band light to unprecedented levels. These antireflective (AR) microstructures form an integral part of an optic component, yielding an AR property that is as mechanically durable, radiation-hard, and resistant to damage from high optical energy, as the bulk material.

Three types of AR surface relief microstructures are being developed for a wide variety of applications utilizing light within the visible to very long wave infrared spectrum. For applications requiring broad-band operation, Motheye AR textures consisting of a regular periodic array of cone or hole like structures, are preferred. Narrow-band applications such as laser communications, can utilize the very high performance afforded by sub-wavelength structure, or SWS AR textures that consist of a periodic array of simple binary, or step profile structures. Lastly, Random AR textures offer very broad-band performance with a simple manufacturing process, a combination that proves useful for cost sensitive applications such as solar cells, and for complex devices such as silicon and HgCdTe sensor arrays.

An update on the development of AR microstructures will be discussed for many specific applications. Data from SEM analysis, reflection and transmission measurements, radiation testing, and laser damage testing, will be shown for high performance AR microstructures fabricated in ZnGeP, CdZnTe, silicon, GaAs, borosilicate glass, BGG glass, As_2Se_3, and As_2S_3.

6545-35, Session 7

Recent advances in ALON optical ceramic

J. M. Wahl, T. M. Hartnett, L. M. Goldman, R. Twedt, C. Warner, Surmet Corp.

Aluminum Oxynitride (ALONTM Optical Ceramic) is a transparent ceramic material which combines transparency from the UV to the MWIR with excellent mechanical properties. ALON's optical and mechanical properties are isotropic by virtue of its cubic crystalline structure. Consequently, ALON is transparent in its polycrystalline form and can be made by conventional powder processing techniques. This combination of properties and manufacturability make ALON suitable for a range of applications from IR windows, domes and lenses to transparent armor. Surmet is currently selling ALON into a number of military (e.g., windows and domes) and commercial applications.

Recent advances in size capability, blank and fabrication geometry and materials characterization, including optical homogeneity, will be presented.

6545-36, Session 7

Grinding and polishing of polycrystalline alumina, AlON and spinel domes, utilizing the UltraForm 5 axis finishing system

M. J. Bechtold, D. E. Mohring, OptiPro Systems; E. M. Fess, Univ. of Rochester

Finishing using bound and loose abrasives, requires consistent static environmental conditions and deterministic control over the dynamic variables. Experimental analysis of these variables is used to determine their influence on resultant surface form and finish on Polycrystalline Alumina, AlON, and Spinel domes. Currently OptiPro Systems is in development of a 5-axis computer controlled grinding and polishing system which will be used for manufacturing complex, commercial and military optical systems. Presentation will include the current status of the UltraForm Finishing Hardware, Graphical User Interface, Software and Process developments specific to the grinding and finishing of hemispherical and ogive shaped domes.

6545-37, Session 7

Near-net shape forming of AlON domes via wet processing techniques

B. J. Robinson, K. McNeal, Materials Systems, Inc.

Scalable manufacturing processes are needed to cost-effectively manufacture missile seeker domes in large quantities. Under Army SBIR funding*, MSI is investigating two “wet processing” techniques for the formation of AlON domes as part of the Army's ongoing cost-reduction effort towards full-scale production of the Joint Common Missile (JCM). As proof of concept, AlON discs and domes have been injection molded by both low and high pressure injection molding technique yielding near net-shaped AlON parts having higher green densities than obtainable by conventional dry forming processes, such as cold isostatic pressing. Injection molding is capable of generating high piece run rates and very near net shape parts, reducing both dome blank and subsequent machining costs. The ultimate objective of this investigation is to establish the most rapid and cost-effective “wet processing” technique for producing near net-shape AlON dome blanks having the required optical properties, and to demonstrate that the selected approach is capable of meeting the Army's needs for full-scale dome production.

6545-38, Session 7

An improved soft-chemistry approach to the preparation of spinel powders

R. L. Cook, TDA Research, Inc.

Spinel powders have been produced using a number of traditional ceramic and sol-gel methods. Previously we had reported on the use of new approach to the synthesis of spinel powders via the reaction of surface modified boehmite and magnesium acetylacetonate. While this approach produced fine grained spinel powders, it has limitations of high cost and labor-intensive purification of the magnesium acetylacetonate. A re-evaluation of the reaction mechanism has allowed us to identify lower-cost and higher purity magnesium sources for the low-temperature metal-exchange reaction. Properties of the powders and preparation of transparent spinel windows using the new materials will be discussed.

6545-39, Session 7

Recent advances in magnesium aluminate spinel

T. J. Mroz, L. M. Goldman, R. Twedt, C. Warner, Surmet Corp.

Magnesium aluminate ($MgAl_2O_4$) spinel is a material of interest for windows and domes in visible to mid-wavelength infrared (MWIR) applications where demanding optical, physical and environmental conditions exist. Spinel has properties similar to Sapphire and ALON, but has advantages over each. Relative to sapphire, spinel's advantages are that it has isotropic optical and mechanical properties. Consequently, it can be produced by conventional powder processing techniques and is substantially easier to grind and polish. Relative to ALON, which can also be produced by powder processing, Spinel transmits further into the MWIR, making it preferable for certain applications.

Significant improvements in processing have resulted in an improved spinel material, which combines high strength (~46 Ksi) and excellent optical performance. This improved process has been used to produce full scale windows and domes. Results to be presented will include scale up to large size flat windows, as well as optical and mechanical characterization of the improved spinel material itself.

6545-40, Session 7

Polycrystalline transparent spinel domes for multimode seeker applications

A. A. DiGiovanni, A. LaRoche, L. Schubel, L. Fehrenbacher, Technology Assessment and Transfer; D. W. Roy, Consultant

The transmission characteristics of polycrystalline $MgAl_2O_4$ spinel exceed that of both ALON and sapphire at the end of the mid-wave IR spectrum, which makes it especially attractive for the ever-increasing performance requirements of current and next-generation seeker platforms. With a theoretical transparency from the UV through the MWIR of up to 87%, transparent spinel ceramics are being evaluated in a wide range of optical applications including windows, domes, armor, and lenses. Technology Assessment and Transfer Inc. (TA&T) have established a 9000 ft2 production facility for optical quality spinel based on the traditional hot-pressing followed by hot isostatic pressing (HIPing) route. The hot pressing method has proved the most viable for high aspect ratio parts such as windows, which can be pressed in large stacks similar to commercial opaque armor products. Complicated shapes, however, like spherical domes, require a highly scalable, near net shape processing method. Pressureless sintering is a processing method that forms the basis of the traditional ceramic industry. By taking advantage of the polycrystalline nature of the spinel ceramic, near net shape green parts can be produced, such as a dome, and then fired and ultimately HIPed to transparency. These two main processing approaches, hot pressing and pressureless sintering, allow the widest variety of applications to be addressed using a range of optical components and configurations. This paper will address some of the challenges to fabricating optical quality spinel domes and windows with respect to starting raw material through forming and ultimately firing.

6545-41, Session 7

Recent developments in transparent polycrystalline spinel and other transparent ceramics

I. Aggarwal, Naval Research Lab.

The U.S. Naval Research Laboratory (NRL) has developed a unique process which allows very controlled and uniform sintering of polycrystalline ceramics into full transparency. The process is highly reproducible. It facilitates sintering to occur at lower temperatures and times resulting in a uniform microstructure with fine grains and superior mechanical and optical properties. High optical quality spinel ceramic has been fabricated in various sizes and shapes and is readily scalable to industrial sizes to produce large windows & domes for various applications including HEL windows to survive in hostile environments as well as light weight transparent armor for personnel protection. In addition, this process has been used to make transparent Yb^{3+} doped Y_2O_3 ceramic laser material with potential for very high power output at around 1 µm.

In both cases, for spinel and Yb^{3+} doped Y_2O_3, we have developed the capability to make high purity powder and then sintered this to make high optical quality ceramics. We will describe the processing conditions used to make the powders and ceramics, and then discus the optical properties of these ceramics.

6545-42, Session 7

Spinel and BGG glass composite domes

S. S. Bayya, J. S. Sanghera, I. Aggarwal, Naval Research Lab.; E. Welsh, Lockheed Martin Missiles and Fire Control; R. Twedt, L. M. Goldman, Surmet Corp.; J. C. Kirsch, U.S. Army Research, Development and Engineering Command

Barium Gallo-Germanate (BGG) glass has excellent transmission in the visible and infrared wavelength region and is therefore useful for many applications. This presentation focuses on the development of spinel and BGG composite domes. In order to do this, a modified BGG glass composition was specifically developed which wets and bonds to the spinel. The new glass was also designed with matching refractive index and coefficient of thermal expansion (CTE) to optimize the optical properties and minimize the thermal stresses, respectively. We have demonstrated excellent bonding between spinel and BGG glass flats and also dome shapes. The bonded substrates have been very stable under severe thermal cycling runs. Preliminary bonding with an intermediate metal grid has also been very promising. We will present these and other results from environmental testing (Ultra Violet light exposure and rain erosion resistance).

6545-43, Session 7

Investigation of critical parameters for grinding large sapphire window panels

J. Bashe, I. Akwani, G. Dempsey, D. L. Hibbard, Exotic Electro-Optics, Inc.

Advancements in optical manufacturing and testing technologies for sapphire material are required to support the increasing use of large aperture sapphire panels as windscreens for various electro-optical system applications. Surface grinding is a crucial step in both the figuring and finishing of optical components. Improper grinding can make the subsequent polishing operations more difficult and time consuming. Poor grinding can also lead to the introduction of surface stress and sub-surface damage which can affect critical opto-mechanical performance characteristics such as strength and durability. Work is presently underway at Exotic Electro-Optics to investigate a number of process enhancements in the grinding of a-plane sapphire. EEO has completed a twelve run Plackett-Burman design of experiment (DOE) to study the effects of fundamental grinding parameters on sapphire panel surfaces. The results of that study will be presented.

6545-44, Session 7

Clear large aperature sapphire sheets (CLASS(tm)) for aerospace and transparent armor applications

C. D. Jones, Saint Gobain Crystals; J. W. Locher, J. B. Rioux, H. E. Bates, S. A. Zanella, Saint-Gobain Crystals

Saint-Gobain Crystals produces CLASS225(tm) and CLASS300(tm) material as large, thick sheet measuring 225 x 660mm and 305 x 510mm respectively, the largest monolithic surface area sapphire in the world, for commercial and military applications. The newest addition to the CLASS product line is CLASS400(tm), measuring 400 mm wide. Recent development effort has led to thicker CLASS225(tm) products. The main applications of CLASS(tm) are for aerospace FLIR windows and transparent armor. Crystal quality, transmission, scatter, and ballistic testing on CLASS products will be discussed.

6545-45, Session 7

Improvements in large window and optics production

B. Hallock, W. Messner, C. Hall, C. Supranowitz, QED Technologies Inc.

Fabrication of large optics has been a topic of discussion for decades. As early as the late 1980s, computer controlled equipment has been used to semi-deterministically correct the figure error of large optics over a number of process iterations. More recently, Magnetorheologic Finishing (MRF(r)) has been developed and commercialized to predictably and reliably allow the user to achieve deterministic results on a variety of optical glasses, ceramics and other common optical materials. Large optics such as primary mirrors, conformal optics and off-axis components are efficiently fabricated using this approach. More recently, specific processes, MR fluids and equipment have been developed and implemented to enhance results when finishing large aperture sapphire windows.

MRF, by virtue of its unique removal process, overcomes many of the drawbacks of a conventional polishing process. For example, lightweighted optics often exhibit a quilted pattern coincident with their pocket cell structure following conventional pad-based polishing. MRF does not induce mid-frequency errors and is capable of actually removing existing quilt patterns. Further, odd aperture shapes and part geometries which can represent significant challenge to conventional polish processing are simply and easily corrected with MRF tools. Similarly, aspheric optics which can often present multiple obstacles - particularly when lightweighted and off-axis - typically have a departure from best-fit sphere that is not well matched with static pad-based polishing tool resulting in pad misfit and associated variations in removal. The conformal sub-aperture polishing tool inherent to the QED process works as well on typical circular apertures as it does on irregular shapes such as rectangles and trapezoids for example and matches the surface perfectly at all points. Flats, spheres, aspheres and off-axis sections are easily corrected. The schedule uncertainties driven by edge roll and edge control are virtually eliminated with the MRF process.

This paper presents some recent results of the deterministic finishing typified by the QED product line and more specifically of its large-aperture machines, presently capable of finishing optics up to one meter in size. Examples of large sapphire windows and meter-class aspheric glass optics will be reviewed. Associated metrology concerns will also be discussed.

6545-46, Poster Session

Polarization discriminating optical filters based on surface relief microstructures

D. S. Hobbs, TelAztec LLC

Many defense and security applications rely on optical sensors combined with wavelength selective optical filters to identify unique features of a target, or to identify friend versus foe. Laser communications systems also depend on optical filters to remove background light and to increase the signal detection range. The addition of polarization discriminating filters would allow a significant increase in signal detection range for a laser communications system, an additional level of information encoding for security systems, and an increased ability to discriminate targets from background clutter in imaging sensors. Conventional multi-layer thin-film optical filters are not capable of polarization discrimination, are not rugged enough for typical space or military applications, and are too expensive for commercial security applications.

Surface structure resonant, or SSR, optical filters are a low cost, highly durable alternative to thin-film filters that also offer the potential for unique functionality such as multiple pass or rejection bands in a single device. SSR filters are constructed as an array of microstructures built directly in the surface of an optical component such as a window or lens. One SSR micro-texture can perform to a level that would require many hundreds of stacked material layers in a conventional thin-film filter design. Because SSR filters operate through a resonant interaction with microstructures, by fabricating non-absorbing asymmetric surface structures a highly efficient SSR filter can be realized that simultaneously discriminates both wavelength and polarization.

The design and fabrication of polarization discriminating SSR filters built into the surface of visible and infrared light transmitting materials such as fused silica and ClearTran, will be discussed. Optical performance data for prototype structures will be presented together with a discussion of target applications such as polarizing color filters for displays, near-infrared security tags and communications, and linear variable filters for long wave infrared hyper- and multi-spectral imaging.

6545-47, Poster Session

Particle impact/erosion phenomena and materials failure for supersonic KV(S)

K. George, Jr., M. Wilson, MilSys Technologies LLC; B. E. Moylan, U.S. Army Aviation and Missile Research, Development and Engineering Ctr.

A project has been undertaken as part of a Phase II, Small Busibiess Inovative Research Program (SBIR) to evaluate material response of Si_3N_4 when impacted by rain drops or other atmospheric particulate. Central to this project is the development of finite element model using LS-DYNA to simulate the impact event. Although this approach has been used to a certain degree of success in the past, the current project aims to attain a higher degree of fidelity by considering material discontinuities or fractures within the matrix. Also, the evolution of damage through repeated, random impacts will be studied and quantified, perhaps by using a mechanistically-based probabilistic model. The finite element model will be evaluated through the execution of an empirical impact test program conducted at the Marshal Space Flight Center. Impact specimens will be made from two grades of Si_3N_4: 147-1B and 147-31N. In addition, supporting work will be carried out to update atmospheric rain drop density information in such documents as MIL-STD 210C or its replacement MIL-HNBK-310.

6545-48, Poster Session

Reduced angle-shift infrared bandpass filter coatings

B. M. Lairson, J. Mosier, K. Gibbons, J. H. Sternbergh, M. George, Deposition Sciences, Inc.

A common problem with infrared bandpass filter coatings is the characteristic wavelength shift associated with changes in the angle of incidence. This shift limits the signal-to-noise performance available to a detection system, due to the wider passband required to accommodate the shift. In addition, for particularly wide-angle applications, divergence between s- and p-polarization exacerbates the loss of performance. We have developed a coating system which minimizes this degradation, by increasing the average refractive index available for stack design, and incorporating the ability to precisely control thicknesses of the coating materials across curved surfaces. The durability of the coating allows use in harsh environments. Examples of improvements of performance for specific wavelength bands and requirements will be discussed.

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6546-01, Session 1

Key performance requirements for military low-light television cameras

G. B. Heim, S. E. Shimer, Ball Aerospace & Technologies Corp.

Low-light-level video cameras have benefited from the incredible advances in digital technology over the past two decades. In legacy cameras, the video signal was processed using analog electronics which made real time, non-linear processing of the video signal very difficult to implement. In state-of-the-art cameras, the analog signal is digitized right from the sensor and is processed entirely in the digital domain, enabling the application of many advanced processing techniques to the video signal in real time. In fact, all aspects of modern low light television cameras are controlled via digital technology. This results in many capabilities which were simply not possible to implement using analog electronics.

In addition to video processing, large scale digital integration enables precise control of the operation of the image intensifier and image sensor in these low light level cameras, enabling large inter-scene dynamic range capability, extended intra-scene dynamic range and blooming control. Digital video processing and digital camera control are utilized to provide improved system level performance including nearly perfect pixel response uniformity, correction of intensifier blemishes, and electronic boresight. Compact digital electronics also enable comprehensive camera built-in-test capability which provides coverage for the entire camera-from photons into the sensor to the processed video signal out the connector.

Individuals involved in the procurement of present and future low-light-level cameras need to understand these advanced camera capabilities in order to write meaningful specifications for their advanced video system requirements. This paper provides an overview of these modern video system capabilities along with example specification text.

6546-02, Session 1

Signal processor for acoustic sensors on UAV platforms and ground vehicles

R. A. Wagstaff, The Univ. of Mississippi

One way to gather intelligence, conduct surveillance, or perform reconnaissance (ISR) for potential threat activities on the ground is to use acoustic sensors on rapidly moving ground and airborne vehicles, such as HMMWVs and UAV platforms. There are some significant challenges in doing that. One focus has been on the development of an acoustic sensor shroud that is specially designed to reduce the noise caused by the high-speed flow of air past the acoustic sensor. Significant improvements have been achieved to date, but additional improvements are needed. An independent, and complimentary approach will be presented. It involves an acoustic signal processor that has been developed to preserve the acoustic signals, while eliminating the component of flow noise that is not successfully filtered out by the shroud. The flow noise that remains is eliminated by the combined exploitation of two independent Fluctuation-Based Processor (FBP) temporal coherence parameters. One parameter is related to the spectral phase, and the other parameter is related to the spectral amplitude. This FBP recognizes the incoherence of flow noise measured by both coherence parameters, and uses their incoherence to eliminate the noise. Simultaneously, the processor also recognizes the temporal coherence of signals and uses it to preserve them. The manner in which these two parameters preserve the signals and eliminate the flow noise will be described. Results will be presented to illustrate this FBP's performance with measured acoustic data from an airborne vehicle with an air speed of 50 knots.

6546-03, Session 1

High performance Sagnac interferometers for LWIR hyperspectral imaging

P. G. Lucey, K. A. Horton, T. J. Williams, Univ. of Hawaii at Manoa

Imaging interferometry in the infrared has several potential advantages for hyperspectral imaging in airborne reconnaissance. Infrared hyperspectral offers day/night capability and interferometers offer the potential for very low power systems. The multiplex advantage enables high sensitivity when using uncooled detector arrays and the large throughput enables the use of uncooled optics when using using cryogenic detectors. These characteristics translate into low power and rapid response. We will present measurements and model results using Sagnac interferometers to illustrate the potential of this technology for airborne reconnaissance.

6546-04, Session 1

A rugged 65-gram IR dual FOV MAV payload

J. Wisted, J. Leighton, Fluke Electronics

This paper will present an ultra-light weight, 65 gram, dual-image infrared camera. The camera has been optimized for use in small micro-air vehicles, as well as other weight-sensitive applications. There are three key features of the system. First, it has no moving parts, as the calibration shutter has been removed. The technological hurdle of removing the shutter from conventional un-cooled VOx imagers was overcome by innovative software correction techniques. This shutter-less operation renders the camera significantly more rugged and allows its use in environments that were previously intolerant of such systems. Second, the assembly contains a one-piece rigid-flex board design. This adds significantly to ruggedness and assembly simplicity. Finally, the two lens/sensor assemblies incorporate sturdy, yet extremely light housings. The design considerations for such a system will be described and the resulting performance trade-offs will be detailed. The high-quality imaging of this camera system will be demonstrated and described in association with the technical design considerations. Ongoing considerations for small form-factor cameras will be described where the significance is relevant.

6546-05, Session 2

GlobalScanner: a very high resolution miniaturized EO reconnaissance airborne system

H. J. Guiot, G. Kryze, B. Achddou, COSE (France)

Cose GlobalScanner are very high resolution miniaturized EO reconnaissance airborne systems used, by French Army since 2000, on several rotorcrafts, in pod and internal integration, to acquire, record, process and transmit trough RT digital data-link georeferenced imagery. More recently, the new GlobalScanner, using a modular approach that offers many configurations, was integrated on fixed wing aircrafts to comply with various missions. The system includes now a mission planning environment, a very near real time interface with satellite data link that can be used on board or on ground to export images file in NSIF, Stanag 4545 and Geotiff, orthorectified or in raw mode formats. It includes its own IMU and a 3 axis stabilization system (under 10µrad HF stability) and can be fitted with several focal lenses offering various effective ground resolution between 0.1 to 0.6m at altitudes from 1500 to 20000ft. His small size and weight (minimal configuration around 25kg) and his complete autonomy (don't need any information from aircraft) offer the capability to achieve discreet integration on UAV and even on small aircrafts and rotorcrafts. It can be used in many fields including tactical and strategical military application, homeland security, environmental, disaster monitoring, and many other applications that require complete high resolution coverage of large areas without any gap. Approximatively 350 square Km per flight hour \@ 17cm GSD can be covered. The paper summarizes performances, internal architecture, integration and capabilities. Sample missions will be presented including imagery at various altitudes, light and weather conditions.

6546-07, Session 2

The longer, not always the better

S. Larroque, Thales Optronique (France)

Today, as a alternate operational choice replacing the satellite IMINT, many Forces worldwide expressed the need to acquire a Strategic LOROP capability, able the collect day and night imagery at long or very long stand-off ranges. If the natural trend coming for “optics” engineers from the wet film technology is to enlarge the focal length in order to achieve the better spatial resolution [GSD, Ground Sampling Distance], within airborne constraints, the laws of physics are unfortunately limited by the restrictions of oblique atmosphere transmission, by the quality of the window buffing but also by the ability to achieve a nearly perfect stabilization performance when the sensor is integrated on board the collecting platform.

Now, the maturity of digital imagery techniques and processing has led to optimize the full imagery chain and the sensor optics architecture in order to guarantee an acceptable and useful operational image resolution performance more oriented towards a larger operational DRI capability [Detect, Recognize, Identify] within many overseas operations under various climatic conditions.

In particular, step and stare imagery collection allows today some image accumulation capability through a high rate of imaging on the same scene ; and thus is able to enhance to S/N [Signal to Noise] ratio, even when the number of photons crossing the field between the target and the detector remains very poor. On the same line, this technique associated with a high image rating technology is also able to image large areas while permitting a high V/H [Velocity/ Height] ratio giving again a larger and more flexible operational Recce capability with regards to the tactical situation on the battlefield.

6546-18, Session 2

DB-110 reconnaissance: the 3rd generation system: an update

M. A. Iyengar, D. A. Lange, Goodrich Corp.; G. R. Dyer, Goodrich (United Kingdom)

The latest development of the Goodrich DB-110 system provides users with a high performance Airborne Reconnaissance capability that incorporates a dual-band day and night time imaging and real time recording and data transmission capability to support long, medium, and short range standoff and over-flight mission scenarios with a single system. Goodrich has developed their 3rd Generation Airborne Reconnaissance Pod for compatibility with operation on a range of aircraft types and their 3rd Generation Ground System to provide flexible scaling to meet user requirements. This system upgrades the existing, operationally proven, DB-110 design with enhancements in sensor resolution, flight envelope and other performance improvements. Goodrich recently flight tested their 3rd Generation Reconnaissance System on a Polish Air Force F-16 aircraft with excellent results. This paper presents key highlights of the system and presents results from this successful flight test.

6546-08, Session 3

Perceived interpretability of motion imagery: implications for scale development

J. M. Irvine, G. O’Brien, S. A. Israel, D. M. Cannon, Science Applications International Corp.; C. P. Fenimore, J. W. Roberts, National Institute of Standards and Technology; J. Bartolucci, The Boeing Co.

The motion imagery community would benefit from the availability of standard measures for assessing image interpretability. The National Imagery Interpretability Rating Scale (NIIRS) has served as a community standard for still imagery, but no comparable scale exists for motion imagery. Previous studies have explored the factors affecting the perceived interpretability of motion imagery and the ability to perform various image exploitation tasks. More recently, a study demonstrated an approach for adapting the standard NIIRS development methodology to motion imagery. This paper presents the first step in implementing this methodology, namely the construction of the perceived interpretability continuum for motion imagery. We conducted an evaluation in which imagery analysts rated the interpretability of a large number of motion imagery clips. Analysis of these ratings indicates that analysts rate the imagery consistently, perceived interpretability is unidimensional, and that interpretability varies linearly with log(GSD). This paper presents the design of the evaluation, the analysis and findings, and implications for scale development.

6546-09, Session 3

Metrics to estimate image quality in compressed video sequences

G. O’Brien, J. M. Irvine, D. M. Cannon, Science Applications International Corp.; J. Bartolucci, The Boeing Co.; C. P. Fenimore, J. W. Roberts, National Institute of Standards and Technology; J. R. Miller, S. A. Israel, Science Applications International Corp.

A fundamental problem in image processing is to find objective metrics that agree with human perception of image quality. In this study, several metrics were examined to rate compression algorithms in terms of perceived loss in image quality. In addition, we sought to describe the relationship of image quality as a function of bitrate. The compression schemes used were JPEG2000, MPEG2, and H.264. The frame size was fixed at 853x480 and the encoding varied from 6000Kps to 200Kps. The metrics examined were PSNR, SSIM an edge localization metric and a blur metric. To varying degrees the metrics displayed ‘desirable’ properties, namely they were monotonic in the bit rate, the GOP structure could be inferred, and they tended to coalesce with human perception of quality degradations. Additional work is being conducted to quantify the sensitivity of these measures with respect to our Motion Imagery Quality Scale.

6546-10, Session 3

User-oriented evaluation of compression for motion imagery

J. M. Irvine, G. O’Brien, S. A. Israel, Science Applications International Corp.; C. P. Fenimore, J. W. Roberts, National Institute of Standards and Technology; J. Bartolucci, The Boeing Co.; D. M. Cannon, Science Applications International Corp.

Motion imagery will play a critical role in future intelligence and military missions. The ability to provide a real time, dynamic view and persistent surveillance makes motion imagery a valuable source of information. The ability to collect, process, transmit, and exploit this rich source of information depends on the sensor capabilities, the available communications channels, and the availability of suitable exploitation tools. While sensor technology has progressed dramatically and various exploitation tools exist or are under development, the bandwidth required for transmitting motion imagery data remains a significant challenge. This paper presents a user-oriented evaluation of several methods for compression of motion imagery. We explore various codecs and bitrates for both inter- and intra-frame encoding. The analysis quantifies the effects of compression in terms of the interpretability of motion imagery, i.e., the ability of imagery analysts to perform common image exploitation tasks. The findings have implications for sensor system design, systems architecture, and mission planning.

6546-11, Session 3

Perceptual evaluation of frame rate effects on the interpretability of motion imagery II

C. P. Fenimore, National Institute of Standards and Technology; J. M. Irvine, D. M. Cannon, Science Applications International Corp.; J.

W. Roberts, A. I. Aviles, National Institute of Standards and Technology; J. R. Miller, L. Simon, S. A. Israel, Science Applications International Corp.; J. Bartolucci, The Boeing Co. and Science Applications International Corp.

The development of a motion imagery (MI) quality scale, akin to the National Image Interpretibility Rating Scale (NIIRS) for still imagery, would have great value to future intelligence and military users of surveillance and other MI systems. In a multi-phase study, we have adopted a perceptual approach to identifying the main attributes that affect motion imagery interpretibility. The exploitation of the rich information content of motion imagery data depends, in part, on the characteristics of the communication channels, where the bandwidth required for transmission is a very significant, continuing challenge. One approach to this challenge is to lower the frame rate. This paper presents a perceptual evaluation of the effects of decreasing frame rate on the interpretibility of motion imagery. We consider motion imagery at frame rates from 30.0 Frames/s (Fps) to 1.0 Fps as well as still imagery. The study includes both synthetic and live-action imagery. Imagery analysts were tasked to perform simple detection and identification tasks. As frame varies, interpretibility depends on the task; we find that successful identification decreases monotonically with frame rate, but that detection is enhanced as frame rate decreases to about 10 Fps. The findings have implications for sensor system design, systems architecture, and mission planning.

6546-13, Session 4

An OEF/OIF study of close combat missions using small unmanned aircraft systems

G. Lifschitz, R. J. Tierney, J. Vitalie, U.S. Army Test and Evaluation Command

The Small Unmanned Aircraft System (SUAS) is a rucksack portable aerial observation vehicle designed to supplement reconnaissance, surveillance and target acquisition tasks of an infantry company. The Raven is an earlier version of the SUAS and has been used for the past two years by Special Operations Forces (SOF) and selected Army units in Operations Enduring Freedom and Iraqi Freedom (OEF/OIF). Army Test and Evaluation Command-led surveys were used to assess the capabilities and limitations of the Raven in OEF/OIF. Results and analyses of the surveys indicate that Raven enhances situational awareness of a small unit in urban areas and in selected close combat missions. Users of the Raven state it is easy to use, although there are major issues with frequency de-confliction, airspace management, short endurance, and sensor performance. The SUAS completed developmental and operational testing in preparation for full rate production. This paper addresses the SUAS effectiveness, suitability, and survivability evaluation strategy based on actual testing of the system. The SUAS was found to be useful in certain infantry company close combat missions where terrain and visual line of sight give the system an advantage over traditional reconnaissance patrols. Army aviation and infantry units uncover new ways every day to use this portable "eye in the sky", especially when unmanned aerial reconnaissance assets are in premium demand. A discussion is included on changes in doctrine with the SUAS, its integration into future combat systems and its likely benefits to the Soldier.

6546-14, Session 4

Field test of an air-to-ground communication link using a bare optical fiber

J. C. Juarez, A. Dwivedi, R. M. Sova, J. E. Sluz, D. W. Young, Johns Hopkins Applied Physics Lab.

The need of for capacity in military networks will continue to grow due to the emerging demand of bandwidth intensive applications such as airborne imagery, surveillance, and communications. Current military RF capabilities provide 100's Mbps per link, but are reaching a limit with respect to spectrum and bandwidth efficiency. Fiber optic communications are an appealing alternative because their information carrying capacity easily surpasses other current technologies. Additionally, the optical fiber is immune to the environment and is resistant to exploitation and jamming. However, fiber-optic communications are usually limited to static, pre-deployed cable systems. Enabling fiber applications in dynamically deployed or ad-hoc conditions will open up a large number of communication possibilities in terrestrial, aerial, and oceanic environments. Applications on platforms like Unmanned Aerial Vehicles (UAV), balloons, and aerostats or airships are of particular relevance.

A field demonstration of an air-to-ground communication link using a self-sustainable optical fiber will be described. The test was conducted by JHU/APL at the TCOM, L.P. Test Facility in Elizabeth City, NC in May 2006 using a 38 m, tethered aerostat raised to an altitude of 2000 ft. A bare, single mode fiber attached between the aerostat and its mooring station was evaluated as an optical link for several hours. Multiplexed channels operating in the 1550 nm band at 1 and 10 Gbps were tested and used to achieve error free data transfers. A cw channel was also multiplexed for performance monitoring. BER vs. link power tests will be described. Eye diagrams and video quality of service data will also be presented.

6546-15, Session 5

Unlimited-size mosaicking of airborne image data

N. Jiang, C. Li, Arizona State Univ.; G. P. Abousleman, General Dynamics C4 Systems; J. Si, Arizona State Univ.

This paper presents a system that creates and navigates an unlimited-size mosaic with geographical information. The input is a sequence of airborne images with or without telemetry data, and the output is a mosaic with a combined geographical coordinate layer inherited from the input images. Rather than registering input images with an orthoimage, which is popular in existing applications, the proposed system does not depend on prior information. The airborne images embedded with geo-information are pair-wise registered, based on image feature correspondence. We extract feature points and form an EDGE-based descriptor for image registration. Subsequently, the geographical coordinate layers derived from the telemetry data stream are fused using a registration matrix computed from the previous step. However, due to the unreliability of the telemetry data, the new geodetic coordinate layer might be inconsistent with the image coordinate layer and therefore requires rectification to minimize the squared error between the mosaic coordinate layer and the warped geographical coordinate layer. The above process is incorporated into a cluster framework so that the output mosaic is extensible to an infinite size. That is, once the current mosaic has expanded beyond computer memory limitations, the image is saved to a database. Its spatial relationship with respect to the world coordinate system is also saved to the database so that the system can navigate the collection of image mosaic data by querying the spatial database and retrieving the relevant mosaics. This method is especially suitable for video sequences spanning large regions, such as surveillance video from a UAV. Results with real-world UAV video are provided to demonstrate the performance of the proposed system.

6546-16, Session 5

Reconfigurable device for enhancement of long-range imagery

F. E. Ortiz, E. J. Kelmelis, P. F. Curt, EM Photonics, Inc.

Atmospheric effects greatly degrade the quality of images collected by land, sea, and sky-based platforms when imaging over great distances. Random atmospheric turbulence blurs imagery in a non-uniform and variable fashion. Assuming ideal observation conditions, the minimum feature size that can be resolved using a given optical system is bounded by the diffraction limit (1.22 * wavelength/ D), which dictates that larger apertures enable finer features to be distinguished. However, in large-aperture systems, turbulence and air movement become the limiting factors long before the diffraction effects appear. Recovering data lost due to this effect requires computationally intense image processing algorithms. One such algorithm is the Bispectrum Speckle Imaging Method. This method allows for recovery of data near the diffraction limit of the imaging system without prior knowledge of atmospheric conditions. Unfortunately, it is far too computationally

intense for a software version to run in real time and thus is currently only suitable for post-processing. In this paper, we present our latest work in mapping this algorithm into a reconfigurable hardware platform. This device will allow for the real time processing of high-definition video signals, many orders of magnitude faster than is possible from the software implementation.

6546-17, Session 5

On a nascent latency-information theory

E. H. Feria, College of Staten Island/CUNY

The central theme of Shannon's mathematical theory of communication is information. Information is defined as the essential part of the memory-space used to represent the output of a signal source. Computation-time is the time dual of memory-space. In turn, latency is the central theme of a novel mathematical theory of recognition which is the computation-time dual of Shannon's theory. Latency is defined as the minimum amount of computation-time associated with the scalar output of a signal processor after the signal processor is redesigned subject to implementation components and architectural constraints. Processor coding was developed earlier as the computation-time dual of source coding. In this paper the computation-time memory-space duality development continues when it is noted that the computation-time dual of channel coding is sensor coding. While channel coding deals with the space displacement of memory-space in a noisy channel environment, it is shown here that sensor coding deals with the time displacement of computation-time in a time-limited sensor environment. In addition, it is found that the cascade of a sensor coder with a processor coder is an intelligent system. The developed ideas are illustrated with a real-world knowledged-aided radar application.

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6547-01, Session 1

Wideband SAR processing with segmented chirps for phased-array radars

A. W. Doerry, Sandia National Labs.

Fine resolution SAR requires wideband signals to be transmitted and received. Electronically steered phased-array antennas have difficulty steering wideband signals without the use of expensive and cumbersome true time delay elements. More desirable phase shifters are by themselves inadequate to the task.

Wideband radar signals can be generated from series or groups of narrow-band signals centered at different frequencies. A wideband Linear FM (LFM) chirp can be assembled from lesser-bandwidth chirp segments. The chirp segments can be transmitted as separate pulses, each with their own steering phase operation. Each chirp segment's bandwidth would essentially be narrow-band by itself. Doing so allows each pulse to be steered by phase shifters alone. This overcomes the problematic dilemma of steering wideband chirps with phase shifters alone. True time-delay elements are not required.

The Phase History data can then be processed in a manner to reconstruct the image by combining all pulses with all chirp segments. In this manner the image will exhibit resolution consistent with the entire resolution bandwidth, which can be much larger than any individual segment's chirp bandwidth.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

6547-02, Session 1

Anisotropic diffusion techniques on synthetic aperture radar data

J. D. Allen, E. Ganthier, Harris Corp.; G. B. Tenali, Florida Institute of Technology

Speckle in SAR imagery is a by-product of constructive and destructive interference between scatterers within a resolution cell. This speckle phenomenon gives SAR imagery a "noise-like" appearance and is often exploited in near angle and/or coherent stereo pairs. However, in many cases, this speckle is unwanted and can be considered noise or interference. We use partial differential equation (PDE) methods for speckle mitigation for detected imagery and the collected complex image data. In particular, we study the effect of non-linear anisotropic diffusion filters on collected SAR image data. In the past, anisotropic diffusion (AD) techniques have been successfully used in the analysis of EO data. However, the use of these techniques on SAR image data is recent and much is yet to be done. We expect the application of AD techniques on SAR image data in combination with a fluid dynamic perspective to yield rich dividends in terms of image interpretability. Through our approach we demonstrate that it is possible to spatially maintain areas of high dynamic range (bright scatterers) and smooth areas of low dynamic range in the scene. We also exhibit the role of these non-linear filters in correlation, registration, compression, decompression, and image interpretability for SAR analysts.

6547-03, Session 1

Results from an x-band synthetic aperture radar collection in Antarctica

D. L. Bickel, G. Sander, Sandia National Labs.; W. Hallman, The National Guard Bureau; J. Bradley, Sandia National Labs.; M. Armstrong, New York Air National Guard

In January, 2006, the New York Air National Guard requested that Sandia National Laboratories develop an X-band synthetic aperture radar to use for an experiment to detect crevasses in Antarctica. Sandia provided a MiniSAR radar that was modified to operate at X-band. Data was collected with this system in the Antarctic summer of 2006. The results from this data collection are presented in this paper.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

6547-04, Session 1

Bistatic VHF and UHF SAR for urban environments

J. R. Rasmusson, G. Stenstrom, B. Larsson, A. Gustavsson, L. M. H. Ulander, Swedish Defence Research Agency (Sweden)

In this paper will be outlined recent bistatic modifications of CARABAS and LORA, two airborne monostatic SAR platforms operating at the VHF (20-90 MHz) and UHF (200-800 MHz) bands to enable syncronized bistatic SAR measurements with the receiver and transmitter physically separated. Bistatic results and SAR images from initial experiments performed in the urban environments of Linkoping during 2006 with an airborne transmitter and a stationary receiver at the VHF-band will be presented and compared to corresponding monostatic results.

6547-05, Session 1

Two joint time-frequency transforms for velocity separation of moving target synthetic aperture radar data

M. A. Ferrara, D. G. Arnold, Air Force Research Lab.; M. Cheney, Rensselaer Polytechnic Institute

This paper describes work that considered two Joint Time-Frequency Transforms (JTFTs) for use in a SAR-based (single sensor/platform Synthetic Aperture Radar) 3D imaging approach. The role of the JTFT is to distinguish moving point scatterers that may become collocated during the observation interval. A Frequency Domain Velocity Filter Bank (FDVFB) was compared against the well-known Short Time Fourier Transform (STFT) in terms of their maximal-simultaneous Time-Frequency energy concentrations. The FDVFB and STFT energy concentrations were compared for a variety of radar scenarios. In all cases the STFT achieved slightly higher energy concentrations while simultaneously requiring half the computations needed by the FDVFB.

6547-06, Session 2

Detection and tracking of humans and vehicle targets using high definition television signals in urban areas

E. F. Greneker III, Georgia Tech Research Institute

The detection and tracking of humans and vehicles using radar systems operating at microwave frequencies was first achieved almost 40 years ago. Personnel detection radars have been used on the battlefield for almost as many years. Each generation of these radars has improved their overall detection and target recognition capability. To date, almost all of these radars have incorporated a co-located (monostatic) transmitter and receiver. Two decades ago the bi-static human and vehicular detection radar was introduced and used for security at nuclear weapons manufacturing facilities, military bases and other high value targets. In these applications the bi-static radar "fence" uses a transmitter and receiver that are a matched pair transmitter and receiver and located at each end of a bistatic baseline. An intruder breaks the microwave beam and is detected.

This paper describes "quick-look" experiments that have been conducted in the Atlanta, Georgia area to detect humans and vehicles using very long baseline bi-static radar techniques. More accurately described, the system to be described is a passive radar requiring no coordination between the receiver and transmitter. The illumination source (transmitter) is a High Definition Television (HDTV) broadcast transmitter located approximately 19 miles from the test area. The transmitter is broadcasting the broadband digital signal and also a pilot carrier on a frequency of 548.310 MHz. It is the continious wave (CW) pilot carrier that is used for the experiments to be described. The system utilizes a commercial off-the-shelf (COTS) communications receiver. A set of multi-element back to back Yagi antennas are used to provide a reference signal and the signal from the area where the human subject is located. The walking human generates micro-Doppler that can be detected using micro-Doppler signal processing techniques. Vehicular targets can be detected without special processing due to a vehicle's larger radar cross section and higher Doppler shift (higher velocity). The technical challenges that have been addressed include receiver stability, common signal cancellation, and multi-path situations and geometries. The technique has also been tested inside of a building and it has been found that humans can be detected through walls and down long halls.

6547-07, Session 2

Estimation of electromagnetic parameters and thickness of a wall using synthetic aperture radar

H. C. Khatri, C. Le, Army Research Lab.

One of the challenges of using synthetic aperture radar (SAR) to detect and classify an object behind a wall consists of determining the amount of signal attenuation introduced by the signal's propagation through the wall. This attenuation is difficult to determine because the electromagnetic properties of the wall, along with its thickness are normally not known a priori. We describe a procedure for determining the necessary parameters given that the SAR has high enough resolution such that the front and the rear surfaces of a uniform wall or cinder block wall can be determined from the SAR image. In addition, we provide a procedure for estimating the signal level behind the wall, or equivalently the attenuation due to the wall from measured returns from its front and rear surfaces. We demonstrate the effectiveness of this procedure using data generated by XPATCH simulations.

6547-08, Session 2

Performance of autofocusing schemes for single target and populated scenes behind unknown walls

F. Ahmad, M. G. Amin, Villanova Univ.

The quality and reliability of through-the-wall radar imagery is governed, among other things, by the knowledge of the wall characteristics. Ambiguity in wall characteristics has a two-fold effect. It smears and blurs the image, and also shifts the imaged target positions. Higher order standardized moments have been shown to be good measures of the degree of smearing and blurriness of through-the-wall images. These moments can be used to tune the wall variables to achieve autofocusing. It is noted that the solution to the autofocusing problem is not unique and there exist several assumed wall characteristics, in addition to the exact, that lead to similar focused images. In this paper, we analyze the dependency of the tuned wall parameters on the target distribution in the presence of single uniform walls. We consider single and multiple target cases with different scene complexity and population. The paper deals with both point and extended targets. Supporting simulation results are also provided.

6547-09, Session 2

Adaptive see-through-the-wall imaging: the IRIS algorithm

J. A. Marble, Univ. of Michigan; H. Bagci, Univ. of Illinois/Urbana-Champaign; A. O. Hero III, E. Michielssen, Univ. of Michigan

The Iterative Redeployment of Illumination and Sensing (IRIS) algorithm is an adaptive imaging scheme that deploys imaging resources according to the content of the scene being imaged. In this work the IRIS algorithm is applied to the area of See-Through-The-Wall radar image reconstruction. The algorithm works iteratively in four steps: (i) It observes the scene at an initial location and creates a scattering model of the environment. (ii) It generates a confidence map to determine poorly-measured areas of the scene based on the scattering model. (iii) It places virtual transmitters at locations of uncertainty in the scene and utilizes an electromagnetic field solver to compute the electric fields exiting the building. (iv) It uses an information gain criteria to determine the next location for the imaging array outside the building. Previous versions of the IRIS used a simple geometrical-optics based electromagnetic solver. In this work, a more sophisticated Method of Moments (MoM)-based field solver is utilized. This solver is capable of simulating two dimensional (2D) scattering problems involving (lossy) dielectric scatterers. In order to allow for analysis of electrically large scatterers, the solver is accelerated by using a 2D Adaptive Integral Method (AIM). The acceleration is achieved by exploiting the spatial invariance of the Green's function through the use of an auxiliary uniform grid that encloses the scatterer. The computational complexity of the AIM-accelerated solver scales as O(Nclog(Nc)) as opposed to classical MoM-based solver's computational complexity, O(Nv^2) Here, Nc and Nc~Nv are the numbers of cells discretizing the scatterer and the nodes of uniform grid, respectively. Further acceleration is achieved by parallelization, which reduces the computational cost to O(Nclog(Nc)/p) per processor, where p is the number of processors. The final product of this four-step iterative scheme is an image of the scene that has been constructed from a few carefully placed imaging arrays.

6547-10, Session 2

Micro-Doppler analysis of multiple frequency continuous wave radar signatures

M. G. Anderson, R. L. Rogers, The Univ. of Texas at Austin

Micro-Doppler refers to Doppler scattering returns produced by non rigid-body motion. Micro-Doppler gives rise to many detailed radar image features in addition to those associated with bulk target motion. Targets of different classes (for example, humans, animals, and vehicles) produce micro-Doppler images that are often distinguishable even by untrained observers. Micro-Doppler features have excellent potential for use in automatic target recognition algorithms. Although the potential benefit of using micro-Doppler in classification algorithms is high, relatively little experimental (non-synthetic) micro-Doppler data exists. Much of the existing experimental data comes from highly cooperative targets (human or vehicle targets directly approaching the radar). This research involved field data collection and analysis of micro-Doppler radar signatures from non-cooperative targets. The data was collected using a low cost X-band multiple frequency continuous wave (MFCW) radar with three transmit frequencies. The collected MFCW radar signatures contain data from humans, vehicles, and animals. The presented data will include micro-Doppler signatures previously unavailable in the literature such as crawling humans and various animal species. The animal micro-Doppler signatures will include deer, dog, and goat datasets. This research focuses on the analysis of micro-Doppler from non-cooperative targets approaching the radar at various angles, maneuvers, and postures. The micro-Doppler content of the MFCW radar signatures will be analyzed in the joint time-frequency domain.

6547-11, Session 2

Sparse array of RF sensors for sensing through the wall

R. Innocenti, Army Research Lab.

In support of the U.S. Army need for intelligence on the configuration, content, and human presence inside enclosed areas (buildings), the Army Research Laboratory is currently engaged in an effort to evaluate RF sensors for the "Sensing Through The Wall" initiative (STTW).Detection and location of the presence of enemy combatants in urban settings poses significant technical and operational challenges. This paper shows the potential of hand held RF sensors, with the possible assistance of additional sources like Unattended Aerial Vehicles (UAV), Unattended Ground Sensors (UGS), etc, to fulfill this role. In this study we examine both monostatic and multistatic combination of sensors, especially in configurations that allow the capture of images from different angles, and we demonstrate their capability to provide comprehensive information on a variety of buildings. Finally, we explore the limitations of this type of sensor arrangement vis-à-vis the required precision in the knowledge of the

position and timing of the RF sensors. Simulation results are provided to show the potential of this type of sensor arrangement in such a difficult environment.

6547-12, Session 2

Microwave and millimeter-wave Doppler radar heart sensing

O. Boric-Lubecke, A. Host-Madsen, V. M. Lubecke, Univ. of Hawaii at Manoa and SensCorp, Inc.; J. Lin, Univ. of Florida; T. Sizer, Bell Labs.

Technology that can be used to unobtrusively detect and monitor the presence of human subjects from a distance and through barriers can be a powerful tool for meeting new security challenges, including asymmetric battlefield threats abroad and defense infrastructure needs back home. Our team, a collaboration between researchers at the University of Hawaii (UH), the University of Florida (UF), and Bell Labs, Lucent Technologies is developing mobile remote sensing technology for battle-space awareness and warfighter protection, based on microwave and millimeter-wave Doppler radar motion sensing devices that detect human presence. This technology will help overcome a shortfall of current see-through-the-wall (STTW) systems, which is, the poor detection of stationary personnel. By detecting the minute Doppler shifts induced by a subject's cardiopulmonary related chest motion, the technology will allow users to detect personnel that are completely stationary more effectively. This personnel detection technique can also have an extremely low probability of intercept since the signals used can be those from everyday communications. The software and hardware developments and challenges for personnel detection and count at a distance will be discussed, including a 2.4 GHz quadrature radar single-chip silicon CMOS implementation, a low-power double side-band Ka-band transmission radar, and phase demodulation and heart rate extraction algorithms. In addition, the application of multiple input multiple output (MIMO) techniques for determining the number of subjects will be discussed.

6547-13, Session 3

Generating precision nonlinear FM chirp waveforms

A. W. Doerry, Sandia National Labs.

It is well-known that Non-Linear FM (NLFM) chirp modulation can advantageously shape the transmitted signal's Power Spectral Density such that the autocorrelation function (i.e. matched filter output) exhibits substantially reduced sidelobes from its Linear FM (LFM) counterpart. Consequently, no additional filtering is required and maximum Signal-to-Noise Ratio (SNR) performance is preserved. This yields a 1-2 dB advantage in SNR over the output of a LFM waveform with equivalent sidelobe filtering. However precision NLFM chirps are more difficult to design, produce, and process.

This paper presents design and implementation techniques for Nonlinear FM waveforms.

A simple iterative design procedure is presented that yields a NLFM phase/frequency function with the desired inherent sidelobe response.

We propose to then generate the NLFM waveform by using a cascaded integrator/accumulator structure. Several specific architectures are examined to meet target performance criteria, including bandwidth constraints and sidelobe reduction goals.

We first examine a fixed parameter set to generate a fixed polynomial phase function. Polynomial coefficients are selected to be constant during the pulse.

Alternatively, a NLFM waveform can be generated via integrating a stepped parameter set, whereby parameters are constant over specific intervals, with the pulse width encompassing multiple intervals. The parameter changes in steps during the course of the pulse as a function of time.

Alternatively, the parameter steps can be made a function of the pulse's instantaneous frequency.

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6547-14, Session 3

Vehicle-mounted UWB radar for improvised explosive device detection

O. Kegege, C. Ibarra, J. Li, H. Foltz, The Univ. of Texas-Pan American

IEDs pose a great danger to the troops. A detection system is required to help in warning and preventing injury from these devices. Contrasting to systems that base their detection on the identification of the IED initiation mechanisms or IED explosives, we set out to investigate and design a system for detection of bomb shells directly. UWB radar has the advantage of both high resolution and good penetration. Our immediate objective is to assess the capability of UWB radar as additional detection mode. The ultimate goal is to develop a vehicle-mounted UWB radar system for identification of buried targets including roadside IEDs. Such a system shall be able to detect the target at a safe range on the move, to provide visual feedback/warning to the vehicle operator of a potential target, and to assist in go-no-go decisions. We have done simulations and various measurements to understand the unique scattering characteristics of IED models. Specifically, we have: (i) experimented the capabilities of UWB antennas and signaling (ii) investigated the effects of target orientation, wave polarization, frequency, and operating distance on target visibility, (iii) studied wave underground propagation at different frequencies, (iv) tested a VNA-based radar system on a moving cart from both indoor and outdoor settings and collected data with artillery shells on ground surface, recessed, buried, and at various ranges. We then focus on the technical challenges of the IED detection, clutter/non-target discrimination, and target information extraction problems, and discussed possible solutions, including (i) polarization synthesis/diversity for improved clutter/non-target discrimination, (ii) lowered frequency for better penetration, (iii) array/scanning antennas for target locating and increased cross-range resolution, (iv) fast data acquisition and real-time DSP implementation.

6547-15, Session 3

SAR image formation using phase-history data from non-uniform aperture

L. H. Nguyen, J. P. Sichina, Army Research Lab.

Synthetic aperture radar (SAR) imagery is formed using radar data collected from a moving platform (aircraft, vehicle, human, etc.). The radar transmits and receives backscatter signals in down-range direction at a fixed pulse repetition interval (PRI) while the platform moves along cross-range direction to generate a synthetic aperture. In the ideal situation, the platform moves at a constant speed and as a result, the radar will collect the phase-history data that are uniformly sampled along the aperture. However, in many situations the radar platform cannot be kept at a constant speed, e.g. a helicopter maneuvers over an imaging area for surveillance. The problem is even worse in the case of urban warfare with human-borne radar. A soldier moves at his own speed and creates erratic aperture sections with phase-history data that are either sparse or dense. The collected SAR data in such situation will result in SAR imagery with severe artifacts that might prevent us from detecting targets of interest.

In this paper, we will present the SAR imagery of non-uniform aperture data formed using the backprojection image formation algorithm. Although the backprojection image former is well suited with an arbitrary radar aperture, the SAR image artifacts are obvious from the non-uniform aperture. Using the non-uniform aperture phase-history data, we interpolate the data using a uniform grid along the aperture. We will show the resulting imagery with reduced artifacts. We will use both simulated data and the Army Research Lab BoomSAR data to illustrate the artifacts generated by non-uniform sampling and the improvement using this interpolation technique.

6547-16, Session 3

Localization of nodes and personnel in multi-static radar node sensor network

J. R. Yee, V. M. Lubecke, Univ. of Hawaii

As our nation is confronted with new security challenges, including asymmetric battlefield threats abroad and defense infrastructure needs back home, enhanced battle-space awareness and effective warfighter protection are essential. Expeditionary warfighters are faced with unknown enemy threats from behind barriers, for which extreme precautionary measures must be encumbered to minimize risk. We propose to use a miniature hand-held Doppler radar, as “mobile sensor,” in combination with a network of small scattered receiver “nodes” which lie in wait and report on change or motion within a targeted perimeter. Radar nodes could be deployed from a distance, for example they may be air-dropped. The first problem to be addressed in such a system is localization of radar nodes, which will further provide information on personnel location. A mobile sensor produces an interrogation signal, and analyzes locally received echoes for signs of motion activity in the targeted area. Scattered nodes in the targeted vicinity form an ad-hoc network which also receives and compares the mobile sensor signal and its target echoes, and reports sensed activity to the mobile sensor. We will describe a protocol to calculate localization estimates for radar nodes, that could be extended to localization of personnel within the perimeter of the nodes. The development of the protocol is based on an optimization model where the objective is to minimize the mean squared error of the localization estimates. The protocol solves the optimization model using distributed computation as well as specifies the information needed to be passed to neighbor sensor nodes.

6547-17, Session 3

Polarimetric, combined, short pulse scatterometer-radiometer system at 15GHz for platform and vessel application

A. K. Arakelyan, A. K. Hambaryan, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia); S. F. Clifford, Univ. of Colorado

In this paper a Ku-band (15GHz), dual polarization, combined short-pulse scatterometer-radiometer is developed for short distance remote sensing of the water surface, bare soil and snow cover, as well as for simultaneous and coincident measurements of the microwave reflective and emissive characteristics of the observed medium under laboratory-controlled conditions. The developed system is set on a mobile buggy moving at the height of 6.5m along a stationary platform 32m long. The system allows us to carry out polarimetric (vv, vh, hh, hv), simultaneous and coincident microwave active-passive measurements of the observed surface (soil, vegetation, snow and water surface) parameters at angles of incidence from 0-60o

The main technical characteristics of the radiometer-scatterometer system are: the central frequency is 15GHz, the radar pulse duration is ~25ns, pulse power is 70mW, radar sensing at vv; vh; hv; hh polarizations, scatterometer receiver’s threshold sensitivity is -130dB/W, radiometric observation at vertical and horizontal polarizations, radiometer’s sensitivity at 1s is <0.15K, radiometer receivers’ bandwidths is ~800MHz. A block diagram of the developed system, as well as time series of scatterometer and radiometer channels and control signals of some microwave and low frequency elements of the system are presented in this paper. The system simultaneously operates in active and passive modes and this allows comparisons between spatially coincident, microwave scattered and emissive characteristics of observed surface and subsurface targets.

The originality of the developed system is in the spatial-temporal combination of microwave active and passive channels of observation and its application for short distance sensing (the operational range is ~5m) under far field conditions for both radar and radiometric observations. The main problems in the development of such a device are: first, a necessity to create very short pulses (~25ns), and second, while receiving signals reflected from a short distance (~5m), the necessity to provide decoupling between the radar’s transmitter and receiver and between the simultaneously operating radar and radiometer channels of observation.

Although the system was developed for platform and vessel application, a higher power version may also be successfully employed for airborne applications for land and sea surface remote sensing.

6547-18, Session 3

C band, polarimetric, combined, short pulse scatterometer-radiometer system for platform and vessel application

A. K. Hambaryan, A. K. Arakelyan, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia)

In this paper a C-band (5.6GHz), dual polarization, combined short-pulse scatterometer-radiometer is developed, for short distance remote sensing of the water surface, bare soil and land snow cover, as well as for simultaneous and coincident measurements of the microwave reflective and emissive characteristics of the observed medium under laboratory-control conditions. The developed system is set on a mobile buggy moving on the height of 6.5m along a stationary platform 32m length. The system allows carry out polarimetric (vv, vh, hh, hv), simultaneous and coincident microwave active-passive measurements of the observed surface (soil, vegetation, snow and water surface) parameters at angles of incidence from 0-60o

The main technical characteristics of the radiometer-scatterometer system are: the central frequency is 5.6GHz, the radar pulse duration is ~25ns, pulse power is ~50mW, radar sensing at vv; vh; hv; hh polarizations, scatterometer receiver’s threshold sensitivity is -130dB/W, radiometric observation at vertical and horizontal polarizations, radiometer’s sensitivity at 1s is ~0.1K, radiometer receivers’ bandwidths is ~650MHz. A block diagram of the developed system, as well as time series of scatterometer and radiometer channels operation and control signals of some microwave and low frequency elements of the system are presented in this paper. The system simultaneously operates in active and passive modes and this allows comparisons between spatially coincidence, microwave scattered and emissive characteristics of observed surface and subsurface targets.

The originality of the developed system is in the spatial-temporal combination of microwave active and passive channels of observation and its application for short distance sensing (the operational range is ~5m), under far field conditions for both radar and radiometric observations. The main problems in the development of such a device are: first, a necessity to create very short pulses (~25ns), and second, while receiving signals reflected from a short distance (~5m), the necessity to provide decoupling between the radar’s transmitter and receiver and between the simultaneously operating radar and radiometer channels of observation.

Although the system was developed for platform and vessel application, a higher power version may also be successfully employed for airborne applications for land and sea surface remote sensing.

6547-19, Session 4

Multipath data analysis and exploitation for the design of distributed radar systems

A. K. Mitra, P. Robinson, J. P. LaRue, A. Vega-Irizarry, J. Glett, Air Force Research Lab.

A description of the design parameters for a scaled RF environment is presented. This scaled RF environment was developed for purposes of simulating and investigating multipath phenomena in urban environments. A number of experiments were conducted with this scaled urban environment including a series of tests with eight spatially distributed receivers and one transmitter. Details with regard to the instrumentation system along with the measurement philosophy are provided. The primary focus of this paper is a detailed treatment of data analysis and exploitation techniques for the multipath data generated by this scaled RF environment. A portion of the material on multipath data analysis and exploitation is focused on developing techniques for identifying a optimum placement of receiver pairs for purposes of maximizing information content on a embedded target. In other words, data from the eight distributed receiver locations are analyzed and

techniques are presented that allow for the selection of receiver pairs that provide the most information on targets that are embedded within the multipath environment. The last section of the paper discusses visualization and pseudo-imaging techniques for targets embedded in multipath environments.

6547-20, Session 4

Performance analysis of dual-frequency CW radars for motion detection and ranging in urban sensing applications

F. Ahmad, M. G. Amin, Villanova Univ.; P. D. Zemany, BAE Systems

Single frequency (Doppler) radars cannot be used in range estimation due to their range ambiguities. An additional frequency can be used to increase the maximum unambiguous range to accepted values for indoor range estimation of moving targets. The dual-frequency technique uses phase comparison of the transmitted and received CW signals to provide an estimate of the target range. It offers the benefit of reduced complexity, fast computation time, and real time target tracking. However, the dual-frequency approach for range estimation can be compromised due to the presence of frequency drift, noise, and multipath. In the paper, we provide statistical analysis of the effect of noise and frequency separation on the bias and variance of the range estimate. We consider targets with both linear and simple harmonic motions. Computer simulation are provided for illustrating the performance as a function of SNR and bandwidth.

6547-21, Session 4

Indication of slowly-moving targets via change detection

K. I. Ranney, A. Martone, Army Research Lab.; M. Soumekh, Univ. at Buffalo

Radar systems have long been recognized as an effective tool for detecting moving targets-a problem commonly referred to as moving target indication (MTI). Recent advances, including Space Time Adaptive Processing (STAP), allow for even more precise determination of a target's location relative to the radar. Still, most of these methods approach MTI from the point of view of parameter estimation, and this sort of an approach can become problematic when the target speed is low and its associated Doppler frequency is near zero. In such cases the target signature is masked by the stationary, background clutter. Another potential drawback to STAP techniques arises from the fact that they require a relatively large number of receive channels, adding additional complexity to the radar system hardware.

In this paper we present a moving-target-indication (MTI) technique that is based on a change detection paradigm. That is, rather than estimating the Doppler frequency associated with a target's motion, we propose to detect subtle differences between simultaneously collected, complex SAR images. We use simulated data to illustrate the feasibility of the approach under several different operating scenarios.

6547-22, Session 4

Prediction and detection of multiple-scattering events from 3D GTD-based parametric scattering models

M. A. Ferrara, Air Force Research Lab.; M. Cheney, Rensselaer Polytechnic Institute; D. G. Arnold, Air Force Research Lab.

This paper describes the development of an algorithm for detecting multiple-scattering events between separate scattering centers within the 3D Geometric Theory of Diffraction (GTD)-based Jackson-Moses scattering model. Microlocal analysis techniques were used to compute the locations of multiple-scattering events within SAR data. The proposed multiple-scattering detection algorithm utilized the theory of geometric invariants to estimate the microlocal analysis-predicted multiple-scattering events. After multiple-scattering returns were estimated, the algorithm employed the Generalized Radon Transform to determine the existence of multiple scattering in the measured data. The algorithm was tested on an X-band simulation of isotropic point scatterers as well as on the Air Force Research Laboratory's XPATCH-generated Backhoe Dataset.

6547-23, Session 4

Development and assessment of a complete ATR algorithm based on ISAR Euler imagery

C. S. Baird, R. H. Giles, Univ. of Massachusetts/Lowell; W. E. Nixon, U.S. Army National Ground Intelligence Ctr.

The Euler decomposition, when applied to the polarization scattering matrix, attempts to extract phenomenological information about the scattering target. Because the Euler parameters constitute a more physically relevant set of parameters than the traditional HH-VV ISAR representations, they have potential to improve ATR performance. The Euler parameter's usefulness in target recognition, however, is effected by several layers of signature variability. Unfortunately, many of the variability layers are often omitted in a typical ATR study. A complete ATR algorithm was therefore developed that allows for all layers of variability and requires no previous knowledge of the target's position, orientation, or average reflectivity. The complete ATR algorithm was then used to assess the effectiveness of Euler ISAR imagery in target recognition when all layers of variability are considered. The general approach and sub-methods used to construct the complete ATR system will be presented, including the methods to determine the targets orientation, registration, and to compare it to a library of pre-rendered target images. Finally, the performance of the Euler parameters in target recognition using the complete ATR algorithm will be presented.

6547-24, Session 4

A novel change detection method in polarimetric SAR data

M. Qong, Kyushu Tokai Univ. (Japan)

Change detection is an important application of the satellite images. For polarimetric SAR (POLSAR) images, it is ideal that scattering geometries of the same target should display resemblance between multidate images, which are used in change detection applications, since the scattering mechanisms may change due to the data acquisition geometry. However, sometimes it is difficult to achieve these conditions. An attempt is made to maximize the resemblance between the scattering geometries in multidate images for a specific target. An algorithm is developed based on the polarimetric basis transformation along with the polarization signatures. As a result, the resemblance between the scattering mechanisms of the same target in both images is maximized. The effects predicted by the theory are confirmed by the change detection analysis of POLSAR data acquired by the Jet Propulsion Laboratory SIR-C mission and Japanese ALOS-PALSAR data. We have confirmed that the results of this study can be utilized when extracting differences between any two observations for fully polarimetric SAR images.

6547-28, Poster Session

A portfolio of products from the rapid terrain visualization interferometric SAR

D. L. Bickel, A. W. Doerry, Sandia National Labs.

The Rapid Terrain Visualization interferometric synthetic aperture radar was designed and built at Sandia National Laboratories as part of an Advanced Concept Technology Demonstration (ACTD) to "demonstrate the technologies and infrastructure to meet the Army requirement for rapid generation of digital topographic data to support emerging crisis or contingencies". This sensor was built by Sandia National Laboratories for the Joint Programs Sustainment and Development (JPSD) Project Office to provide highly accurate digital elevation models (DEMs) for military and civilian customers, both inside and outside of the United States. The sensor achieved better than HRTe Level IV position accuracy in near real-time. The system was flown on a deHavilland DHC-7 Army aircraft.

This paper presents a collection of images and data products from the RTV Interferometric SAR radar. The imagery includes orthorectified images and DEMs from the RTV interferometric SAR radar.

The Rapid Terrain Visualization ACTD was managed by the Joint Programs Sustainment and Development Project Office, Ft. Belvoir, Virginia.

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6548-01, Session 1

New steps for passive millimeter imaging

A. N. Pergande, Lockheed Martin Missiles and Fire Control

Passive imaging for security and other applications has reached an important level of development. Ka and W band imaging systems are now commercial products, thanks to cheap and stable amplifiers. While deployment numbers are still modest, improvements to these systems will come from engineering and algorithm development, and not fundamental research. What research should focus on is system volume reduction and resolution improvements.

Fundamental research has several potential paths to solve these problems. Silicon Germanium CMOS can build acceptable millimeter wave amplifiers, and while SiGe noise figure is higher than GaAs, the ability to integrate RF and back end processing will push us closer to a CCD-like sensor. Antimony Arsenide features higher mobility than GaAs, with very low flicker noise and operation above 200 GHz which will reduce aperture size for equivalent resolution. Another potential path to higher frequencies lies in MEMS technology, where microbolometers show potential for operation into the THz region. Ultimately, systems need broad band monolithic detectors with built in analog and digital functions.

Finally, Sparse Array technology may build flat, conformal structures with high resolution and relatively low detector count. Rather than system volume proportional to the cube of aperture size, Spares arrays allow volume proportional to the square of aperture size, with multi-meter diameter apertures a potential goal. This paper will briefly discuss the time line of past innovations, and explore the advantages and challenges of the new technologies that will drive this field forward.

6548-02, Session 1

Millimeter-wave propagation through a controlled dust environment

D. A. Wikner, Army Research Lab.

A one-week experiment was conducted to determine the millimeter-wave transmission loss due to dust. Transmission data was collected at 35, 94, and 217 GHz through a recirculating dust tunnel. The dust was engineered to have a density and particle size distribution equal to the dust clouds formed by helicopters in an arid environment. The actual dust cloud characteristics were measured during the experiment. The millimeter-wave measurements were non-coherent, using transmitting sources on one side of the dust tunnel and antenna/detectors on the other. The hardware was designed to minimize noise and drift. Even so, it was found that the transmission loss across the 1-m dust tunnel at high dust densities was lower than could be measured accurately with the equipment. Therefore, the results given are limited to system noise and represent maximum transmission losses at the various frequencies. The results show losses less than 0.02 and 0.08 dB for 94 and 217 GHz respectively across one meter of dust with density 3000 mg/m3. The actual losses are lower and a long baseline interferometer will be required to determine the loss values precisely. Despite the limitations of the experiment, the data show that millimeter-wave imager performance will not be significantly impacted by even a very dense helicopter dust cloud.

6548-03, Session 1

A 190 GHz active millimeter-wave imager

M. Brothers, G. P. Timms, J. D. Bunton, J. Archer, J. Tello, G. C. Rosolen, Y. Li, A. Hellicar, Commonwealth Scientific and Industrial Research Organisation (Australia)

The design and testing of a 190 GHz imaging system is presented. The system features two beam-scanning antennas one of which produces a vertical, and the other a horizontal fan beam. By correlating the signals from the antennas an estimate of the millimeter-wave reflectivity at the intersection of the fan beams is obtained. Each fan beam is scanned by rotating a small subreflector within the antenna; this simple rotation motion allows rapid scanning. The system is portable, currently approximately 0.6m x 0.6m x 2m high; the key size constraint is provided by the 450 mm aperture length of the antennas. The imager has an angular resolution of 0.25 degrees and a field of view of 14 x 14 degrees, resulting in a raw image of approximately 50 x 50 pixels. The raw image is processed using super-resolution techniques.

Images will be presented which show the capability of the system to image metallic, plastic and ceramic objects beneath clothing. These images were obtained by illuminating the scene with a frequency-doubled Gunn oscillator. While this paper focuses on active imaging, the system can also operate in passive mode with greatly reduced sensitivity.

6548-04, Session 1

Influence of complicated background noise on passive ground-based radiometer with low elevation angle

L. Wu, Huazhong Univ. of Science and Technology (China)

Focused on the features of the low-scattering targets far away in the air under detection, the source of the complicated background noise which enters passive ground-based radiometer is analyzed in detail, and the influence of complicated background noise on the target radiate signal received by the main-lobe and the minor-lobe of passive ground-based radiometer antenna is also analyzed separately.

For the noise entering the main-lobe, the relationship of the elevation angle of radiometer, the frequency of radiometer, and the absorption of the background noise is analyzed, and shown as the curve in the plot. At the same time, for the noise entering the minor-lobe, the effect introduced by the variation of elevation angle of radiometer and different terrestrial surfaces to the absorption of the background noise by passive ground-based radiometer is also analyzed, and demonstrated as a formula with several plots.

At last, the mathematical models and theoretical curves introduced in this paper are supported by the experimental data on measuring kinds of terrestrial surface's brightness temperature using 8mm passive ground-based radiometer. The conclusion drawn in this paper can be a valuable reference for passive detection of low-scattering aerial targets for long distance.

6548-05, Session 2

High resolution passive millimeter-wave security screening using few amplifiers

C. A. Martin, A. Shek, V. G. Kolinko, Trex Enterprises Corp.

Trex Enterprises has applied the frequency scanned antenna architecture found in the ST-150 stand-off imager to close-in personnel screening devices, including a full-body imager and a handheld scanning imager. These devices presnt the user with an image with 1/8 inch-square pixels using few amplifiers and a low level of mechanical complexity. The frequency scanned architecture permits the instantaneous imaging of a linear array of 64 or 128 pixels with a single amplfier maodule. The linear imager or imagers are slowly mechanically scanned to provide a 2-D image. The imagers were used to capture images of concelaed threat items at various thermal resolutuions, dependent upon mechanical scan speed. The detection rate of threats by the user is investigated using perception test software. This software can determine the thermal resolution and level of operator training necesary for a certain rate of detection against a threat object. The software can also determine whether other system enhancements, such as IR fusion, can improve detection rates or reduce false alarms.

6548-06, Session 2

Low cost imaging and sensing technologies for security and defense applications

B. J. Harker, Roke Manor Research Ltd. (United Kingdom)

This paper describes some of the recent developments which have occurred at Roke in field of imaging and sensing technologies, for security and defence applications. The paper describes three recent developments which are based on technologies operating in the millimetre-wave, sub-millimetre-wave (low terahertz) and ultra-wideband regions of the frequency spectrum. An important objective of the work is to initiate and facilitate the transition from relatively costly and non-portable detectors over to lower cost and compact imaging systems, particularly in providing a stand-off detection capability. The paper describes the applications, technologies, low cost design characteristics and concludes with an account for the future direction of the work.

6548-07, Session 2

Spectral decomposition of ultrawideband terahertz imagery

E. N. Grossman, National Institute of Standards and Technology; C. R. Dietlein, National Institute of Standards and Technology and Univ. of Colorado/Boulder; J. Chisum, National Institute of Standards and Technology; A. R. M. Luukanen, MilliLab (Finland)

We present passive indoor imagery of both artificial scenes (test objects) and natural scenes (human figures with threat items concealed beneath clothing). These are obtained using an ultrawideband cryogenic microbolometer and a simple monochromator based on frequency-selective surfaces, both of which have been described in detail elsewhere. The bandwidth if the receiver, nominally 0.2 - 1.8 THz, is broad enough to span large variations (\>10 dB) in clothing transmittance and in (diffraction-limited) spatial resolution (factor of x8). Certain features of the ultrawideband images make the presence of threat items in them easy to discern by eye with high detection probability and low false alarm rate. We show that this can be understood by regarding the images as superpositions of (low frequency) images with good penetration and poor resolution and (high frequency) images with poor penetration and high resolution. The implication is that the favorable ROC-curve obtained with visual inspection could be obtained automatically when appropriate filtering is incorporated into the hardware.

6548-08, Session 2

Passive Euro-American terahertz camera (PEAT-CAM): passive indoors THz imaging at video rates for security applications

A. R. M. Luukanen, L. Grönberg, P. Helistö, J. S. Penttilä, H. Seppä, H. Sipola, MilliLab (Finland); C. R. Dietlein, National Institute of Standards and Technology and Univ. of Colorado and MilliLab (Finland); E. N. Grossman, National Institute of Standards and Technology

The objective of this program is to demonstrate a system capable of passive indoors detection and identification of concealed threat items hidden underneath the clothing of non-cooperative subjects from a stand-off distance of several meters. To meet this difficult task, we are constructing an imaging system utilising superconducting ultrawideband antenna-coupled microbolometers, coupled to innovative room temperature read-out electronics, and operated within a cryogen-free pulse tube refrigerator. Previously, we have demonstrated that these devices are capable of a Noise Equivalent Temperature Difference (NETD) of 125 mK over a pre-detection bandwidth from 0.2-1 THz using a post-detection integration time of 30 ms. Further improvements on our devices are reducing this number to a few tens of mK. Such an exquisite sensitivity is necessary in order to achieve the undoubtedly stringent requirements for low false positive alarm rate combined with high probability of detection dictated by the application. Our technological approach allows for excellent per frame NETD (0.2 K or below at 30 Hz frame rate), and is also amenable to multispectral (colour) imagery that enhances the discrimination of innocuous objects against real threats. In the paper we present results obtained with an 8-pixel subarray from our linear array of 128 pixels constructed using a modular approach. Two-dimensional imaging will be achieved by the use of conical scanning.

6548-09, Session 2

Speckle in active millimeter-wave and terahertz imaging and spectroscopy

D. M. Sheen, D. L. McMakin, T. E. Hall, Pacific Northwest National Lab.

Wideband millimeter-wave imaging techniques and systems have been developed at PNNL for concealed weapon detection and other applications. These techniques evolved from single-frequency millimeter-wave holographic imaging methods to wideband three-dimensional planar and cylindrical techniques and systems. The single-frequency holographic method was derived from optical and ultrasonic holography techniques. Speckle is highly significant in this case, and is caused by constructive and destructive interference from multiple scattering locations or depths within a single resolution cell. The wideband three-dimensional techniques developed at PNNL significantly reduce the speckle effect through the use of high depth resolution obtained from the wide bandwidth of the illumination. For these techniques, speckle can still be significant in some cases and affect image quality. In this paper, we explore the situations in which speckle occurs and it's relationship to lateral and depth resolution. This will be accomplished through numerical simulation and demonstrated in actual imaging results. Speckle may also play a significant role in altering reflection spectra in wideband terahertz spectra. Reflection from rough surfaces will generate speckle, which will result in significant variation in the reflection spectrum as measured over very wide bandwidths. This effect may make if difficult to interpret spectral absorption features from general reflectance data. In this paper, physical optics numerical simulation techniques will be used to model the reflection from arbitrary random surfaces and explore the effect of the surface on the reflection spectra and reconstructed image. Laboratory imaging and numerical modeling results in the millimeter-wave through the terahertz frequency ranges are presented.

6548-10, Session 3

Broadband THz Wave Photonics for Defense and Security Applications

X. Zhang, Rensselaer Polytechnic Institute

Terahertz (THz) radiation offers innovative sensing and imaging technologies that can provide information unavailable through conventional methods such as microwave and X-ray techniques. With the advancement of THz technologies, THz wave sensing and imaging will impact a broad range of interdisciplinary fields, in particular, the opportunity for transformational advances in defense and security. In recent work THz technologies have shown promise regarding the standoff detection and identification of explosives and their related compounds. Handheld broadband THz spectrometry with real-time detection capability in short distance for defense and security applications is available.

This presentation will report on an all-air THz photonic system which uses ambient air as a broadband emitter and sensor with a commercial pulsed laser as an optical source. By transmitting and focusing optical beams in close proximity to the target(s), broadband far-infrared/THz waves can be generated and detected locally. This process reduces the far-infrared/THz wave beam path in order to minimize the water vapor attenuation in the far-infrared region. Preliminary results on the generation, manipulation, enhancement, amplification, and detection of highly directional far-IR/THz waves through the use of ambient air as an emitter, modulator, amplifier, and sensor medium will be presented.

6548-11, Session 4

Sparse aperture millimeter-wave imaging using optical detection and correlation techniques

C. A. Schuetz, Univ. of Delaware; R. Martin, EM Photonics, Inc.; M. S. Mirotznik, The Catholic Univ. of America; S. Shi, G. J. Schneider, J. A. Murakowski, D. W. Prather, Univ. of Delaware

For many applications, the usefulness of millimeter-wave imagers is limited by the large aperture sizes required to obtain images of sufficient resolution. Sparse aperture techniques could open up wider range of applications by mitigating the volume requirements of high resolution imagers. In previous proceedings, we have presented an approach towards the realization of millimeter-wave, sparse-aperture imagers using optical techniques. By using electro-optic modulators to upconvert received millimeter-wave fields onto an optical carrier, such fields can be readily captured, routed, and processed using optical techniques. Such techniques could provide significant advantages over traditional heterodyne techniques.

Herein, we present progress towards the physical realization of such an imager. Specifically, we discuss the implementation challenges that must be addressed to create such an imager and present in further detail the numerous advantages such an approach will yield. We also present results obtained from a working prototype system and show that these results are in good agreement with theoretical performance models.

6548-12, Session 4

Passive millimeter-wave camera with interferometric processing

H. Nohmi, NEC Corp. (Japan)

The passive millimeter-wave (MMW) camera with interferometric processing will be presented. The system have been developed as a proto-type of a non-real-time imager to evaluate the characteristics of MMW images. The basic configuration, processing algorism and the performance were presented at SPIE 2006 in Orlando. The hardware configuration and the software algorithm are based on interferometric principle. This system consists of two sets of a W-band front end with a horn antenna, a receiver, an A/D converter, high-speed processing hardware, and a computer for image reconstruction. The position of these two antennas with a W-band front-end moves on the precision linear slider in horizontal and vertical axis. The synthesized aperture size is 1m for horizontal and 50cm for vertical axis. The coherently received two channel signals are digitized and processed in the hardware processor. The process is comprised of phase error compensation, correlation of all combination of each axis data, and integration to improve the signal to noise ratio. The computer input the integrated data to make an image by matched filter processing. In this year, we improved the performance. New LNAs were attached. The A/D sampling frequency and signal band width were increased 10 times. The integration time is the same as the old system. The total S/N ratio was improved more than 10dB. The processed images and the new performance will be shown. Also, future plan for a real-time camera using this technique will be presented.

6548-13, Session 4

Electronic scanning for passive millimeter wave imaging

N. A. Salmon, QinetiQ Ltd. (United Kingdom)

This paper reviews the use of electronic scanning technology for the passive millimetre wave imagers. Looking at the mathematics of beam-forming, the developments in technology and the end user requirement indicates a new architecture of imager might offer an attractive prospect. The potential applications are reviewed and technological and physics considerations are given in the performance prediction with respect to the frequency. A programme to build a small demonstrator of such a beam-forming system is overviewed.

6548-14, Session 4

Passive mm-wave imaging using two scanning fan-beam antennas

Y. Li, G. P. Timms, J. Archer, G. C. Rosolen, J. Tello, M. Brothers, A. Hellicar, Y. J. Guo, Commonwealth Scientific and Industrial Research Organisation (Australia)

A proto-type cross-correlating 190 GHz passive mm-wave imaging system has been developed. This system is based on the Mills Cross system used for radio astronomy imaging. It uses two pillbox antennas arranged in a T configuration. Each antenna generates a fan beam and the two fan beams are orthogonal to each other. By cross-correlating the signal received from the two antennas, an output is obtained which is proportional to the millimeter-wave intensity radiated from the target at the intersection of the two fan beams. Beam scanning is generated by rotating a small sub-reflector inside each antenna. As a result, these relatively heavy antennas are stable during scanning and a high frame rate can be achieved. Another advantage of this approach is that only two receivers are required. The baseline (the displacement between the phase centers of the two antennas) of this system is not zero, because the phase centers of the two antennas are not located at the same position. The baseline generates a fringe in the imaging system and its influence on the performance of the system is analyzed in this paper. The scanning speed of this system is also much faster than that of the Mills Cross imaging system and its influence on the resolution is also analyzed. It is found that the effect of the scanning speed is minimized when the beam scans along the equal-phase line of the fringe. This system can also be used as an active imaging system and this is discussed in another paper.

6548-15, Session 5

Unamplified direct detection W-band imaging array

J. N. Schulman, J. J. Lynch, H. P. Moyer, J. H. Schaffner, P. H. Lawyer, R. L. Bowen, Y. Royter, M. Sokolich, R. D. Rajavel, HRL Labs., LLC

This paper describes HRL's design approach, fabrication, and measured results for a purely passive (i.e. unamplified) direct detection receiver that operates at W band. These efforts are part of DARPA's MIATA program for passive millimeter wave imaging sensors. HRL's receiver integrates Sb-based backward tunnel diodes directly with an antenna to provide efficient collection of energy from the environment and high sensitivity detection without the use of low noise amplifiers. The design approach allows for straightforward integration of multiple elements for 2D staring arrays and is amenable to low cost manufacturing. The authors describe an integrated transition from W band waveguide to the detector using common millimeter wave circuit board techniques where the detector is located directly within the waveguide cavity, thus providing a compact, efficient, and wideband transfer of power to the detector. Discussions of the design approach and trade-offs will be followed by a description of the fabrication techniques for the antenna array and millimeter wave printed circuit board. Measured results of the overall NEDT for the integrated sensor will be reported. Finally, the utilization of the resulting sensor module in large imaging arrays will be discussed.

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6548-16, Session 5

The development of affordable front end hardware for millimeter wave imaging using multi-layer soft board technology

D. C. Bannister, QinetiQ Ltd. (United Kingdom)

No abstract available

6548-17, Session 5

Performance of 94GHz MMIC receivers

R. G. Humphreys, QinetiQ Ltd. (United Kingdom)

No abstract available

6548-18, Session 5

LiNbO3 optical modulator for MMW sensing and imaging

C. Huang, C. A. Schuetz, R. Shireen, S. Shi, D. W. Prather, Univ. of Delaware

In this paper we present several novel technologies for sensing millimeter-wave (MMW) radiation for imaging and spectroscopy based on photonic devices. Along these lines, in our high-sensitivity millimeter-wave (MMW) imaging system, which is based on optical upconversion, the power of MMW radiation is transferred to the sidebands on an optical carrier via an electrooptic (EO) modulator fed by a broadband horn antenna. The detection is realized by measuring the transferred optical power of the sidebands. The sensitivity of this detection system is primarily controlled by the conversion efficiency of the EO modulator at the desired MMW frequency (e.g. 95GHz). This requires that the modulators can work at an ultra-broad bandwidth and under a small driving voltage. In this paper, we present the design, fabrication, and characteristics of LiNbO3 traveling-wave modulator for the MMW detection system. In a traveling-wave modulator, the bandwidth is limited by the mismatch between electrical and optical propagation constant. We have developed several techniques to finely tune the propagation constant of the MMW in the modulator and eliminated this mismatch. The further bandwidth limitations for the modulator are the losses from the electrode conductor, the substrate and buffer layer dielectrics, and coupling between the traveling-wave mode and the substrate modes. Some novel modulator structures have been proposed to reduce those losses without increasing the device driving voltage. The bandwidth and conversion limits of these structures are also discussed. The MMW detection pixels using the fabricated modulators were assembled, characterized, and analyzed. A high-sensibility W-band detection system with a low noise equivalent temperature difference will be demonstrated at a standard video rate of 30 Hz.

6548-19, Session 5

Direct detection antenna-coupled mmW sensors for the detection of explosive vapors

M. A. Gritz, Raytheon Vision Systems and Raytheon Network Centric Systems; R. Hernandez, A. Larussi, Raytheon Co. and Raytheon Space and Airborne Systems; E. E. Gordon, Raytheon Vision Systems and Raytheon Network Centric Systems; G. Zummo, College of Optics & Photonics/Univ. of Central Florida; G. D. Boreman, Univ. of Central Florida; L. P. Chen, Raytheon Vision Systems and Raytheon Network Centric Systems

The low vapor pressure and concentration of explosive such as TNT and RDX pose significant problems for the detection of explosive vapors in the mmW bands. For the positive identification of explosive vapors using an uncooled passive mmW imaging spectrometer with a low false alarm rate (FAR) requires an unprecedented sensitivity of <150 fW. We report on the recent development of a novel uncooled mmW antenna-coupled direct detector, which shows promise of meeting this requirement. Furthermore our technology is capable of being implemented as a “spectrometer on a chip” by using existing frequency agile technology previously demonstrated at the University of Central Florida/CREOL in the long wave infrared (LWIR) by the author1.

Our antenna-coupled direct detector works by collecting the incident electro-magnetic radiation with a scalable, planar lithographic antenna element. The collected radiation is directly injected into the sensor electronics, which rectify the signal. The rectification of the radiation is achieved by using a GaAs Schottky diode to convert the high frequency input signal to DC power. Using advanced semiconductor processing, Raytheon built sample GaAs Schottky diodes integrated with a half-wave dipole antennas with a measured noise-equivalent-temperature difference (NETD) of <10K at room temperature. Additional improvements on the antenna design indicate that the direct combination of an optimum antenna design with our Schottky diode enables unprecedented sensitivities in the <150 fW range (<1K NETD).

6548-20, Session 5

FPGA acceleration of superresolution algorithms for embedded processing in millimeter-wave sensors

F. E. Ortiz, E. J. Kelmelis, EM Photonics, Inc.; D. W. Prather, Univ. of Delaware

Superresolution reconstruction (SR-REC) algorithms combine multiple frames captured using spatially under-sampled imagers to produce a single higher-resolution image. Sub-pixel information is gained from natural motion within the image instead of active pixel scanning (dithering/micro-scanning), eliminating the reliability issues and power consumption associated with moving parts. One of the major computational challenges associated with SR-REC methods is the estimation of the optical flow of the image (determine the unknown pixel shifts between consecutive frames). A linear least square approximation is the simplest method for estimating the pixel movements from the captured data, but the size of the problem (directly proportional to the number of pixels in the image) creates a computational bottleneck, which in turn limits the usability of this algorithm in real-time portable systems. We propose the use of a reconfigurable platform to implement these computations in a low power/size environment, suitable for integration into portable millimeter wave imagers.

6548-21, Session 5

Determination of dielectric material properties with passive MMW measurements for security applications

S. Dill, M. Peichl, H. Suess, DLR Standort Oberpfaffenhofen (Germany)

Microwaves in the range of 1-300GHz are used in many respects for remote sensing applications. Besides two-dimensional imaging methods, the application for the extraction of depth information about the material structure is of basic interest. For example the use of radar in mining and geology has a long tradition, and recently the application of radar and radiometric sensors was also considered for landmine detection. However, the investigated materials in those cases are almost of a natural composition, but newer and future applications like people screening or through-walls imaging require increasingly the analysis of the interaction of electromagnetic radiation with manifold artificial matter like building materials and textiles.

In order to characterize the material of interest in the microwave region, its permittivity is of basic interest besides its physical structure. In many cases the permittivity is unknown, inaccurately known, or known for only specific frequencies, and for a specific situation the range of values given in the literature can have a large variability. Several methods to determine the permittivity can be applied. Basically we discriminate active and passive methods, and measurements in a closed waveguide, coaxial line, or in free space using a specific antenna arrangement. In addition, the measurement of a specific material can be complicated by its physical size and structure, which rules out the use of a closed line approach as in the case of a waveguide.

In this paper we describe a procedure to determine the permittivity from radiometric free-space measurements of nearly arbitrary materials. A combined and advanced method of passive transmission and reflection

measurements is outlined. The corresponding measurement assembly including the material sample and the necessary reference targets for almost environmentally independent measurements is illustrated. The configuration allows the investigation on large material probes like brick or wooden plates, and materials like textiles, which all are hard to mount in a defined way in a waveguide. An estimation of the presently achieved precision is given and some representative results for MMW measurements of different materials are shown.

6548-22, Session 5

Aqueous blackbody system: a novel THz absolute calibration source

C. R. Dietlein, National Institute of Standards and Technology and Univ. of Colorado/Boulder; E. N. Grossman, National Institute of Standards and Technology

We describe a novel broadband calibration source for the mm-wave to THz frequency band, the Aqueous Blackbody System (ABS). The blackbody in this design is a body of water, which is extremely absorptive in this frequency range, held at a uniform and known temperature by a commercial immersion circulator. The problem of non-zero reflectance is not solved by specialized material properties (as with microwave anechoics) but circumvented by use of a special “optical trap” geometry, as in the calibration of optical fiber power meters (Lehman et al 1998, Lehman & Cromer 2002). The undesirable reflectance arises at the interfaces between the water and the walls of the expanded polystyrene (EPS) container. EPS is used because of its exceptionally high transmittance and near-unity refractive index throughout the 0.1 - 2 THz band. The shape of the custom-molded container is carefully designed to ensure that all beams incident within the acceptance area and solid angle of the source undergo four 45-degree reflections - two “s” and two “p” orientations - off the water-EPS interface. This ensures an effective emissivity \> 99% over the operating band. This has been verified by measurements of EPS transmittance and geometric optics simulation over the entire band, and by spot measurements at selected frequencies of the effective reflectance of the completed source.

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6549-01, Session 1

Advanced terahertz imaging system performance model for concealed weapon identification

S. R. Murrill, B. C. Redman, Army Research Lab.; R. L. Espinola, U.S. Army Night Vision & Electronic Sensors Directorate; C. C. Franck, U.S. Army; F. C. De Lucia, The Ohio State Univ.; D. T. Petkie, Wright State Univ.; E. L. Jacobs, S. T. Griffin, C. E. Halford, The Univ. of Memphis; J. P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate

In response to the need to develop new technologies to better protect U.S. and NATO ally personnel and materiel assets against asymmetric terrorist threats, the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) and the U.S. Army Research Laboratory (ARL) have developed a terahertz-band imaging system performance model for detection and identification of concealed weaponry. The details of this MATLAB-based model which accounts for the effects of all critical sensor and display components, and for the effects of atmospheric attenuation, concealment material attenuation, and active illumination, were reported on at the 2005 SPIE Europe Security & Defence Symposium. The focus of this paper is to report on recent advances to the base model which have been designed to more realistically account for the dramatic impact that target and background orientation can have on target observability as related to specular and Lambertian reflections captured by an active-illumination-based imaging system. The advanced terahertz-band imaging system performance model now also accounts for target and background thermal emission, and has been recast into a user-friendly, Windows-executable tool. This advanced THz model has been developed in support of the Defense Advanced Research Project Agencies' Terahertz Imaging Focal-Plane Technology (TIFT) program. This paper will describe the advanced THz model and its new radiometric sub-model in detail, and provide modeling and experimental results on target observability as a function of target and background orientation.

6549-02, Session 1

Terahertz spectroscopy of TNT for explosive detection

R. E. Peale, A. V. Murajov, Univ. of Central Florida; L. P. Chen, M. D. Jack, M. A. Gritz, Raytheon Vision Systems

The low vapor pressure and concentration of explosives such as TNT and RDX pose significant problems for the detection of these compounds. Spectral sensing of explosive material requires a-priori knowledge of spectrum of the material. We report measured transmittance spectra of solid and vapor samples of trinitrotoluene (TNT) in the spectral range 0.6 to 4.2 THz at resolutions up to 1 GHz using a Fourier-transform spectrometer. A uniform film of approximately 0.1 mm thickness of TNT on top of a polyethylene substrate was measured to compare with previously reported data. Our sample preparation led to stronger absorption for all of the lines previously reported, and we were also able to resolve more structure in the spectrum. For spectroscopy of TNT vapor, a 10 meter fixed-length long- path gas cell was modified for use in the THz range. Additionally the gas cell was heated ~15 C above ambient to enhance the concentration of the TNT vapor. The measured spectrum reveals a broad strong absorption band at the low frequency limit of the data. The results suggest that TNT vapor absorption remarkably increases below 35 cm-1 (or 1 THz), implying that mm-wave spectral region holds promise for detection of TNT vapors.

6549-03, Session 1

Modeling and characterization of cloth at sub-millimeter wavelengths

E. L. Jacobs, S. T. Griffin, The Univ. of Memphis

A primary source of "clutter" in sub-millimeter wave and terahertz imagery used in security applications is the random reflections from clothing. In this paper, techniques for modeling and characterizing these reflections are described. This work is motivated and, in part, based on previous work done in support of imaging radar for remote sensing. A first order model of the response of a cloth covered object is described along with a method for performing measurements on draped cloth. The measurement method involves the simultaneous measurement of the sub-millimeter wave response of the cloth and the underlying drape of the cloth. A rigorous model of the scattering from draped cloth is developed and compared with results from the first order model. Conclusions regarding the suitability of the first order model for image simulation and performance predictions are stated.

6549-04, Session 1

Broadband terahertz time-domain and Raman spectroscopy of explosives

A. D. Burnett, W. Fan, P. Upadhya, J. E. Cunnigham, Univ. of Leeds (United Kingdom); H. G. M. Edwards, J. Kendrick, T. Munshi, M. Hargreaves, Univ. of Bradford (United Kingdom); E. H. Linfield, A. G. Davies, Univ. of Leeds (United Kingdom)

Broadband terahertz time-domain spectroscopy (THz-TDS) has been shown to be a valuable technique for the analysis of explosives and drugs-of-abuse, and to be a possible tool for their detection. In this paper, we present recent work on the use of THz-TDS to analyse three pure explosives, 1,3,5-trinitroperhydro-1,3,5-triazine (RDX), 2-Methyl-1,3,5-trinitrobenzene (TNT), and 1,3-Dinitrato-2,2-bis(nitratomethyl)propane (PETN). Spectra have also been obtained of a number of plastic explosives, plastics and dyes to allow for a systematic analysis of real world samples. Finally THz-TDS spectra of the explosives have been studied over a range of temperatures. These variable temperature measurements, when compared with Raman spectroscopy measurements and molecular modelling calculations, can lead to a greater understanding of the vibrational modes observed in the terahertz region of the spectrum.

6549-05, Session 1

Terahertz measurement and imaging detection of delamination and water intrusion in ground based radome panels

D. A. Zimdars, J. S. White, G. Fichter, G. Stuk, Picometrix LLC

We demonstrate the ability of time domain Terahertz (THz) imaging to locate and identify defects such as delaminations and water intrusion in advanced composite materials used in ground based radome panels, shelters and towers. We show the ability of terahertz analysis, both with time domain and Fourier domain (i.e., spectroscopy) analysis, to detect defects of interest. These measurements are used to generate 2- and 3- dimensional high-resolution maps of the composite material structures. Additionally we demonstrate the feasibility to detect other types of defects, such as metal intrusions, resin poor or rich areas and fluid contaminations (e.g., oil, fuel).

6549-06, Session 2

Towards an active real-time THz camera: first realization of a hybrid system

T. Löffler, C. am Weg, A. Alcin, B. Hils, H. G. Roskos, Univ. Frankfurt am Main (Germany)

In this contribution we report the first realization of a hybrid system for stand-off THz reflectrometry measurements. The basic idea is to combine the best of two worlds: the high radiation power of sub-THz micro-electronic emitters and the high sensitivity of coherent opto-electronic detection. Our system is based on a commercially available multiplied Gunn source with a cw output power of 0.7 mW at 0.65 THz. We combine this with electro-optic mixing with femtosecond light pulses in a ZnTe crystal. This schema can be described as heterodyne detection with a Ti:sapphire fs-laser acting as local oscillator and

therefore allows for phase-sensitive measurements.

Example images of test objects are obtained with mechanical scanning optics and with measurement times per pixel as short as 10 ms. The test objects are placed at a distance of 1 m from the detector and also from the source. The results indicate diffraction limited resolution. Different contrast mechanisms, based on absorption, scattering, and difference in optical thickness will be employed. Based on careful signal-to-noise determination, we conclude that the system has the potential to reach a power dynamic range of up to 8 orders of magnitude for single-pixel detection. Our evaluation shows that it will be possible to realize a real-time multi-pixel detector with several hundreds of pixels and a dynamic range of at least two orders of magnitude in power.

In summary, our system represents a good starting point for the future realization of real-time active THz camera systems for security and other applications.

6549-07, Session 2

Terahertz standoff imaging testbed design and performance for concealed weapon and device identification model development

C. C. Franck, CACI Technologies Inc.; R. L. Espinola, U.S. Army Night Vision & Electronic Sensors Directorate; S. T. Griffin, E. L. Jacobs, The Univ. of Memphis; S. R. Murrill, Army Research Lab.; D. Lee, E-OIR Measurements, Inc.; D. H. Tofsted, S. O'Brien, Western Space Missile Range; C. E. Halford, The Univ. of Memphis; J. P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate

This paper describes the design and performance of the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate's (NVESD), active 0.640 THz imaging testbed, developed in support of the Defense Advanced Research Project Agencies' (DARPA), Terahertz Imaging Focal-Plane Technology (TIFT) program. The laboratory measurements and standoff images were acquired during the development of NVESD and Army Research Laboratory terahertz imaging performance model for concealed weapon identification. The imaging testbed is based on a 12 inch diameter off-axis ellipse (OAE) mirror designed with one focal length at 1m and the other at 10m. This paper will describe the considerations and design of the OAE mirror, the dual capability active imaging testbed (X-Y stage and scanning) that uses a 640GHz source and receiver; and the measurement/imaging results used to further develop the model.

6549-08, Session 2

Terahertz interferometric imaging of RDX

A. M. Sinyukov, R. B. Barat, D. E. Gary, Z. Michalopoulou, I. K. Zorych, J. F. Federici, New Jersey Institute of Technology

Terahertz radiation can propagate through nonmetallic, non-polar materials providing a positive detection of weapons and dangerous agents concealed behind barriers, such as clothing, book bags, envelopes etc. In addition, many materials of interest for security applications (for example C-4, HMX, RDX, TNT) have characteristic transmission/reflection spectra in the THz range. Therefore, these materials appear as different "colors" to the THz detector as compared to non-hazardous items. Among other methods for THz detection, interferometric imaging is attractive for security screening applications due to a potentially rapid and confident identification of lethal agents with a limited number of THz detectors. Also, a compact and inexpensive imaging system based on semiconductor lasers can be designed.

In our group, we are developing a THz interferometric imaging system for stand-off detection of concealed weapons, explosives and dangerous chemical/biological agents.

We present experimental results of 2D terahertz interferometric imaging. Only one detector placed at several positions is used to imitate the performance of a detector array. Interferometric images of a point source are in a good agreement with theoretical predictions. At 0.5 m, an RDX sample is detected behind a nylon book bag barrier. The barrier is ~2 mm thick non-transparent to visible light. Reconstructed 2D interferometric images provide both spatial and spectral information about the target. Also, we are exploring several modulation methods that can reduce the imaging time and increase the resolution of our imaging system.

6549-09, Session 2

Terahertz imaging system for stand-off detection of threats

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Suicide bombers and hidden bombs or explosives have become serious threats especially for mass transportation. Until now there exists no established system which can be used against these threats. Therefore new technologies especially for stand-off detection of threats are required. Due to their unique properties such as penetration of clothes terahertz (THz) rays offer an alternative inspection method, which can cope with these new challenges. In this contribution the design and results of a THz stand-off imaging system will be presented. The sensor is based on active illumination of the object and sensitive heterodyne detection of reflected and backscattered radiation. A THz laser is used for illumination and a superconducting hot-electron bolometric mixer for detection. The local oscillator required for heterodyne detection is a multiplied microwave source. Imaging is achieved by raster scanning of the object. The optical system is designed to allow for stand-off detection up to 20 m. Such a system may eventually lead to an increased level of security in public places and improve the security of mass transportation for example at airports or train stations.

6549-10, Session 3

A high resolution terahertz spectrometer for chemical detection

A. J. Majewski, Goodrich Corp.

Goodrich has been developing a high resolution, broad band spectrometer that operates in the Terahertz (THz) region of the spectrum with the intent of performing chemical detection. THz spectroscopy exploits rotational resonances for detection of gas phase compounds. High resolution THz spectroscopy (at MHz scales) can improve detection and identification through increased probability of detection and reduced false alarms.

The Goodrich THz spectrometer is based upon CW photomixer technology in a heterodyne configuration. The current Goodrich design offers continuous tunability across a 0.001 GHz to 1.2 THz frequency range. One of the unique aspects of the Goodrich spectrometer is laser system control that has demonstrated difference frequency line widths on the order of 1.5 MHz with stability measured over a 1-10 second time scale. Absolute frequency accuracy is of the order of 4 MHz. The spectrometer design enables high THz energy densities with narrow line widths over a broad spectrum. The system has demonstrated SNR better than a cryogenically cooled hot electron bolometer. This capability allows the Goodrich system to accurately determine absorption signatures of multiple chemicals with exceptional performance.

Goodrich has completed initial system testing and verified performance. Initial tests were completed in a single pass spectrometer configuration to determine SNR of the heterodyne photomixer transceiver. System performance was also verified for laser line width, stability, and repeatability. The spectrometer was tested against various toxic industrial chemicals. Preliminary data for HCN, HCl, NH_3, and SO_2 will be presented.

6549-11, Session 3

Real-time THz detection using microbolometer infrared camera

B. N. Behnken, G. Karunasiri, M. Lowe, Naval Postgraduate School; D. R. Chamberlin, P. R. Robrish, Agilent Technologies, Inc.; J. Faist, Univ. of Neuchatel (Switzerland)

The THz wavelengths cover the frequency range of 0.1-10 THz or 30-3000 micrometer wavelength band. Currently, the detection of THz radiation is carried out using either antenna-coupled semiconductor detectors or superconducting bolometers. The imaging of objects using these detection schemes requires complex scanning mechanisms which limits the applications involving real time imaging. For fast detection it is desirable to employ the focal plane arrays which leads to more compact systems. Photon detectors used in infrared require cooling which becomes stringent as the detection involves THz wavelengths. On the other hand, thermal detectors which are based on temperature change as a result of infrared absorption have a broad wavelength response and operate at room temperature. The advances of microbolometer technology allow real time imaging in the 7-13 micron wavelength range with sensitivities close to that of the cooled counterparts. However, their ability to detect THz radiation is relatively unknown. In a recent experiment using a 160x120 uncooled microbolometer focal plane array, we have successfully demonstrated real time imaging using a 3.7 THz (82 micron) quantum cascade laser beam with power less than 1 mW. In this presentation, operation of the microbolometer infrared camera in THz spectral band, and video recordings of the THz source with various objects obscuring it, will be presented.

6549-12, Session 3

A superconducting terahertz imager

T. May, V. Zakosarenko, S. Anders, H. Meyer, Institut für Physikalische Hochtechnologie e.V. (Germany); E. Kreysa, N. Jethava, Max-Planck-Institut für Radioastronomie (Germany); G. Thorwirth, Jena-Optronik GmbH (Germany); M. Siegel, Univ. Karlsruhe (Germany)

Mapping objects at frequencies around one terahertz from a significant distance poses a considerable challenge for any imaging device. The power emission of bodies at room temperature is very weak, so a purely passive map requires an extremely sensitive detector. Room temperature detectors are only applicable for actively illuminated scenes; for a passive map a cooled detector is required. Even if the imager is powerful enough to operate passively it still can profit from an additional active illumination.

For sub-mm wavelength recently a big leap forward in the detector performance and scalability was driven by the astrophysics community. Superconducting bolometers and midsized arrays of them have been developed and are in routine use. Concepts for larger devices are already projected. It is conceivable that such devices will become larger, less costly and available for a wider market. So a THz imager for industrial or security applications based on superconducting detectors comes into reach.

Although devices with many pixels are foreseeable nowadays a device with an additional scanning optic is the straightest way to an imaging system with a useful resolution. Our superconducting THz imager (SCOTI) is a small cassegrain telescope with a scanning secondary mirror designed for a frequency of 0.34 THz. It can map objects from a distance between 5 meter and 20 meter using a small array of superconducting bolometers. The resolution at the object area is about 1 cm. Purely passive images of interesting objects can be taken, opening a wide field of applications.

6549-13, Session 4

An integrated continuous-wave terahertz biosensor

M. Neshat, D. Saeedkia, Univ. of Waterloo (Canada); R. Sabri, Defence Research and Development Canada (Canada); S. Safavi-Naeini, Univ. of Waterloo (Canada)

An integrated continuous-wave (cw) terahertz biosensor based on the edge-coupled terahertz photomixer source with guided-wave optical excitation scheme is proposed.

In this device, the laser beams are guided inside an optical dielectric waveguide structure and gradually absorbed by an overlying ultra-fast photoabsorbing layer, hence, generating a terahertz signal due to photomixing phenomena. The generated THz signal is guided by a coplanar-stripline (CPS) and is coupled to an integrated CPS resonator, which acts as a sample carrier and transducer.

The great advantage of cw THz biosensors compared to their pulsed counterparts is their higher frequency resolution, which results in higher sensitivity and lower sample requirement. The proposed CPS resonator is coupled directly to CPS transmission lines to avoid extra insertion loss due to transitions.

As the result of interaction with the bio-sample, terahertz wave is guided by a CPS line to a wide-band antenna and is detected by free-space photoconductive sampling technique. Performance analysis of the proposed cw terahertz biosensor supports the feasibility of the device. The proposed scheme is ideal for designing system-on-a-chip terahertz sensors and spectrometers used for THz spectroscopy and signature management.

6549-14, Session 4

Reflectivity and emissivity modeling for metals and plastics at THz frequencies

S. T. Griffin, E. L. Jacobs, The Univ. of Memphis; S. R. Murrill, Army Research Lab.

The dynamic range of the signal return from metals is a significant source of image interpretation difficulty. Techniques such as logarithmic image compression have been used to improve the recognition. Alternative techniques for improvement may be developed. This development depends in part on the ability to accurately model the surface reflective behavior including phase shifts introduced by the reflection. This work presents the results of an enhanced model development. Models of high frequency behavior in materials divide into regions such as non-relaxation region, relaxation region, optical absorption and plasma frequencies. In traditional infrared and longer imaging systems, optical absorption may play a role and it is generally assumed that the system operates in or very near the relaxation region defined as frequencies significantly greater than the reciprocal of the Boltzmann relaxation time. Though typical THz frequencies are below the relaxation time, they are not far enough below to be considered completely in the non-relaxation region. This introduces a number of issues atypical of imaging in either the RF or IR regime. Further realism is gained from the incorporation of plastic into the reflectivity and emissivity model. Empirical model validation is accomplished for selected materials.

6549-15, Session 4

Guided-wave propagation on a cylindrical conductor at millimeter-wave or terahertz frequencies

J. C. Wiltse, Georgia Institute of Technology

Surface-wave propagation on coated or uncoated conducting wires, rods, or tubes has been shown to provide low attenuation, moderate field extent, low dispersion, and high power-handling at frequencies from 100 GHz to 1 THz. Typical conductors are copper, aluminum, or stainless steel. Uncoated conductors provide the lowest loss, while conductors coated with a thin layer of low-loss dielectric (such as Teflon, polystyrene, or polyethylene) have the smallest field extent. The guided mode is the TM01, often referred to as the Sommerfeld mode. The properties of the guided wave were theoretically analyzed by King and Wiltse in 1962, and measured results were obtained at 105 and 140 GHz. In the last two years the work has been rediscovered, and now four different research groups have reported new results. While the earlier work was conducted in the search for long, low-loss transmission lines (100 meters to 1 kilometer), the current applications are for lengths about 1 meter long, as might be used in probes. The recent results will be summarized, and an optimized design will be presented, along with general curves of attenuation, field extent, and power handling capability from 100 GHz to 1 THz.

6549-16, Session 4

THz-frequency vibrational-spectrum of DNA nucleotides bounded to Si substrates

B. N. Woolard, Athens Drive Senior High School; P. Zhao, North Carolina State Univ.

Bio-sensing systems are being developed widely due to their potential future importance in medical and military applications. Two basic concepts, direct sequencing and DNA hybridization , are presently the preferred methods used for the detection and characterization of polynucleotides. More recently, the THz-frequency spectroscopy has been identified as a potential new approach for the detailed analysis of biomolecules. Currently, one of the major hurdles facing THz applications in biological science is its extreme sensitivity to water vapor absorption, which introduces an enormous obstacle for sensing the available spectral signatures using traditional techniques. In this paper, a new technique for label-free detection of ultra-low concentrations of DNA molecules is investigated. This technique combines the advantages of both the DNA hybrization technique and THz frequency spectroscopic detection. The goal is to utilize measurable phenomenon at the molecular-level to avoid the problems of signature acquisition introduced by obscurants such as water vapor. In this new approach, the detection of the DNA molecules is to be based on the variations in electron current that are produced by the application of THz-frequency radiation. Here, the vibrational behavior of the bound DNA molecule is the key element because the THz-excitation of phonon modes has the potential to greatly influence average electron flux. In this paper, results are presented for the vibration spectrum of the bound DNA molecules and their utility in sensor applications. These studies utilize the chemical-structure analysis packages Amber and GAMESS to generate valuable information needed for understanding THz-based DNA detectors.

6549-17, Session 5

Examining explosive residues on surfaces with terahertz technology

M. J. Fitch, M. R. Leahy-Hoppa, R. Osiander, Johns Hopkins Applied Physics Lab.

It is well-known that many explosives have characteristic terahertz (THz) absorption features, and that THz waves can penetrate many dielectric materials. However security applications generally prohibit using THz technology for transmission measurements, either because of standoff distances, thick targets, or opaque targets (metals). As a result, we focus our attention on THz reflection spectroscopy. A human fingerprint weighs about 0.05 mg. The potential to detect this small amount of material on a surface has a wide variety of applications including security and homeland protection. The capability to detect trace explosives on surfaces with THz beams leads to non-contact and standoff detection using THz technology. We have measured THz reflectivity signature of RDX “fingerprints” on ideal metal surfaces containing about 0.4 mg of RDX. We will discuss our efforts in detecting trace explosives in reflection as well as our recent results including THz spectroscopy of 4 explosives from 1 to 6 THz, and measurement of the absolute absorption cross-section of explosives.

6549-18, Session 5

Unsupervised image segmentation for passive THz broadband images for concealed weapon detection

M. D. Ramirez-Velez, C. R. Dietlein, Z. Popovic, Univ. of Colorado/Boulder; E. N. Grossman, National Institute of Standards and Technology

This works presents results of applying a classical unsupervised classification algorithm for the segmentation of indoor passive terahertz images. The 30,000 pixel broadband images of a person with concealed weapons under clothing are taken at a range of 0.8-2m over a frequency range of 0.1-1THz using single-pixel row-based raster scanning with spatial resolution of 4-8mm. The spiral-antenna coupled Nioboium bridge cryogenic micro-bolometers are developed at NIST (Terahertz Imaging Laboratory, Optoelectronics Division). The antenna is evaporated on a 250-um thick Si substrate with a 4-mm diameter hyperhemispherical Si lens. The NETD of the microbolometer is 125mK at an integration time of 30ms. The background temperature calibration is performed with a known hot-spot at 330K, and the measured background fluctuation was 200-500mK. Several weapons (ZrO2 knife, metal gun, RAM AN-72) were concealed under different fabrics: cotton, polyester, windblocker jacket, and thermal sweater. Measured temperature contrasts ranged from 0.5-1K for wrinkles in clothing to 5K for a zipper and 8K for the concealed weapon.

The image segmentation algorithm is divided in two stages: (1) segment the NETD image data with a k-means clustering algorithm; and (2) integrate spatial information. In the first stage, the second order information computed by the image covariance matrix is included, and the data is clustered using the Mahalanobis distance criterion. In the second stage, we plan to include spatial information estimated from the Kolmogorov length scales, describing the characteristic distance among the objects in the image and compare it to k-nearest neighbors.

6549-19, Session 5

THz wave generation in inert gases and molecular vapors

M. Yamaguchi, Y. Chen, M. Wang, X. Zhang, Rensselaer Polytechnic Institute

Devlopment of intense THz wave source is one of the most urgent issues in the application of THz spectroscopy to biological and chemical detections. However exisitng THz sources are tend to be saturated or damaged when they are excited with high energy optical pumps. The development of intense THz sources based on novel generation mechanism is desirable.

Recent years, the generation of THz wave in laser induced plasma has been reported. We have been studying the THz wave generation mechanims in gaseous media.

we will present the recent results of THz wave generaiton from laser induced plasma in inert gases and molecular vapors. We have observed strong THz wave emission from many of samples than the most commonly used ZnTe THz emitters.

6549-20, Session 5

Comparison of the THz absorption feature in lactose to related saccharides

J. E. Bjarnason, E. R. Brown, Univ. of California/Santa Barbara; T. M. Korter, Syracuse Univ.

Solid-state compounds such as lactose and biotin have been shown to have narrow and intense THz absorption features at room temperature. We compare a frequency-domain tunable coherent THz photomixing spectrometer with a time-domain spectroscopy system and demonstrate how the coherent spectrometer resolves finer absorption linewidths. Our interest in linewidths in the sub-THz region is justified not only for practical reasons, since it is of crucial importance to spectroscopy-based identification of materials, but also by the information the linewidths contain about the solid-state physics of the materials. The linewidth of sub-THz absorption features (generally from lattice vibrations) in solids is excepted to be inversely proportional to the scattering time of optical phonons. The linewidth of absorption features might thus have implications on the solid-state physics of the material, in particular, the interaction of phonons and the phonon density of states. In this work, we show the narrow absorption line of lactose and compare it to the THz spectra of other di- and trisaccharides: raffinose, maltose, sucrose, trehalose, and melecitose. Since lactose has a much more distinct absorption feature than any of its closely chemically related saccharides, this comparison study is an important step in understanding the mechanism of THz radiation absorption by organic solids and what linewidths to expect in THz spectroscopy.

6549-27, Session 5

Gain and far-field patterns for phase-correcting Fresnel zone plate antennas at millimeter-wave and terahertz frequencies

J. C. Wiltse, Georgia Institute of Technology

The Fresnel zone plate lens antenna, which provides advantages compared to a normal paraboloidal or spherical lens, has been extensively investigated in the millimeter-wave and terahertz regions. The advantages include reduced weight, volume, and attenuation and simplicity of design. The principal disadvantage is that the zone plate often provides reduced gain compared to a true lens, except at high millimeter-wave or terahertz frequencies where the low loss of the zone plate more than compensates for the reduced directivity. This paper investigates the gains and far-field patterns for a number of cases and gives both the analysis and numerical results for the examples. These cases have dealt with large-angle designs, where the focal length (F) and diameter (D) are comparable (F/D = 0.5 to 2.5), unlike the typical optical examples. The antenna patterns are found to have beamwidths and first sidelobes that are similar to what one would obtain with a standard lens, given the same aperture illumination. Appropriate feed designs are also described. For best aperture efficiency the illumination taper is about 10 dB, and this gives first sidelobe levels of about -24dB for a circular aperture. Far-out average sidelobes are not as low as for a true lens, and this is where the gain is affected.

6549-21, Session 6

Performance comparison of Nb and NbN broadband antenna-coupled microbolometers

C. R. Dietlein, National Institute of Standards and Technology and Univ. of Colorado/Boulder and VTT Technical Research Ctr. of Finland (Finland); A. R. M. Luukanen, J. S. Penttilä, L. Grönberg, H. Seppä, P. Helistö, MilliLab (Finland); E. N. Grossman, National Institute of Standards and Technology

We report the first experimental results of the comparison between free-standing Nb and NbN microbolometer bridges coupled to identical circular-spiral antennas on an Si substrate. Because of the difference in material resistivity, the bolometers' resistance and aspect ratio (hence reactance) could be varied independently. Antenna bandwidth is nominally 0.2-3.6 THz. Room-temperature antenna patterns measured over the 500-700 GHz band with a backward-wave oscillator are presented, as are noise-equivalent power (NEP) results, optical responsivity measurements, IV curves at ~4K in a commercial cryogen-free pulse-tube refrigerator, and a comparison of "optical efficiency" (based on electrical and optical responsivities). Similar Nb devices presented previously have reached NETDs in the ~100 mK range with a post-detection integration time of 30 ms (i.e., video-rate).

6549-22, Session 6

Carbon nanotube field-emission based Orotron scanning THz source

S. J. Papadakis, Johns Hopkins Univ.; A. H. Monica, Georgetown Univ.; R. Osiander, Johns Hopkins Univ.

THz radiation offers the potential for spectroscopic identification of chemical analytes hidden behind dielectric barriers such as clothing, cardboard, wood, etc. We describe progress towards the development of a high-efficiency THz source with the ability to scan through a large frequency range of ~.05 to 10 THz. The source is an Orotron, driven by a sheet-beam of electrons created by field-emission from a carbon-nanotube array. For this talk, we discuss the parameters of the device and its predicted performance, and focus on the fabrication and performance of the carbon-nanotube-based electron gun, which may also find application as an ionization source for other types of sensors. Our goals include a large total current density in the sheet-beam, good electrical contact between the carbon nanotubes and the substrate, and reproducibility in the growth. The carbon nanotubes are grown by conventional chemical vapor deposition of Acetylene gas on Silicon substrates, using evaporated iron thin films as catalysts. In order to minimize the electrical resistance between the carbon nanotubes and the Si substrate, we deposit the Fe directly on the Si; in contrast to most previous investigations which insert a diffusion barrier layer of a metal oxide between the catalyst and the Si. We describe the conditions necessary to grow CNT arrays without this diffusion barrier, and offer hypotheses as to why the growth is successful or unsuccessful under various conditions. We also discuss the effect of the catalyst pattern dimensions and shape on the effectiveness of extracting a large current density from the emitters, as well as the effects of pre-growth and post-growth treatment of the samples with oxygen plasma.

6549-23, Session 6

Compact, mission configurable mm-wave spectrometer based on a channel drop filter

E. I. Smirnova, A. G. Bailey, L. M. Earley, S. S. Kurennoy, Los Alamos National Lab.

We have developed a novel mm-wave spectrometer based on a Photonic Band Gap (PBG) channel-drop filter (CDF). There is a need for a compact wide-band versatile and configurable mm-wave spectrometer for applications in mm-wave communications and remote sensing. PBG structures are two-dimensional periodic structures of rods. CDFs present us with a unique means for filtering frequencies at mm-waves. CDF is a novel concept allowing filtering the frequency spectra and channeling selected frequencies into separate waveguides through a PBG structure. We have designed a spectrometer with a CDF working in the frequency range of 90-130 GHz. The CDF can be connected to any type of antenna and detector. A large ground based outdoor antenna can be used for remote sensing with radars. A compact antenna can be used for indoor or space applications. The signal in the waveguide channels can be measured with any type of sensor such as a cooled bolometer or a room temperature mm-wave diode. The size of the spectrometer is under 5 inches by 5 inches and just a quarter of an inch in thick. Multiple filters can be stacked together to construct a mission specific package. We propose to construct the filter with silicon rods on a 100mm silicon wafer using MEMS technology. We will then evaluate the filter at our mm-wave laboratory to demonstrate the channeling of frequencies in a proof-of-principle experiment at 100GHz. This technology will work well for frequencies from 60GHz to 1000GHz.

6549-24, Session 6

Compact fiber pumped terahertz source

D. Creeden, J. C. McCarthy, P. A. Ketteridge, T. Southward, P. G. Schunemann, J. J. Komiak, W. Dove, E. P. Chicklis, BAE Systems

We have demonstrated a novel terahertz source based on dual-wavelength amplification in PM Yb-doped fiber and difference frequency mixing in a zinc germanium phosphide (ZGP) crystal. The system consists of two orthogonally polarized signals, whose difference frequency is in the terahertz region, amplified in a single all-fiber amplifier chain and mixed in a ZGP crystal to generate high peak-power terahertz radiation. Currently, 2mW of average THz power (20W peak, 20nJ/pulse) has been produced at a repetition rate of 100kHz and pulse widths of 1ns with a conversion efficiency of 0.137%.

6549-25, Session 7

Semiconductor based optically controlled THz optics

I. A. Chen, S. Park, C. Karaalioglu, Stevens Institute of Technology; N. Vallestro, A. Meshal, U.S. Army Communications-Electronics Command; R. Martini, Stevens Institute of Technology

With the combination of improved THz sources and time domain spectroscopy (TDS), THz technologies have sprouted application possibilities spanning many disciplines. However, fundamental control of broadband THz radiation is still lacking development considering the advances in improved sources and detection methods. In particular, THz spectroscopy of materials has revealed certain interesting properties of semiconductors paving way for new applications in the THz regime.

The first manifestation appears in the form of THz modulation experiments, where recently highly efficient (-3dB \@ <5mW absorbed NIR) THz modulation using CW optically excited B-doped Si for both pulsed and CW THz sources was demonstrated. However, using spatially confined charge carriers in a Fresnel zone pattern, the previously demonstrated modulator can be transformed into a THz zone lens that is insensitive to current THz systems. Furthermore, spatial aberrations as well as other detrimental factors plaguing traditional lenses are easily overcome through pattern correction. Thus, a complete adaptable THz optical system would be characterized by a Si wafer, CW optical source, and a spatial light modulator. Also following this prescription, any form of wavefront applications such as adaptive THz polarizers, wavefront imaging, and reflective gratings are possible. We will discuss preliminary results for optically controlled THz optics with applications in military and homeland security.

6549-26, Session 7

Terahertz scanning Fabry-Perot interferometer based on dielectric mirrors

J. W. Cleary, C. J. Fredricksen, A. V. Muravjov, R. E. Peale, T. W. Du Bosq, Univ. of Central Florida; W. R. Folks, S. Pandey, College of Optics & Photonics/Univ. of Central Florida; G. D. Boreman, Univ. of Central Florida; O. J. Edwards, Zyberwear, Inc.

A scanning Fabry-Perot interferometer composed of a pair of high reflectivity dielectric mirrors has been demonstrated in the range 0.075 to 2.8 THz. The mirrors are formed by alternating quarter-wave layers of silicon and air in the usual Bragg configuration. Characterization was performed using a gas laser together and Golay cell or using a backward wave oscillator and crystal detector or microwave power meter. A finesse exceeding 410 for a Fabry-Perot cavity composed of three-period Bragg mirrors was experimentally demonstrated at 0.081 THz, and this implies achieved mirror reflectivity of at least 99.24%. Finesse values of several thousand are possible, which would enable a compact terahertz Fabry-Perot spectrometer with high free spectral range and high spectral resolution simultaneously. Such a device is directly suitable for airborne/satellite and man-portable sensing instrumentation.

6549-28, Session 7

Processing multi-species terahertz spectra for detection of a particular species

R. J. Noll, Goodrich Corp.

In terahertz spectroscopy a critical problem is the separation of spectra from different molecules. When trying to detect the presence of a particular molecule in the presence of other molecules, it is important to find ways to minimize the masking of the desired spectra by the various background molecular spectra. These background molecular spectra or interferents block the detection process of the desired spectra. The present paper describes the use of a principle components analysis method that can enhance the fast detection of molecular species in the presence of many other background constituents. Examples of this background interferent problem are given and how principle component analysis can address the problem.

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6550-01, Session 1

High-resolution 3D coherent laser radar imaging

J. R. Buck, A. I. R. Malm, A. Zakel, B. W. Krause, B. G. Tiemann, Lockheed Martin Coherent Technologies

The Super-resolution Sensor System (S3) program is an ambitious effort to exploit the maximum information a laser-based sensor can obtain. At Lockheed Martin Coherent Technologies (LMCT), we are developing methods of incorporating multi-function operation (3D imaging, vibrometry, polarimetry, aperture synthesis, etc.) into a single device. The waveforms will be matched to the requirements of both hardware (i.e., optical amplifiers, modulators, etc.) and the targets being imaged. The first successful demonstrations of this program have produced high-resolution, three-dimensional images at intermediate stand-off ranges. In addition, heavy camouflage penetration has been successfully demonstrated. The resolution of a ladar sensor scales with the bandwidth as dR = c/(2B), with a corresponding scaling of the range precision. Therefore, the ability to achieve large bandwidths is crucial to developing a high-resolution sensor. While there are many methods of achieving the benefit of large bandwidths while using lower bandwidth electronics (e.g., an FMCW implementation), the S3 system produces and detects the full waveform bandwidth, enabling a large set of adaptive waveforms for applications requiring large range search intervals (RSI) and short duration waveforms. This presentation will highlight the three-dimensional imaging and camo penetration.

6550-02, Session 1

The angle-angle-range-Doppler imaging (AARDI) ladar

L. A. Jiang, J. Luu, D. R. Schue, MIT Lincoln Lab.

The goal of the angle-angle-range-doppler imaging ladar program is to greatly enhance the capability to do discrimination and precision aimpoint selection on stressing mid-course ballistic missile defense objects. Successful discrimination and aimpoint selection require a ladar that is capable of both direct and coherent detection. The AARDI ladar is a flash ladar system that has this unique capability, able to switch between the two detection modes with the same transmit and receiver hardware. The various laser measurement modalities are made possible through the use of a 32 x 32 InGaAs Geiger-mode avalanche photodiode array and a 1064-nm flexible waveform laser. In this paper, we introduce, explain, and demonstrate the idea of coherent photon counting - a method of using arrays of photon-counting detectors for nearly shot-noise-limited coherent measurements. The AARDI laser transmitter is capable of generating laser pulses at 1 kHz repetition rate with a pulse duration from 1 ns to 30 µs at 100-W average power levels. The short 1-ns pulse is used for direct detection measurements and the pulse width can be lengthened to match the target's coherence length for optimal use of photons for coherent measurements. In addition, the transmitter can also impress a bi-phase-shift-keyed phase-code with 2-ns chips onto the outgoing laser pulse for high-resolution range-Doppler measurements. This paper contains an overview of the brassboard system and recent measurement results in Lincoln Laboratory's Active Range of the Optical Systems Test Facility.

6550-03, Session 1

Coherent ladar imaging of the SEASAT satellite retro-reflector ring

D. G. Youmans, SPARTA, Inc.; J. M. Ceniceros, The Boeing Co.

Coherent laser radar imaging of the SEASAT satellite's retro-reflector ring, as observed from a ground telescope, is analyzed. Range resolved Doppler and intensity (RRDI) images of the retro-ring at megameters of range are simulated. The return strength of an individual corner-cube is calculated, including atmospheric effects, and then the entire corner-cube array return is simulated so that the interference effects and image resolution both down-range and in frequency (cross-range) can be accurately analyzed. A pulse-burst waveform ladar is used to create the RRDI images following conventional ISAR techniques. The coherent ladar may also have a flexible waveform, so pulse-pair and binary phase-shift keying waveforms are also analyzed.

Boeing-SVS is currently testing the DST Ladar at the JPL Optical Communications Telescope Laboratory (OCTL) under a MDA / SMDC program. Assuming these tests are successful and authorization is obtained, the theoretical image analysis will be compared with the data collections.

6550-04, Session 2

Chirped amplitude modulation ladar for range and Doppler measurements and 3D imaging

B. L. Stann, B. C. Redman, Army Research Lab.

Shipboard infrared search and track (IRST) systems can detect sea-skimming anti-ship missiles at long ranges. Since IRST systems cannot measure range and line-of-sight velocity, they have difficulty distinguishing missiles from slowly moving false targets and clutter. In a joint Army-Navy program, the Army Research Laboratory (ARL) is developing a chirped amplitude modulation ladar to provide range and velocity measurements for tracking of targets handed over to it by the distributed aperture system IRST (DAS-IRST) under development at the Naval Research Laboratory (NRL) under Office of Naval Research (ONR) sponsorship. By using an array receiver based on Intevac Inc.'s Electron Bombarded Active Pixel Sensor (EBAPS) operating near 1.5 * m wavelength, ARL's ladar also provides 3D imagery of potential threats in support of the force protection mission. This year, ARL has further refined our advanced breadboard ladar. This advanced breadboard incorporates the following improvements: an order-of-magnitude increase in photocathode quantum efficiency, more uniform and greater modulation depth across the chirp bandwidth, a more compact chirp generator, range resolution increase from 1 m to .5 m, improved thermal management, quasi-real-time data processing and display, quasi-real-time image motion compensation, and a transmitter beam expander with a new design that eliminates spherical aberration induced diffraction rings to produce a smoother illumination field. This paper discusses these improvements and presents the results of laboratory and field tests with the advanced chirped AM ladar breadboard.

6550-05, Session 2

Multiscale target manifold characterization for 3D imaging ladar

E. Whittenberger, D. E. Waagen, N. N. Shah, D. R. Hulsey, Raytheon Missile Systems

Manifold extraction techniques, such as ISOMAP, are capable of projecting nonlinear, high-dimensional data to a lower-dimensional subspace while retaining discriminatory information. In this investigation, ISOMAP is applied to 3D LADAR range imagery. Selected man-made objects are reduced to sets of spin-image feature vectors that describe object surface geometries. At various spin-image support scales, we use a distribution-free test to quantify differences between man-made objects in both the high-dimensional spin-image vector representation and in the low-dimensional spin-image manifold extracted using ISOMAP.

6550-06, Session 2

Dual-band spacecraft sensor suite for lunar and small-body landing

B. G. Boone, Johns Hopkins Applied Physics Lab.

NASA is planning missions to small planetary bodies in which low-risk high-accuracy soft-landing must be accomplished independent of ground control. Accurate estimates of range, descent rate, attitude, and translational drift rate must be made to enable precision landings in low gravity environments down to very low (< 1 cm/sec) drift velocities. Operational ranges are expected to range from a kilometer down to one meter. Poorly characterized landing sites will require real-time obstacle avoidance and abort options. Although passive sensors are being considered, active sensors enable the spacecraft designer to exploit more optimal measurement techniques in which the illumination is controlled by design rather than accommodated by default. This paper addresses the development and validation of a robust combination of sensors, which reduce risks while minimizing impact on spacecraft mass and power. This paper will address the design, test, and evaluation of two technologies: a miniature lidar and a millimeter-wave Doppler radar. A pulsed Nd:YAG lidar with a two-axis scanner is co-boresighted with a Ka-band CW Doppler radar on a two-axis gimbal, along with a MEMS inertial measurement unit and a data acquisition PC on a mobile test-bed. Test results will be presented and discussed for conditions that emulate appropriate landing and proximity operations. Fixed test structures with corner reflector targets are used to validate this approach and calibrate sensor sensitivity to different geometries and kinematics. Guidance and control simulations for landing will ultimately be validated with sensor models derived from these tests prior to instrument redesign and future full-scale tests.

6550-07, Session 2

Characterization of 3-D imaging lidar for hazard avoidance and autonomous landing on the Moon

D. F. Pierrottet, Coherent Applications, Inc.

No abstract available

6550-08, Session 2

Aerial vehicle navigation over unknown terrain environments using inertial measurements and dual airborne laser scanners or flash ladar

M. Uijt de Haag, A. Vadlamani, Ohio Univ.

This paper discusses a precise navigation system for unmanned or manned aerial vehicles over unknown or partially known terrain environments that integrates measurements from an Inertial Measurement Unit (IMU) with measurements from either a dual airborne laser scanner system or a flash Ladar. The proposed system will be a reliable alternative to the Global Positioning System (GPS) for areas where GPS is unavailable due to unintentional interference caused by atmospheric effects, interference from communication equipment, as well as intentional jamming. It may also be used for autonomous lunar or martial landing systems.

Two approaches are described in this paper, one approach using Dual Airborne Laser Scanners (DALS) (one pointing forward, one pointing aft) and the other approach using an Airborne Flash Ladar (AFL). Advantages and disadvantages of both approaches will be discussed. The proposed navigation system uses strapdown IMU measurements to estimate the aerial vehicle position and attitude and to geo-reference the sensor data. Then it uses the estimated maps from both the fore and aft-pointing scanning Ladars or consecutive flash Ladar range frames to estimate the systematic IMU errors such as the position and velocity drift errors.

Results from an AFL and DALS simulator will be used to evaluate the system performance. The AFL and DALS simulators have been developed at Ohio University and use real trajectory and attitude profiles from flight tests performed with Ohio University's DC-3. The paper will furthermore include limited flight test results with Ohio University's DC-3. At the current moment position accuracies at the meter-level are achieved.

6550-09, Session 2

Use of 3D laser radar for navigation of unmanned aerial and ground vehicles in urban and indoor environments

M. Uijt de Haag, D. Venable, M. Smearcheck, Ohio Univ.

This paper discusses the integration of Inertial measurements with measurements from a three-dimensional (3D) imaging sensor for position and attitude determination of unmanned aerial vehicles (UAV) and autonomous ground vehicles (AGV) in urban or indoor environments. To enable operation of UAVs and AGVs at any time in any environment a Precision Navigation, Attitude, and Time (PNAT) capability is required that is robust and not solely dependent on the Global Positioning System (GPS). In urban and indoor environments a GPS position capability may not only be unavailable due to shadowing, significant signal attenuation or multipath, but also due to intentional denial or deception. Although deep integration of GPS and Inertial Measurement Unit (IMU) data may prove to be a viable solution an alternative method is being discussed in this paper.

The alternative solution is based on 3D imaging sensor technologies such as Flash Ladar (Laser Radar). Flash Ladar technology consists of a modulated laser emitter coupled with a focal plane array detector and the required optics. Like a conventional camera this sensor creates an "image" of the environment, but producing a 2D image where each pixel has associated intensity vales the flash Ladar generates an image where each pixel has an associated range and intensity value. Integration of flash Ladar with the attitude from the IMU allows creation of a 3-D scene. Current low-cost Flash Ladar technology is capable of greater than 100 x 100 pixel resolution with 5 mm depth resolution at a 30 Hz frame rate.

The proposed algorithm first converts the flash Ladar measurements to a point cloud of the 3D environment using the IMU measurements, next, significant environmental features such as planar features (walls), line features or point features (corners) are extracted and associated from one flash Ladar frame to the next. Finally, characteristics of these features such as the normal or direction vectors are used to compute the platform position and attitude changes. These "delta" position and attitudes are then used calibrate the IMU. Note, that the IMU is not only required to form the point cloud of the environment expressed in the navigation frame, but also to perform association of the features from one flash Ladar frame to the next.

This paper will discuss the performance of the proposed system using both simulator data and data collected from a moving platform in an indoor environment. The former consists data from a simulated IMU and flash Ladar installed on an aerial vehicle for various trajectories through an urban environment. The latter consists of measurements from a CSEM Swissranger 3D imaging sensor, a MicroStrain low-cost IMU, and a Honeywell MEMS IMU. Data was collected on both a ground vehicle and a manually operated aerial vehicle inside the Ohio University School of Electrical Engineering and Computer Science building.

6550-10, Session 2

Correlation between LIDAR reflux intensity and the accuracy of the associated elevation information

G. Heidelmeyer, U. Klingauf, Technische Univ. Darmstadt (Germany)

Due to the growing demand of digital height information in the aviation data sources providing a high degree of integrity have to be ascertained. Especially for ground near operations (e.g. helicopter missions) and autonomous operating aircrafts (e.g. UAV) the supply of reliable terrain information is necessarily demanded. Beside INSAR laser scanning appears to be an appropriate data origin for the provision of such high resolution height information.

Normally terrain data (DEM) is related to the "bare earth" in order to obtain a "Digital Terrain Model" (DTM). However to meet the specific requirements for aviation purposes the elevation information should be provided as a "Digital Surface Model" (DSM) representing the real surface of the earth including all cover like vegetation and buildings. But due to the characteristics of active remote sensors the derived height model always describes something in between the two elevation representations.

To guarantee the applicability of LIDAR elevation data in the aviation the Technische Universität Darmstadt (TUD) deals with the determination of the correlation between the degree of reflux intensity and the correctness of the provided height information. With the intention to implement a procedure to prepare the LIDAR data for such special constraints, in addition to the determination of the impact of the reflux intensity the surface characteristics (topography, terrain slope etc.) will be considered. By knowing the correlation between all the influencing factors the LIDAR data will be enhanced to satisfy the needed integrity for a dedicated aviation application.

6550-11, Session 2

Distributed aperture active imaging

J. C. Marron, R. L. Kendrick, Lockheed Martin Coherent Technologies

No abstract available

6550-12, Session 3

ASTM-57: 3D Ladar Standards Development Committee

G. S. Cheok, National Institute of Standards and Technology

No abstract available

6550-13, Session 3

The advanced measurements optical range ladar test facility

C. E. Keffer, T. J. Papetti, CAS, Inc.; E. Johnson, U.S. Army Space and Missile Defense Command

The Advanced Measurements Optical Range (AMOR) began operations in 1978 with a mission to measure ladar target signatures of ballistic missiles and to advance the understanding of object features useful for discrimination of reentry vehicles from decoy objects. Ground breaking ladar technology developments and pioneering ladar target signature studies were completed in the early years of AMOR operations. More recently, AMOR functions primarily as a user test facility measuring ladar signatures of a diverse set of objects such as reentry vehicles and decoys, missile bodies, and satellite materials as well as serving as a ladar sensor test-bed to recreate realistic missile defense engagement scenarios to exercise and test missile seeker technologies. This paper gives a status report on current AMOR capabilities including the optical system, target handling system, laser systems, and data measurement types. Plans for future facility enhancements to provide improved service to ladar data users in the modeling and simulation field and to ladar system developers with requirements for advanced test requirements are also reported.

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6550-14, Session 3

3D imagery quality metrics

G. W. Kamerman, FastMetrix, Inc.

No abstract available

6550-15, Session 3

A validation procedure for a ladar system radiometric simulation model

B. C. Leishman, S. E. Budge, R. T. Pack, Utah State Univ.

The validation process is crucial in measuring the value and accuracy of a computer simulation. These validation efforts become increasingly difficult for simulations attempting to model random or interrelated processes. As explained in a previous publication, the USU LadarSIM software package has recently been enhanced to include the modeling of Ladar beam footprints. This paper will discuss the pertinent issues involved in verifying the radiometric model of the simulation and present a practical validation approach.

In order to validate the complicated and interrelated processes, a systematic approach had to be developed. Once all of the known parameters were gathered, the variable parameters of the system were determined from simulation test scenarios. This was done in a way to isolate as many variables as possible; then build on the previously obtained results. First, the appropriate voltage threshold levels of the discrimination electronics were set by analyzing the number of false alarms seen in actual data sets. With this threshold set, the noise was then adjusted to achieve the appropriate number of dropouts. Once a suitable system noise level was found, the range errors of the simulated and actual data sets were compared and studied.

Because of the importance of range errors, the validation of them was analyzed using two methods: first by examining the range error of a surface with known reflectivity and second by examining the range errors for specific detectors with known responsivities. This gave insights into the discrimination method and receiver electronics used in the actual system.

6550-16, Session 3

MRDF and BRDF measurements of low scatter materials

B. E. Walker, T. J. Papetti, C. E. Keffer, CAS, Inc.; E. Johnson, U.S. Army Space and Missile Defense Command

The results of Mono-static Reflectivity Distribution Function (MRDF) and Bi-static Reflectivity Distribution Function (BRDF) measurements of several low scatter materials at 1.064μm and 532nm wavelengths are presented. Materials such as ELSI Vel-Black, Edmund Scientific Flock Paper, and 2% Spectralon were measured. The MRDF/BRDF system at the Advanced Measurements Optical Range at Redstone Arsenal in Huntsville, Alabama was used for these measurements. The system is capable of mono-static measurements with incidence angles from 0 to 80 * and bi-static angles ± 3 * both in- and out-of-plane. All materials were measured using both parallel and crossed transmit and receive polarizations.

6550-17, Session 3

Analysis of Geiger-mode APD direct detection ladar receivers

P. Gatt, Lockheed Martin Coherent Technologies

No abstract available

6550-18, Session 3

Analysis of Geiger-mode APD ladar systems

R. M. Heinrichs, MIT Lincoln Lab.

No abstract available

6550-19, Session 4

High resolution foliage penetration with gimbaled lidar

M. W. Roth, Johns Hopkins Univ.

No abstract available

6550-20, Session 4

Sandblaster: addressing the helicopter landing brown-out problem

L. R. Brothers, Defense Advanced Research Projects Agency

No abstract available

6550-21, Session 4

Full wave form processing

A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria)

Further advances with High resolution laser scanner with waveform digitisation for subsequent Full Waveform Analysis

6550-22, Session 4

Jigsaw phase 3: a miniaturized airborne 3D imaging laser radar with photon-counting sensitivity for foliage penetration

R. M. Marino, J. E. Drover, R. Hatch, D. R. Schue, R. Freehart, G. Rowe, J. Mooney, MIT Lincoln Lab.

The goals of the DARPA Jigsaw Phase 3 program include the development and demonstration of miniaturized high-resolution 3-D imaging laser radar (ladar) sensor technology and system that can be operated semi-autonomously form unmanned air vehicles (UAV) to image and identify military ground vehicles that may be hiding under camouflage or foliage such as tree canopy. In this third phase of the program, MIT Lincoln Laboratory has developed a light-weight compact 3-D imaging ladar system that has successfully demonstrated the feasibility and utility of this mission. With our Harris Corp. team members, the sensor system has been integrated into a 12-inch gimbal (from Sonoma EO), and used in airborne data collects from a UH-1 manned helicopter. The sensor system operates day or night and produces high-resolution 3-D spatial images using short laser pulses (< 200 ps fwhm) and a focal plane array of Geiger-mode avalanche photo-diode (APD) detectors with independent digital time-of-flight counting circuits at each pixel (< 500 ps fwhm timing resolution). The sensor technology includes Lincoln Laboratory developments of advanced microchip laser and focal plane array technologies. The miniaturized telescope (30 mm aperture) is combined with a miniature Risley prism scanner to provide an 11-deg field -of-regard (FOR). A sequence of of digital time data from the 32x32 FPA are processed with platform GPS/INS state data to produce 3-D geo-located point cloud imagery of the designated scene. Successive image frames from the 12-kilohertz pulse repetition rate laser are accumulated into volumetric histograms to provide 3-D volume and intensity information.

6550-23, Session 5

A texture-based technique for DEM generation from lidar data

D. Charalampidis, Univ. of New Orleans; K. Alphonso, Diamond Data Systems, Inc.

Recent advances LIDAR technology have allowed rapid collection of topography measurements over large areas. The LIDAR technology is becoming an important approach for generating high-resolution digital terrain models. The high-resolution advantage of the LIDAR technology over other methods of data acquisition has made it important in several applications such as flood modeling and landslide prediction. In order to generate a Digital Elevation Model (DEM), measurements from non-ground features such as manmade objects including buildings and vehicles, and vegetation have to be classified and removed. In this work, a novel algorithm has been implemented and tested. In general, most existing techniques do not use highly sophisticated methods for DEM generation, but they rather concentrate on simple approaches such as interpolation methods and adaptive median-like or slope-based filters. This work presents one of the few attempts that investigate the possibility of using advanced features including multiscale and textural features for the development of an automatic technique. Some experimental results are presented to illustrate the effectiveness of the proposed method. Future work and extensions of the proposed technique are discussed.

6550-24, Session 5

TriDAR for obstacle detection inside aerosol

X. Zhu, L. Gagnon, S. Gagnon, C. Smith, P. M. Church, Neptec Design Group Ltd. (Canada)

The ability to detect obstacles or ground inside an aerosol is a highly sought-after feature for numerous applications. Helicopter pilots need a sensor to assist in a safe landing during white-out conditions (i.e. fog or snow storm) or brown-out conditions, in which it is difficult for a pilot to see obstacles or ground through the dense dust generated by the helicopter's rotorwash. In the upcoming NASA lunar landing and Mars landing missions, the exhaust plume and dust generated by rockets also causes issues for spaceships to land safely.

Conventional LIDARs have been used to detect obstacles inside aerosol with limited success. Although flash LIDARs or gated laser cameras can use timing-discrimination functions to suppress the signals from aerosol, they generally don't have enough optical power to penetrate aerosol and to cover a reasonably large landing area. Conventional scanning LIDARs need to have a co-aligned launching beam and returning beam before the scanning optics. Consequentially, the returning beam from a target is always imaged back on the receiver regardless of the range to target. The scattering from aerosol in front of a LIDAR window can saturate the receiver before any further signal processing can occur.

Neptec TriDAR uses an autosynchronized optical design, which utilizes a triangulation relationship to control the amount of returning beam accepted by the TOF (time-of-flight) receiver as a function of target range. The design also maintains this property during high-speed optical scanning. As a result, TriDAR can suppress the return signals from nearby aerosol scattering and, at the same time, have a sensitivity and dynamic range to detect obstacles or ground inside aerosol. In this paper, TriDAR's applications and results in obstacle detection inside an aerosol will be discussed.

6550-25, Session 5

Performance of laser penetration through forest vegetation

T. R. Chevalier, O. K. Steinvall, H. Larsson, Swedish Defence Research Agency (Sweden)

One of the major advantages with laser sensors compared to passive optronic sensors, are their capability to penetrate sparse vegetation. Therefore, the most limiting performance issue is the portion of laser shots that are absorbed by the foliage. This issue is targeted in this paper and an analysis of the effect of forest vegetation of Nordic type is presented. The conclusions are based on laser scanner measurement as well as photos. While the analysis covers several elevation angles, the evaluation focuses on ground-to-ground measurements.

6550-26, Session 5

Identification of littoral targets with a laser range profiler

J. C. van den Heuvel, H. H. P. T. Bekman, F. J. M. van Putten, TNO-FEL (Netherlands)

Naval operations in the littoral have to deal with threats at short range in cluttered environments with both neutral and hostile targets. There is a need to have a fast identification, which is possible with a laser range profiler.

A high bandwidth, fast laser receiver has been developed to perform tests on the capability of a laser range profiler for identification. Type rise and fall times are 2 nanosec.

The experimental results were compared with simulated range profiles based on 3D target models. It is shown that sea-surface targets can be distinguished from their range profiles. The influence on the identification performance of range resolution and a-priori knowledge of the aspect angle is presented. By scanning the laser beam in the azimuth direction a 2D image with a low lateral and a high-range resolution is obtained. This "1.5D image" gives an improved identification performance especially for side-view images.

Classification algorithms have been tested on simulated range profiles and 1.5D images of a number of small boats. With a range resolution of 0.3 meter (comparable to our fast laser receiver), these small boats could be identified.

6550-36, Session 5

Utilization of full-waveform data in airborne laser scanning applications

A. Ullrich, N. Studnicka, RIEGL Laser Measurement Systems GmbH (Austria)

Direct detection laser radar systems with echo signal digitization and subsequent full waveform analysis provide additional information on the target's properties compared to conventional first-pulse / last-pulse systems. We focus on the advantages of utilizing the additional information especially in the course of airborne laser scanning, improving for example the mandatory process of classifying the measurement data for generating high-quality digital terrain models. We present field data to demonstrate the superiority of full-waveform analysis data over conventional laser data in post-processing.

6550-27, Session 6

Container integrity verification using laser triangulation

A. Busboom, V. Sequeira, Joint Research Ctr. (Italy)

We propose a system for verifying the integrity of containers using a triangulation based laser line scanner, with applications in the field of nuclear containment verification. Our approach is based on the assumption that any intrusion into the container shell and subsequent reconstruction of the surface will inevitably leave slight changes to the surface shape. Even if the changes may not visible to the human eye, the proposed system can detect them by comparing the surface map of the container to a previously acquired reference.

A 3D reference of the entire container surface is acquired by fusing multiple scans from different viewpoints. Subsequently, scans of arbitrary parts of the surface can be made and compared against the reference.

We address two specific problems in detail: Firstly, in order to make the system light-weight and portable, the scanner is mounted on a turntable on top a tripod and the scanner is panned while acquiring the scan. The range data needs to be remapped to a global 3D coordinate frame which requires the exact knowledge of the position and orientation of the panning axis with respect to the scanner coordinate frame. We propose an auto-calibration procedure which involves scanning a planar calibration target, e.g. a coated glass pane. The calibration algorithm uses nonlinear optimization techniques in order to find the parameter set which results in a maximally planar surface after the 3D remapping. We show that this calibration procedure is robust, accurate and easy to use in the field.

Secondly, we discuss the registration of scans against the reference. In a first step, the coarse position of the verification scan on the typically much larger reference scan needs to be determined. We propose a method based on the automated selection and correspondence search of feature points such as dents or intersection of welds. In a second step, the registration is refined using the well-known Iterative Closest Points (ICP) algorithm.

We present results using steel and concrete casks which demonstrate that our calibration and registration procedures yield sufficient accuracy to detect intrusions which cannot be visibly perceived.

6550-29, Session 6

A low-cost multi-static, networked approach to 3D ladar for surveillance

Y. Wang, B. Hu, H. Q. Le, Univ. of Houston

A concept for 3D ladar for surveillance, intrusion detection, and access control of a facility is described. The essence is a non-conventional system architecture that consists of: i) multi-static configuration with an arbitrarily scalable number of transmitters (Tx's) and receivers (Rx's) that form an optical wireless code-division-multiple-access (CDMA) network, and ii) flexible system architecture with modular plug-and-play components that can be deployed for any facility with arbitrary topology. Affordability is a driving consideration. A key feature for low system cost is an asymmetric use of many inexpensive Rx's in conjunction with fewer Tx's, which are generally more expensive. The Rx's are spatially distributed close to the surveyed area for large coverage, and capable of receiving signals from Tx's with moderate laser power, which is also crucial for affordability. There are two unique features of the network approach that are distinctive from the non-network approach. The system produces sensing information that scales as NxM, where N, M are the number of Tx's and Rx's, as opposed to linear scaling ~N in a non-networked system. Also, for target positioning, besides laser pointing direction and time-of-flight, the algorithm includes multiple point-of-view inmage fusion and triangulation for enhanced accuracy, which is not applicable to non-networked monostatic ladars. Scaled-model experiments with low-power semiconductor lasers and theoretical simulation were performed. Results on multiple point-of-view images and fusion for entire scene reconstruction are described. Application concepts for surveillance, intrusion detection, and access control are also discussed.

6550-30, Session 6

Detection of small sea-surface targets with a search lidar

J. C. van den Heuvel, H. H. P. T. Bekman, F. J. M. van Putten, TNO-FEL (Netherlands)

Naval operations in the littoral have to deal with the treat of small sea targets, which are difficult to detect with radar. These targets have a low radar cross-section and low velocity which makes them hard to detect by radar. Typical threats include Jet Skies, FIAC's, and speedboats.

Lidar measurements at the coast of the Netherlands have shown a very good signal to clutter ratio with respect to buoys located up to 10 km from the shore were the lidar system was situated. The lidar clutter is much smaller than the radar clutter due to the smoothness of the sea surface for optical wavelengths, thus almost all laser light is scattered away from the receiver. These results show that due to the low clutter a search lidar is feasible that can detect small sea-surface targets.

The concept of a search lidar is presented and its performance is derived from system models. By using a high rep-rate laser and a variable beam divergence the search time can be limited. The design of a search lidar based on a commercially available high power and high rep-rate laser is shown. This demonstrator will be used to validate the system modeling, determine the critical issues, and demonstrate the feasibility.

6550-31, Session 6

Long distance open path lidar for small molecules

S. Wu, California Institute of Technology

We demonstrate a record open path LIDAR for small molecules, e.g. CO_2, CH_4, based on Two-Tone Frequency Modulation (TTFM) spectroscopy. Our spectrometer could detect 1% change in ambient CO_2, and 100ppbV*1meter of CH_4 plume over a record length of 3km. Our sensors features phase-insensitive detection, and all polarization maintaining EDFA and fiber optics for enhanced power budget for reaching even longer distances.

6550-32, Session 7

Closed loop optimization of optomechanical structure via mechanical and optical analysis software

D. Bonin, B. M. McMaster, Corning Tropel Corp.

This paper will discuss how mechanical and optical analysis software can be used together to optimize an opto-mechanical structure. Mechanical analysis software output is post processed into Zernike polynomial and rigid body motions for analysis with optical modeling software. Structural modifications can then be implemented to improve optical performance.

A Cassegrain telescope, which can be utilized for laser radar applications, will be used to demonstrate this optimization. Two vibrational loading cases are compared. Based on the deformation results of the FEA, Zernike polynomials and rigid body motions are generated and applied to the optical surfaces in CodeV. The effect of these deformations on wavefront can then be computed and compared to a required performance.

Improvements to this methodology will be discussed.

6550-33, Session 7

Progress in laser risk reduction for 1 micron lasers at GSFC

W. S. Heaps, NASA Goddard Space Flight Ctr.

The Laser Risk Reduction Program has concluded five years of operation. The program has supported a number of efforts at Goddard to ensure that lasers employed in future NASA missions will be reliable and affordable include a variety of activities. These include testing of laser pump diodes, testing non linear optical materials, evaluating materials for use in laser construction, and evaluating commonly used materials for their potential to cause contamination.

We are also engaged in prototyping a number of laser designs that we hope will enable us to generically span the range of laser requirements that we may be asked to satisfy by the missions in the foreseeable future.

Finally we are developing wavelength conversion techniques to enable missions requiring laser spectrographic techniques. We are also investigating methods for predicting the performance and survivability of non-linear materials in space.

In this overview report we will present some of the more valuable results that we have obtained over the past five years and discuss plans for future tests and measurements

6550-34, Session 7

Progress on 2-micron laser transmitter for space-based wind and carbon dioxide measurements

U. N. Singh, J. Yu, M. J. Kavaya, NASA Langley Research Ctr.

Under the Laser Risk Reduction Program at NASA Langley Research Center, significant advancements have been made in developing solid-state 2-micron laser for space based measurements of the horizontal and vertical wind velocities with high precision and resolution, utilizing coherent Doppler wind lidar technique. This laser transmitter, with slight modification in design, can also be used in a Differential Absorption Lidar (DIAL) system for measuring atmospheric CO2 concentration profiles. Researchers at NASA LaRC have successfully demonstrated world record 2-micron laser energy, greater than one joule per pulse energy with excellent beam quality, by combining an oscillator with two amplifiers systems. Based on the successful demonstration of a fully conductive cooled oscillator by using heat pipe technology, an improved fully conductive cooled 2-micron amplifier has been designed, manufactured and being integrated for field demonstration. In addition to technology development and demonstration, a compact and engineering hardened 2-micron laser is under development. It is capable of producing 250 mJ at 10 Hz by an oscillator and one amplifier. This compact laser transmitter is expected to be integrated to a lidar system for field measurements.

The recent achievements will enable space-based coherent wind lidar measurement. This paper will give an overview of the progress made towards developing a state-of-the-art solid-state 2-micron laser transmitter. This work is being performed under Laser Risk Reduction Program funded by NASA's Earth-Sun Technology Office.

6550-35, Session 7

Improving lifetime of quasi-CW laser diode arrays for pumping 2-micron solid state lasers

F. Amzajerdian, NASA Langley Research Ctr.

No abstract available

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6551-01, Session 1

Dust in the wind: challenges for urban aerodynamics

J. Boris, Naval Research Lab.

The fluid dynamics of airflow through a city controls the transport and dispersion of airborne contaminants. This is a problem of urban aerodynamics rather than of meteorology. The average flow, large-scale fluctuations and turbulence are closely coupled to the building geometry. Buildings create large “rooster-tail” wakes; there are systematic fountain flows up the backs of tall buildings; and dust in the wind also moves perpendicular to or even against the locally prevailing wind. Requirements for better prediction accuracy demand time-dependent, three-dimensional CFD computations that include solar heating and buoyancy, complete landscape and building geometry specification including foliage and, realistic wind fluctuations. This fundamental prediction capability is necessary to assess urban visibility and line-of-sight sensor performance is street canyons and rugged terrain.

Computing urban aerodynamics accurately is clearly a time-dependent High Performance Computing problem. In an emergency, on the other hand, prediction technology to assess light propagation and sensor performance in the face of industrial spills, transportation accidents, or terrorist attacks has very tight time requirements that suggest simple approximations which produce inaccurate results. In the past we have had to choose one or the other: a fast, inaccurate model or a slow accurate model. Using new fluid-dynamic principles, an urban-oriented emergency assessment system called CT-Analyst was invented that solves this dilemma. It produces HPC-quality results for airborne contaminant scenarios nearly instantly and has unique new capabilities suited to sensor optimization. This presentation treats the design and use of CT-Analyst and discusses the developments needed for widespread use with advanced sensor and communication systems.

6551-02, Session 1

Predicting radiance obscuration during a high altitude nuclear event using the advanced systems survivability integrated simulation toolkit (ASSIST)

M. A. Johnson, M. Hopkins, S. Sokolsky, The Aerospace Corp.

A parametric look at the radiance effects to be encountered, spatially and temporally, of high altitude nuclear events (HANE) on laser communications in the 1-5 um range is presented. The radiance from a high altitude nuclear event is an optical obscurant and will effect the propagation of Laser energy communications systems. The spatial and temporal radiance effects are wavelength dependent. The investigation uses the NORSE and SCENARIO components of the Advanced Systems Survivability Integrated Simulation Toolkit (ASSIST) from the Defense Threat Reduction Agency (DTRA) to explore, through modeling and simulation, the radiance effects of a 1 Megaton Nuclear event occurring at 100 km altitude as seen from above the event by a sensor placed at 35,786 km altitude. ASSIST is a DTRA validated toolkit for performing nuclear effects modeling , simulation, and analysis based upon first principle physics and chemistry, and data garnered from actual atomic tests. In addition, a comparison and contrast of the SCENARIO and NORSE tools for performing similar analyses with like inputs is presented. Simulation results of the SCENARIO and NORSE tools provide a look at the capability of the ASSIST toolkit to predict radiance obscuration effects that would be encountered by optical communications systems during a high altitude nuclear event (U).

6551-03, Session 1

Worldwide estimates and uncertainty assessments of laser propagation for diverse geometries for paths in the altitude regime of 24 km and below at wavelengths 0.355 to 14 μm

S. T. Fiorino, R. Bartell, G. P. Perram, M. Krizo, D. Fedyk, S. Cusumano, Air Force Institute of Technology

The directed energy modeling and simulation community can make important direct contributions to the joint warfighting community by establishing clear and fully integrated future program requirements. These requirements are best determined via analysis of the expected variability/uncertainty in system performance arising from spatial, spectral and temporal variations in operating conditions. In this study of atmospheric effects on HEL systems, the parameter space is explored primarily using the Air Force Institute of Technology Center for Directed Energy’s (AFIT/CDE) High Energy Laser End-to-End Operational Simulation (HELEEOS) parametric one-on-one engagement level model. HELEEOS is anchored to respected wave optics codes and all significant degradation effects—including optical turbulence and molecular, aerosol, and liquid water drop/droplet absorption and scattering—are represented in the model. Beam spread effects due to thermal blooming caused by the various absorbers are considered when appropriate. Strehl Ratio is the primary performance metric used in the study, with results presented in the form of histograms.

The expected performance of laser systems operating at powers from low (~1 W) to high (500 kW) power is assessed at approximately 20 wavelengths between 0.355 um to 14 um for a number of widely dispersed land and maritime locations worldwide. Scenarios evaluated include both up and down looking generally oblique engagement geometries over ranges up to 9000 meters in which anticipated clear air aerosols and thin layers of fog, light rain, various cloud types, and battlefield obscurants occur. Seasonal and boundary layer variations (summer and winter) and time of day variations for a range of relative humidity percentile conditions are considered to determine optimum employment techniques to exploit or defeat the environmental conditions. Each atmospheric particulate/obscurant is evaluated based on its wavelength-dependent forward and off-axis scattering characteristics and absorption effects on high energy laser engagement. In addition to realistic vertical profiles of molecular and aerosol absorption and scattering, correlated optical turbulence profiles in probabilistic (percentile) format are used along with air-to-ground cloud free line of sight (CFLOS) probabilities for platform altitudes from the surface to 20,000 ft and look angles from 0 to 80 degrees from nadir.

6551-04, Session 1

High-speed communications enabling real-time video for battlefield commanders using tracked FSO

M. K. Al-Akkoumi, R. C. Huck, J. J. Sluss, Jr., Univ. of Oklahoma

Free Space Optics (FSO) Technology is currently in use to solve the last mile problem in telecommunication systems by offering higher bandwidth than wired or wireless connections when optical fiber is not available. Incorporating mobility into FSO technology can contribute to growth in its utility. Tracking and alignment are two big challenges for mobile FSO communications. In this paper, we present a theoretical approach for mobile FSO Networks between Unmanned Aerial Vehicles (UAVs), manned aerial vehicles, and ground vehicles. We introduce tracking algorithms for achieving Line of Sight (LOS) connectivity and present analytical results. Two scenarios are studied in this paper: 1 - An unmanned aerial surveillance vehicle, the Global Hawk, with a stationary ground vehicle, an M1 Abrams Main Battle Tank, and 2 - a manned aerial surveillance vehicle, the E-3A Airborne Warning and Control System (AWACS), with an unmanned combat aerial vehicle, the Joint Unmanned Combat Air System (J-UCAS). After initial vehicle locations have been coordinated, the tracking algorithm will steer the gimbals to maintain connectivity between the two vehicles and allow high-speed communication to occur. Using this algorithm, data, voice, and video can be sent via the FSO connection from one vehicle to the other vehicle.

6551-05, Session 2

Corrections to published information about atmospheric attenuation between 10 GHz and 1 THz

J. C. Wiltse, Georgia Institute of Technology

Atmospheric attenuation is one of the most significant factors in limiting the performance of millimeter-wave and terahertz systems. Although atmospheric propagation is fairly well understood up to 1 THz, major errors have been published in numerous locations showing atmospheric propagation at frequencies from 10 GHz to 1 THz. Some of these errors have been reported in the past by the present author. The topic was also reviewed in an invited plenary presentation by H. Bruce Wallace at the 2006 SPIE Defense and Security Symposium in Orlando. Three cases are discussed here, two for clear-air conditions and one for fog. In one example, the attenuation at 4 km elevation has been mislabeled as 9150 m (or 30,000 feet) for the 10 to 400 GHz range. This error has appeared in several journal articles, vendors' catalogs, short-course notes, and a recently-published book. In a second case the attenuation peak near 22.3 GHz (due to water vapor absorption) has been plotted at 20 GHz. The third case deals with an error pertaining to attenuation in fog for frequencies between 10 and 1000 GHz. Specific information and corrections will be given for all three cases. The net result of these errors is that development of sensor and communications applications has been impeded because the errors usually make atmospheric losses appear to be greater than they really are.

6551-06, Session 2

Comparison of near to mid infrared (0.9 - 10μm) laser propagation through the New York City metro area

P. A. Corrigan, R. Martini, E. Whittaker, Stevens Institute of Technology; C. Gmachl, Princeton Univ.

Low power mid-IR laser light exhibits exceptionally less attenuation in propagation though the New York metro area when compared to near-IR wavelengths. Depending on the type of atmospheric extinction we record a gain factor of up to eight in the Beers-Law exponential coefficient for mid-IR light compared to near-IR, thereby increasing deployable range and SNR of current communication systems by significant orders of true magnitude.

We present transmission data from a collinear, coaxial, multi-wavelength laser test bed spanning 0.9 - 10 microns through seasonal atmospheric conditions including most fog types, rain, snow, mist as well as other aerosols.

This is achieved using lasers with average power ranging from a few milliwatts (mid-IR QCL) to tens of milliwatts which have been normalized under lock-in detection over a 500 m free space optical link across the Stevens Institute of Technology campus.

We also present corroborating results from an indoor fog experiment simulating various fog conditions. Here we have also deconstructed Beer's attenuation coefficient and realized the contribution of scattering and absorption separately with a purpose-built polar nephelometer. Using Rayleigh & Mie predictions we correctly determine and measure the extent by which a mid-IR system scatters light less under fog than a traditional near-IR one. We hence account for the performance enhancement in the metro-air test bed.

6551-07, Session 2

Minimization of acquisition time in a wavelength diversified FSO link between mobile platforms

A. Harris, Univ. of North Florida

Free-space optical (FSO) communication links are envisioned as a viable option for the provision of temporary high-bandwidth communication links between moving platforms, such as a ground station and an unmanned aerial vehicle. One of the limitations of FSO links is the transmission of laser beams through various weather phenomena. One technique to attempt to overcome the effects of weather, such as fog, is to implement a wavelength diversity scheme between the FSO transmitter and receiver. This paper investigates the minimization of link acquisition times using a wavelength diversity scheme between mobile FSO platforms. The wavelength diversity scheme consists of three different wavelengths, 1.55 μm, 0.85 μm and 10 μm. Each wavelength has different advantages and disadvantages for transmission depending of prevalent weather conditions and atmospheric turbulence conditions. A detailed simulation analysis of the transmission properties of the wavelength diversity schemes will be presented. Based on the transmission properties, a method for minimizing link acquisition times through the exploitation of various properties of each wavelength is presented and analyzed. The transmission property analysis includes the effects of atmospheric properties on the link power and the effects of atmospheric turbulence on the link. Further analysis to investigate the viability of the wavelength diversity scheme to improve FSO tracking between moving platforms is also presented.

6551-08, Session 3

PDF model for uplink to space in the presence of beam wander

L. C. Andrews, R. L. Phillips, Univ. of Central Florida; R. R. Parenti, R. J. Sasiela, Massachusetts Institute of Technology

In this paper we discuss modeling the probability density function (pdf) for the irradiance of an uplink beam to space. We consider both cases of tracked and untracked beams. The pdf models are compared with simulation data over a broad range of beam diameters.

6551-09, Session 3

Laser beam propagation in the ground-to-OICETS laser communication experiments

M. Toyoshima, T. Takahashi, K. Suzuki, S. Kimura, K. Takizawa, T. Kuri, W. Klaus, M. Toyoda, H. Kunimori, National Institute of Information and Communications Technology (Japan); Y. Takayama, T. Jono, K. Arai, Japan Aerospace Exploration Agency (Japan)

The first bi-directional laser communications demonstration between an optical ground station and the Optical Inter-orbit Communication Engineering Test Satellite (OICETS) was successfully conducted in March, May and September, 2006 with an uplink of 2 Mbps and a downlink of 50 Mbps.

The optical ground station is located in Koganei, Tokyo, which was developed by National Institute of Information and Communications Technology (NICT), Japan. Four laser beams were transmitted from the optical ground station to the OICETS satellite in order to reduce the intensity fluctuation of the optical signal due to atmospheric turbulence. The optical scintillation as a function of the number of beams and the frequency response are measured. The uplink and downlink laser transmission results will be presented.

6551-11, Session 3

Development of laser beam transmission strategies for future ground-to-space optical communications

K. E. Wilson, W. T. Roberts, J. M. Kovalik, A. Biswas, Jet Propulsion Lab.

Optical communications is a key technology to meet the bandwidth expansion required in the global information grid. High bandwidth bi-directional links between sub-orbital platforms and ground and space terminals can provide a seamless interconnectivity for rapid return of critical data to analysts. The JPL Optical Communications Telescope Laboratory (OCTL) is a state-of-the-art facility located at 2.2.km altitude in Wrightwood California that is developing operational strategies for ground-to-space laser beam propagation. Strategies include safe beam transmission through navigable air space, adaptive optics correction and multi-beam scintillation mitigation, and line of sight optical attenuation monitoring. JPL has received authorization from international satellite owners to transmit laser beams to twelve retro-reflecting satellites. This paper presents recent progress in the development of these operational strategies tested by narrow laser

beam transmissions from the OCTL to retro-reflecting satellites. We present experimental results and compare our measurements with predicted performance for a variety of atmospheric conditions.

6551-12, Session 4

Demonstration of non-log normal irradiance behavior in weakly-scintillated beams

G. J. Baker, K. R. Bock, Lockheed Martin Advanced Technology Ctr.

Recent work has shown that a Gaussian beam turbulent propagation region exists where the observed random irradiance fluctuations are weak but follow a non-log normal probability distribution (G.J. Baker, JOSA A 23, 2006, p 395). This region has been named the “D1 region”, and includes such examples as focused beams on horizontal paths and collimated beams on ground to space paths. Within the D1 region, low order turbulence effects dominate the beam irradiance behavior and are responsible for the departure from the log normal statistics typically observed in weak fluctuation conditions. In addition, predictions derived from the Rytov perturbation method are inaccurate within the D1 region, since they are built upon the implicit assumption of log normal irradiance behavior.

The previously cited JOSA paper presented analytic arguments that defined and bounded the D1 scintillation region, yet space limitations restricted the amount of simulation data that could be included. This talk presents additional simulation data that serves to further verify and anchor the analytic predictions of the prior JOSA paper. The simulation data is derived from an independent wave optics simulation of beam propagation through atmospheric turbulence, built upon the split-step numerical solution of the governing stochastic Helmholtz equation.

6551-14, Session 4

A new marine atmospheric spectrum for laser propagation

K. J. Grayshan, F. E. Strömqvist Vetelino, C. Y. Young, Univ. of Central Florida; K. J. Grant, Defence Science and Technology Organisation (Australia); L. Wasiczkoc, Naval Research Lab.; H. R. Burris, Jr., Research Support Instruments, Inc; C. I. Moore, Naval Research Lab.; R. Mahon, L-3 Titan Group; M. R. Suite, G. C. Gilbreath, Naval Research Lab.

Current mathematical models describing laser propagation through the atmosphere apply to terrestrial environments. In this paper we develop statistics for atmospheric propagation in marine environments. An atmospheric index of refraction power spectrum specifically tailored to the marine environment is developed and used in scintillation theory in the weak fluctuation regime. With experimental data taken in a maritime environment, the theoretical scintillation values from both marine and terrestrial theories are compared with experimental values. From this, the necessity of a marine model is discussed.

6551-15, Session 4

Angle of arrival fluctuations for free space laser beam propagation through non Kolmogorov turbulence

I. Toselli, Politecnico di Torino (Italy); L. C. Andrews, R. L. Phillips, Univ. of Central Florida; V. Ferrero, Politecnico di Torino (Italy)

Atmospheric turbulence induces significant variation on the Angle-of-Arrival of optical wave used in free space laser communication. Angle-of-Arrival fluctuations of an optical wave in the plane of the receiver aperture can be described in terms of the phase structure function that already has been calculated by Kolmogorov’s power spectral density model. Unfortunately several experiments showed that Kolmogorov theory is sometimes incomplete to describe atmospheric statistics properly. In this paper we carry out analysis of Angle-of-Arrival fluctuations using a Non-Kolmogorov power spectrum which uses a generalized exponent factor instead of constant standard exponent value 11/3.

6551-16, Session 5

Atmospheric propagation studies at the U.S. Naval Research Laboratory free-space lasercom test facility

L. M. Wasiczko, Naval Research Lab.

The U. S. Naval Research Laboratory has a ten mile, maritime, free-space lasercom test facility across the Chesapeake Bay. Free-space lasercom experiments and atmospheric propagation studies have been conducted at this test range over the past several years. One-way measurements of angle-of-arrival fluctuations, Cn2, and turbulence and transmission are regularly recorded. An analysis of optical propagation data at 1550 nm including available meteorological data will be presented.

6551-17, Session 5

Comparison study of packet error rates and bit error rates at the U.S. Naval Research Laboratory free-space lasercom test facility

M. R. Suite, Naval Research Lab.; H. R. Burris, Jr., Research Support Instruments, Inc.; C. I. Moore, L. M. Wasiczko, Naval Research Lab.; M. F. Stell, Research Support Instruments, Inc.; R. Mahon, L-3 Communications Titan Group; W. S. Rabinovich, G. C. Gilbreath, W. J. Scharpf, Naval Research Lab.

The U.S. Naval Research Laboratory, Chesapeake Bay Detachment (NRL-CBD), has a ten mile free-space optical laser communication (FSO lasercom) maritime testbed. Over the past year, a comparison study between packet error rates and bit error rates has been performed. These are the two most common methods to characterize the quality of an FSO lasercom link. Bit error rate (BER) testing and packet error rate (PER) testing are measured in a variety of atmospheric conditions on the one-way range at the lasercom test facility (LCTF). Results from this study will be presented.

6551-18, Session 5

Lidar system for monitoring turbulence profiles

G. G. Gimmestad, D. W. Roberts, J. M. Stewart, J. W. Wood, Georgia Tech Research Institute

The Georgia Tech Research Institute (GTRI) has developed a new type of LIDAR system for monitoring slant-path profiles of atmospheric refractive turbulence. The LIDAR makes real-time measurements by projecting a laser beam to form a laser beacon at several successive altitudes. The beacon is observed with a multiple-aperture telescope and differential motion of the beacon images from each altitude is characterized by a variance, as in the astronomical Differential Image Motion Monitor (DIMM), which uses natural stars as sources. Whereas the DIMM only provides one number, r0, to characterize the entire atmosphere, an inversion algorithm has been developed for the LIDAR to retrieve the turbulence profile. GTRI has built and tested a brassboard version of the LIDAR instrument. The tests included truth data obtained with balloon-borne microthermal probes. The brassboard system operates at 355 nm wavelength and is capable of measurements during both day and night.

6551-19, Session 5

Comparing horizontal path Cn2 measurements over 0.5 km in the tropical littoral environment and in the desert

E. S. Oh, C. Font, G. C. Gilbreath, Naval Research Lab.; M. Chang, Univ. de Puerto Rico Mayagüez

We have measured the optical turbulence structure parameter measurements Cn2 in two extremely different locations: the first being over sea water on the southwest coast of Puerto Rico. The second location is over the dry desert in central New Mexico. In both cases, the horizontal beam paths are approximately 0.5 km long, within 20 meters of the local surface. We present our findings from comparing the two datasets and attempt to extract a humidity contribution factor to Cn2 for the first time.

6551-20, Session 5

Characterization of atmospheric turbulence during the NATO RTG-40 land field trials

D. H. Tofsted, D. Quintis, S. O'Brien, J. Yarbrough, M. Bustillos, Army Research Lab.

The NATO RTG-40 Active Imaging Land Field Trials were conducted at the High Energy Laser System Test Facility at White Sands Missile Range, NM, during November of 2005. This experiment intercompared six active imager systems operating in the visible, near-infrared, and short-wave infrared sensing bands. The objective was to populate a database suitable for model validation of simulations of active system operation. For this experiment eight scintillometers were arranged along or near the atmospheric path to characterize the vertical and temporal structure of scintillation and inner scale. A met mast, two 32-m met towers, and an 8-m tower complemented the scintillometer data. This report focuses on acquisition and analysis of data from four of the scintillometers arranged in pairs along the 2-km propagation path. It also focuses on analysis of data collected by four 3-D sonic anemometers positioned at midrange on the 8-m tower. These acquired data throughout the 10-day measurement period and have proved highly useful in both characterization of the overall weather conditions present and in the prediction of various surface layer characteristics. Of particular interest is the spectral analysis of wind and temperature data indicating the capability to produce point estimates of Cn2 and the inner scale of turbulence.

6551-21, Session 6

Mitigation of speckle and scintillation via non-imaging techniques

G. W. Lukesh, S. Chandler, Nukove Scientific Consulting, LLC

Ground-to-space laser illumination experiments with the goal of obtaining reflected energy with a large aperture, such as those at the AMOS Facility on Maui or Starfire Optical Range on Kirtland AFB, are subject to several disturbances. Energy requirements dictate that the laser beam at the target must have a full-width-half-maximum (FWHM) as small as several microradians. This in turn dictates the requirement for exceptional pointing. Two major disturbances are known as jitter (a random shot-to-shot error) and boresight (a static offset due to optical misalignment).

For a decade the authors have investigated non-imaging statistical techniques for estimating system pointing based solely on the received time-series signal. The technique easily extends to crude but useful target size and shape identification without imaging. These results have been presented at SPIE and EOS Conferences and at the Institute for Atmospheric Optics (Tomsk, Russia).

Two additional potentially deleterious effects are target speckle and downlink scintillation. Speckle is the result of the illumination of an optically rough (Lambertian surface) and the subsequent interference of the coherent laser on the return path. This can prove to have a critical impact for an imaging system. Scintillation is caused by the atmosphere during the downlink.

The non-imaging nature of the authors' techniques, combined with the large receiving aperture, on the order of 3.5m at the two experiment facilities, largely mitigates the impact of these two effects due to aperture averaging. This paper demonstrates the success of the authors' pointing estimation technique in the presence of speckle and scintillation.

6551-22, Session 6

Mitigating angular misalignment from atmospheric effects in FSO links

P. G. LoPresti, Univ. of Tulsa; H. Refai, J. J. Sluss, Jr., Univ. of Oklahoma

Accuracy of alignment is a key factor for successfully establishing and maintaining connections in networks of free-space optical links, and is particularly critical when one or both of the transceivers are moving. Scintillation and other atmospheric effects create beam deflections that further complicate the alignment process. This paper theoretically studies the effective angular misalignment that can be caused by such deflections and mitigation methods for a traditional free-space optical link. The theory uses Gaussian beam propagation to determine the optical power distribution at the receiver lens and the position of the beam at the lens focal point. Scintillation effects are simulated using commercial software packages. oordinate transformation is used to assist in calculating the amount of power collected by the lens and incident on the collecting core of the fiber. The use of adaptive power and divergence schemes are investigated as possible methods for reducing the receiver sensitivity to misalignment. The simulation results show that some reduction in misalignment sensitivity, though additional measures are likely required.

6551-23, Session 6

Patching Cn2 time series data holes using principal component analysis

M. Chang, H. Nazari, Univ. de Puerto Rico Mayagüez; E. S. Oh, C. Font, G. C. Gilbreath, Naval Research Lab.

Measurements of Cn2 time series using unattended commericial scintillometers over long time intervals inevitably lead to data drop-outs or degraded signals due to wind shake or unforseen events. We present a method using Principal Component Analysis (also known as Karhunen-Loeve decomposition) that seeks to correct for these event-induced and mechanically-induced signal degradations. We report on the quality of the correction by examining both the Eigenvalue spectrum and the Intrinsic Mode Functions generated by Empirical Mode Decomposition.

6551-24, Session 6

Focal plane phase modulation for improved fiber coupling in LaserCom systems

P. Crabtree, Air Force Research Lab.

The atmosphere presents a significant challenge for many electro-optical systems. Attenuation, scattering, clouds, thermal blooming, and turbulence are all potential obstacles to system performance. For this research, turbulence is the sole atmospheric distortion investigated. Atmospheric turbulence can be described by random fluctuations in the velocity of nearly homogeneous patches of air existing in a continuum of sizes. The chaotic mixing of these atmospheric cells leads to a random distribution of air temperature and pressure, and therefore refractive index. The resulting phase distortions imposed on wavefronts traveling through the atmosphere are termed optical turbulence. Extended turbulence and challenging engagement scenarios also lead to amplitude fluctuations, which are sensed as intensity variations by the human eye and optical detectors.

Traditional turbulence compensation systems (a.k.a., adaptive optics) modify optical phase in the pupil plane to improve the focal plane image or increase energy on target in the far field. This work investigates phase modulation in the focal plane. For high-energy laser applications, focal plane phase modulation is not desirable due to extremely high power densities and device damage thresholds. However, LaserCom systems aim to use as little power as possible for reasons such as eye-safety and covert communication. Thus, phase modulation in the focal plane is a reasonable approach for this application. This work investigates focal plane phase modulation for increasing single mode fiber coupling efficiency and decreasing bit-error rate. Potential benefits of phase modulation in the focal plane are considered, such as novel application of existing hardware to real-time systems.

6551-25, Session 7

Fiber bundles in transceivers to mitigate scintillation effects on free-space optical networks

P. G. LoPresti, Univ. of Tulsa; H. Refai, Univ. of Oklahoma; N. Brooks, Univ. of Tulsa

Accuracy of alignment is a key factor for successfully establishing and maintaining connections in networks of free-space optical links, and is particularly critical when one or both of the transceivers are moving. Scintillation and other atmospheric effects create beam deflections that further complicate the alignment process. This paper studies the use of a fiber-optic bundle at the transmitter and receiver to mitigate the atmospheric effects on the link up-time. The bundle at the transmitter allows fast, non-mechanical steering of beam to track and correct for relative motion. The bundle at the receiver allows for a significant improvement in misalignment tolerance, particularly to angular misalignment. Laboratory experiments and theoretical analyses were conducted on a free-space link to determine the inter-relationship between spacing of the fibers within the bundle, the focal lengths of the transceiver lenses, the beam deflection angle, and the misalignment tolerance for varying atmospheric conditions. A shorter focal length lens at the transmitter provides greater coverage, while a moderate focal length lens at the receiver reduces the bundle size required to improve misalignment tolerance. A smaller overall system size is possible, provided that sufficient power is used to overcome the greater spatial spreading and subsequent loss of peak power at the receiver.

6551-26, Session 7

Omnidirectional free-space optical (FSO) receivers

H. H. Refai, J. J. Sluss, Jr., Univ. of Oklahoma; G. A. Cap, Oral Roberts Univ.

Free-space optics (FSO) is an unlicensed line-of-sight technology that uses modulated optical lasers to transmit information through the atmosphere. Using invisible beams of light, FSO can send and receive voice, video, and data information. To date, the primary concentration of FSO research and development has been toward the accurate aligning between two transceivers. This study introduces an advanced FSO receivers that provides wider receiving angle compared with that of conventional FSO systems. Additionally, the study presents viable optical beam steering and capturing mechanism to allow fast tracking and accurate pointing between two transceivers of free-space optic (FSO) link which required continuous alignment. This extra ordinary auto-tracking system can reduce the time needed to lock a laser beam between a flying fighter and a stationery base station to exchange information in addition to its high accuracy. The authors are not aware of any reports in the literature where an advanced FSO Receivers has been evaluated for this application. We present data from measurements of optical power which were very promising, and indicated that these advanced FSO receivers are suitable for FSO alignment applications and perform favorably with similar FSO receivers.

6551-27, Session 7

Large area, high sensitivity, InGaAs receiver development for free-space lasercom

H. R. Burris, Jr., Research Support Instruments, Inc.; M. S. Ferraro, Sachs Freeman Associates, Inc.; P. G. Goetz, C. I. Moore, Naval Research Lab.; W. R. Clark, W. D. Waters, OptoGration Inc.; L. M. Wasiczko, M. R. Suite, Naval Research Lab.; M. F. Stell, Research Support Instruments, Inc.; W. S. Rabinovich, Naval Research Lab.; R. Mahon, L-3 Communications Titan Group; G. C. Gilbreath, W. J. Scharpf, Naval Research Lab.

The U. S. Naval Research Laboratory and Optogration, Inc. have developed large area, high sensitivity, high speed, InGaAs APD receivers for free-space lasercom applications. Two receiver types have been built for initial testing; one receiver is optimized for 622 Mbps while the second is optimized for 2.5 Gbps. These receivers are based on Optogration InGaAs APDs, model OG-A-200-25 (200 micron diameter) and model OG-A-100-25 (100 micron diameter). Initial results from laboratory sensitivity testing and field testing of the devices will be presented.

6551-28, Session 7

Closed-loop field conjugation using decentralized multi-conjugate adaptive optics

L. H. Lee, Lockheed Martin Advanced Technology Ctr.

In multi-conjugate adaptive optics (MCAO), multiple wavefront correctors and wavefront sensors are arranged to control phenomena that often limit the performance of conventional single-conjugate adaptive optics (SCAO). One favored paradigm applies tomography to enable wider-FOV imaging, while another applies field conjugation principles to reduce sensitivity to monochromatic scintillation. Such setups are appearing in advanced adaptive optics (AO) systems and experiments.

With few exceptions, existing MCAO field conjugation schemes are based on explicit beam shaping. They thus require direct measurement and feedback control of beam irradiance profiles. They also rely on numerically sensitive, computationally intensive, and/or optically lossy inverse-model control algorithms based on phase retrieval, intensity transport, modulation, et al.

This paper presents some decentralized MCAO approaches to closed-loop field conjugation. In these, irradiance measurement and feedback are not needed; wavefront sensors and correctors sense and actuate relative phase only, and control algorithms are no more complex than in conventional SCAO. Control of relative amplitude is thus implicit rather than explicit, yet the performance against slowly varying weak scintillation is provably asymptotically optimal in a minimum-variance sense. Barchers' full wave conjugation method is one such approach.

Given standard assumptions such as first-order Rytov perturbation and single scattering, such MCAO field conjugation systems are quite amenable to linear dynamical systems modeling. Modern control theory provides stability criteria and spatio-temporal transfer functions for the closed-loop system. Scalable mean-square error metrics (excluding reconstruction errors) then arise by analytical and/or numerical integration. System performance and model fidelity in weak and strong regimes are explored using closed-loop wave-optic simulations.

6551-31, Session 7

Image processing techniques for optical sensing through a disturbed air-water interface

E. F. Fleet, Naval Research Lab.; A. V. Kanaev, J. R. Ackerman, SFA, Inc.; D. A. Scribner, Northrop Grumman

Previous work on imaging through atmospheric turbulence suggests that for even highly disturbed optical paths, fortuitous turbulent patterns may temporarily emerge to produce highly focused “lucky” patches or frames, possibly even beyond the camera’s normal diffraction limit. To study the possible implications for imaging through the wavy air-water interface, we heavily modified image processing techniques to study video taken through wavy air-water interfaces. We found strong feature migration and multiplication presents severe complications to straightforward application of processing techniques developed for imaging through turbulent air. We will present our image processing techniques, discuss the improvements and limitations of the results, and include a study of how frame rate, exposure time, light level, surface conditions, etc., impact the processed image quality.

6551-30, Poster Session

Imaging through the air-water interface

E. F. Fleet, Naval Research Lab.; A. V. Kanaev, J. R. Ackerman, SFA, Inc.; D. A. Scribner, Northrop Grumman

Previous work on imaging through atmospheric turbulence suggests that for even highly disturbed optical paths, video data may occasionally produce “lucky” patches or frames where regions of a

scene are briefly well-focused, possibly even beyond the camera's diffraction limit. To examine the impact of such "lucky" patch techniques on imaging through a wavy air-water interface, we used both normal and high-speed cameras to image various scenes through artificially generated capillary and gravity waves at different ambient light levels. We will present data and discuss the impact of frame rate, exposure time, light level, and surface conditions on the resultant image quality.

Conf. 6552: Laser Source Technology for Defense and Security III

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6552-01, Session 1

Two-micron thulium-pumped-holmium laser source for DIRCM applications

W. L. Bohn, G. Renz, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

There is an increasing need for the generation of mid-infrared radiation in the 3 to 5-micron region especially in the absorption minima of the atmospheric windows. Recent advents of heat seeking detectors operating in these atmospheric windows make it necessary to develop compact and reliable mid-infrared laser systems that can be installed in airborne platforms. Future DIRCM systems will be equipped with high repetition rate/low energy per pulse lasers as well as low repetition rate/ high energy per pulse lasers. We report on the development of a Tm:YLF-fiber laser (1.9µm) pumped Ho:YAG (2.09) high energy laser system with pulse energies up to 90 mJ at pulse lengths of 20 ns operating at 100 Hz. Using single mode fiber lasers as end-pumped sources for the master-oscillator-power-amplifier (MOPA) system almost diffraction limited beam quality resulted. The frequency conversion into the 3 to 5-micron region is performed with a Zinc Germanium Phosphide (ZGP) crystal in a linear or ring resonator. Propagation of the mid-infrared laser beam through moderate turbulent atmosphere will be simulated numerically using phase screens and Fresnel transformation.

6552-02, Session 1

HEL laser amplifier slab development and fabrication

P. K. Hogan, R. L. Gentilman, M. Holz, Raytheon Co.

Overview of high energy laser slabs, their function and highlights of the manufacturing challenges. The discussion includes the criticality of low absorption undoped YAG, measurement techniques, results, and a vendor comparison. Also discussed will be some of the developmental breakthroughs that enable the fabrication of these devices, along with an overview of key manufacturing process steps.

6552-03, Session 1

Strategic illuminator (SILL) laser: provides state-of-the-art power and beam quality at 5 kHz

G. P. Brossus, R. St. Pierre, J. Guerin, H. Injeyan, J. Jackson, Northrop Grumman Space Technology

Northrop Grumman Corporation, Directed Energy Systems has developed the highest power continuously pulsed diode pumped solid state laser (SSL) ever built. The near diffraction limited, multi-kilowatt SSL can control its pulse frequency between 4250 and a 5750 Hz. The current phase of the SILL program delivers a compact and rugged Brassboard laser system with better than 5% wall-plug efficiency. The baseline SILL design employs a phase conjugated, master oscillator, power amplifier (PCMOPA) laser configuration with two multi-pass amplifier gain modules. The SILL results demonstrate the modularity and scalability of the PCMOPA architecture from one to four kW of average power output.

For SPIE D&SS we will present a SILL design overview, along with results from the Thermal Control Subsystem concept demonstration and the design of the high density (\>22 W/in3) power subsystem currently in fabrication. Performance data from the Brassboard master oscillator and light weight gain module subsystems will be also be presented.

6552-04, Session 1

Evolution of a solid state laser

R. M. Yamamoto, C. D. Boley, K. P. Cutter, S. N. Fochs, K. N. LaFortune, Lawrence Livermore National Lab.; J. M. Parker, Lawrence Livermore National Lab; P. H. Pax, M. D. Rotter, A. M. Rubenchik, Lawrence Livermore National Lab.; T. F. Soules, Lawrence Livermore National Lab

During this past year, the Solid State Heat Capacity Laser (SSHCL) has demonstrated a significant increase in performance. In addition, numerous laser/material interaction experiments were conducted using the SSHCL, providing new insight on how effective a laser weapon may be on a real target. Both of these topics will be the subject of this paper.

The SSHCL have demonstrated 2X diffraction limit beam quality for 4 and 5 second run times. These experimental results show that the heat capacity laser concept for a solid-state laser is indeed viable and can provide the performance coupled with simple, straightforward architecture to be seriously considered for use in a battlefield environment. Discussion of how and why this improved laser performance was attained and how this scales to power levels of 100 kW or more will be addressed. The use of ceramic laser gain media is key to this success story.

In addition, our ability to conduct 25 kW laser-material interaction experiments for up to 10 seconds of run time, with spot sizes up to 16 cm by 16 cm square, and air flow speeds at 100 meters/second enables us to pursue a lethality phase space previously unattainable. The 200 Hz pulse repetition rate and the 1 micron wavelength are characteristics of the SSHCL that enhance the usefulness of the experiments due to its relevancy to a battlefield ready solid state laser system.

6552-05, Session 1

The reflective properties of a volume Bragg grating exposed to a high power laser beam

H. Shu, M. A. Bass, College of Optics & Photonics/Univ. of Central Florida

The material in which a volume Bragg grating is made will always have some absorption at the grating's design wavelength. Thus, when exposed to a high power laser beam the grating will absorb some power, be heated such that a temperature gradient is formed and, consequently, become distorted. We developed an accurate model to calculate the reflection of a high power laser beam by a volume Bragg grating that experiences such distortion. We used the finite difference beam propagation method and an iteration method to account for the counter propagation of the laser beam in the volume Bragg grating. We established a new formulation of the wave equation to include the distortion of the grating structure. The surface distortion and temperature induced index change are not new problems and have been dealt with before. This new formulation that accounts for the grating structure distortion has been validated in our work to be correct and very accurate. We applied our numerical model to calculate the reflection of a high power laser beam by a distorted generic volume Bragg grating which has large grating strength. Our calculation predicts that grating structure distortion could introduce significant changes of both the phase and intensity patterns of the reflected laser beam. Understanding such changes is critical to the application of volume Bragg grating to high power laser systems.

6552-06, Session 1

A silicon carbide face cooled ceramic Nd:YAG laser

G. A. Newburgh, M. A. Dubinskii, Army Research Lab.

We report on the lasing of a Silicon Carbide (SiC) face cooled ceramic Nd:YAG end pumped laser in an unstable cavity mode configuration.

6552-07, Session 1

AFB® CVD diamond composites with laser materials

H. Lee, H. E. Meissner, Onyx Optics Inc.

The thermal conductivity of CVD diamond with about 18-25 W/cm.K at room temperature is one of the properties that make diamond a unique material, with copper a distant second at about 1/5 the value. Since thermal management of solid state lasers is becoming an ever increasing hurdle to scale up to high average power, CVD diamond is an ideal heat spreader to conduct heat away to a heat sink. At the same time, diamond is transparent between 230nm to the far infrared, with two-phonon absorption bands between 2.5 and 6 μm.

Adhesive-free bonding (AFB(r)) of CVD diamond sheet has been demonstrated to be possible because Van der Waals attractive forces constitute the principal bonding mechanism of AFB(r) composites. The coefficient of thermal expansion of CVD diamond is with 0.8 -1.0x10-6/C much lower than any of the common solid state laser media, with YAG being about 8.2x10-6/C. The non-localized nature of Van der Waals bonds allows almost perfect stress equilibration without delamination, while any other bonding technique would be expected to result in highly stressed composites.

Bonding mechanisms, experimental observation of stress relief and parameters for successful AFB(r) CVD diamond/ single crystal composites without or with optical coatings at the interface will be reported, with relevance for disk, slab and waveguide solid state laser geometries at ambient and cryogenic temperatures.

6552-08, Session 2

Progress in Nd:YAG ceramic laser

A. Ikesue, Y. L. Aung, Poly-Techno Co., Ltd. (Japan)

The present author demonstrated in 1994 that the effective laser oscillation was performed successfully for the first time in the world using polycrystalline Nd:YAG ceramics. Successively, we succeeded in developing (a) high-efficiency and high beam quality laser, (b) ultra-short pulse laser with ns~fs, (c) high power blue and green laser, and so on. This paper will cover our latest developments in the following advanced ceramic lasers:

(1) Ceramic Composite by Advanced Ceramic Technology,

(2) Laser Performance of Polycrystal and Single Crystal Nd:YAG by Sintering Process.

(1) Ceramic Composite by Advanced Ceramic Technology

Ceramic composite laser gain media were fabricated successfully for the first time by advanced ceramic processing. Advanced ceramic technology enables the direct formation of composite laser element with complex structures.

Since the composite laser media using single crystal such as Nd:YAG and YAG was reported in 1998 [1], the composites with various structures have been extensively implemented. However, conventional bonding of composite elements is not sufficient for some laser applications, and fabrication process is complex and has long overall processing time. We successfully fabricated all-ceramic composite element using simple ceramic processing without polishing and diffusion bonding for the first time.

(2) Laser Performance of Polycrystal and Single Crystal Nd:YAG by Sintering Process

We report the first demonstration of polycrystalline Nd-doped YAG ceramics with almost perfect pore-free structure and Nd-doped YAG single crystal fabricated by advanced ceramic processing. We obtain optical slope efficiencies of 57% with these microchip ceramic lasers.

To decrease optical loss, it is extremely important to fabricate (1) fully dense ceramic with pore-free structure and (2) ceramics with solid state growth of single crystals (grain boundary free ceramic laser media) from non melting (sintering) method, because both pores and grain boundaries in ceramic materials act as optical scattering centers. We discuss the fabrication and laser properties of both (1) pore-free, fully dense ceramics and (2) ceramics with solid state growth of single crystals.

Reference

[1] Helmuth E. Meissner, “Composite Optical and Electro-Optical Device”, US Patent No.5846638.

6552-09, Session 2

Transparent Yb3+:Y2O3 ceramic laser materials

I. D. Aggarwal, J. S. Sanghera, G. R. Villalobos, W. Kim, L. B. Shaw, S. S. Bayya, Naval Research Lab.; B. Sadowski, Sachs Freeman Associates, Inc.; R. E. Miklos, Naval Research Lab.

Lightweight and compact high power lasers are needed for several defense applications. While free-electron lasers and chemical lasers are capable of high output powers, they are too bulky, toxic and therefore impractical for applications which require mobility and agility. On the other hand solid state lasers based on crystals offer great promise due to their compact size, but are limited to a select number of crystal compositions that can be grown without running into high temperature growth issues which limit size and quality. Consequently, crystal materials that have better properties as a laser host, such as a high thermal conductivity, cannot be grown in good quality. One example is Yb:Y2O3 which has a higher thermal conductivity and significantly lower quantum defect than Nd:YAG. However, it is difficult to grow large crystals due to its high melting point of 2400oC and phase transition at ~ 2200oC. The high melt temperature leads to crucible interactions and volatilization, while the phase transition leads to additional strain which causes cracking and limits the crystal to mm scale sizes. However, we have developed a low temperature process to make high purity Yb:Y2O3 powder containing up to 10%Yb, and then sinter it to a transparent ceramic. This process overcomes the limitations of traditional crystal growing. We will report on the physical and optical properties of the ceramic and demonstrate laser oscillation in this material.

6552-10, Session 2

Domestically produced ceramic YAG laser gain material for high power SSLs

J. C. Huie, R. Gentilman, T. S. Stefanik, Raytheon Co.

Optical quality ceramic Yttrium Aluminum Garnet (YAG, Y3Al5O12) materials for high power solid state lasers have been in development for several years at Raytheon Advanced Materials Laboratory. The biggest challenge facing the ceramic gain materials before they can replace single crystal lies with further loss reduction via elimination of both absorptive and scattering centers. At Raytheon, significant progress has been achieved in the optical quality improvement, scale-up, and demonstration of laser quality Yb, Nd, and Er doped ceramic YAG material. This communication presents Raytheon’s ongoing development effort in ceramic YAG fabrication and doped ceramic YAG material characteristics in comparison to the current state of the art made by Konoshima Chemical in Japan.

6552-11, Session 3

Line tunable visible and ultraviolet laser

N. P. Barnes, B. M. Walsh, NASA Langley Research Ctr.

A novel method of operating a Q-switched Nd:YAG laser was developed to provide a simple, compact, line tunable source that covers much of the visible and ultraviolet spectral regions. The system consists of a single laser and 2 nonlinear crystals. With a novel design, the laser produces synchronous, collinear, Q-switched output at 2 widely separated wavelengths. Because both pulses are created in the same laser, mixing is as easy as second harmonic generation. The first nonlinear crystal tunes over the entire phase matching range by a rotation of only a few degrees. 76 wavelengths are possible between 0.35 and 0.45 μm.

6552-12, Session 3

Novel high-power CW Yb:YAG cryogenic laser

D. C. Brown, J. M. Singley, E. D. Yager, J. W. Kuper, L. L. Bennett, B. J. Lotito, Snake Creek Lasers, LLC

We discuss a CW Yb:YAG cryogenic laser program that has resulted in the design and demonstration of a novel high power laser that utilizes a distributed array of seven highly-doped thin Yb:YAG-sapphire disks in a folded multiple-Z resonator. Individual disks are pumped from opposite sides using 200 micron core fiber sources, each capable of providing 35 W of pump power at 939 nm. Cryogenically-cooled crystalline solid-state lasers, and Yb:YAG lasers in particular, are attractive sources of scalable CW output power with very high wallplug efficiency and excellent beam-quality that is independent of the output power. The device we have demonstrated produces a near-diffraction-limited TEM00 output beam and is cooled using a liquid nitrigen circulator. In addition, the device can be scaled to very high average power in a MOPA configuration, by increasing the number and diameter of the thin disks, and by increasing the power of the individual diodes used to pump the disks.

During this talk we will review the thermal and optical benefits of cryogenically-cooling solid-state lasers , review our Yb:YAG cryogenic laser design and discuss its scalability, and will present experimental results including output power, slope and point efficienies, and beam-quality.

6552-13, Session 3

High brightness-temperature micro-lasers

T. Taira, Institute for Molecular Science (Japan)

Passively Q-switched compact lasers are attractive for scientific and industrial applications owing to their improved reliability and the portability. Moreover, it is suitable for generation of single axial-mode short pulse by the microchip laser cavity. Recently attention has been directed toward the multi-stage fiber amplified system to enhance the peak power up to mega-watt level with maintaining single mode properties. From the point of view of brightness-temperature, single axial and transverse mode mega watt level laser beam has extremely high-coherency to cause any reaction upon the materials. In this talk, we'd like to discuss about the possibility without any amplification system. Even if the stand-alone micro-laser configuration, the brightness-temperature could be up to ~2x10^20K with the 16 mW electrical average power supply. This value is already 10^16 times higher than that of the Sun, 6,000K. Its extremely high brightness allows us the efficient nonlinear wavelength conversion, UV to THz generation, and material process such as micro-drilling even for the stainless steal. Further possibilities will be discussed.

6552-14, Session 3

Performance and applications of optically-pumped semiconductor lasers

L. E. Hunziker, C. Ihli, J. L. A. Chilla, Q. Shu, E. S. Weiss, H. Zhou, J. Lofthouse-Zeis, Coherent, Inc.

We report on recent progress extending the power and lasing wavelength for high power optically-pumped semiconductor lasers (OPSL's). Results for high power laser operation at 920 to 1140 nm are presented with conversion to 460 to 570 nm by intracavity second harmonic generation. Output powers exceeding 50 W with high beam quality (M^2 ≈1.5) have been achieved. In addition, we've developed a rugged laser system that is well suited to meet demanding environmental conditions encountered during field deployment in forensics, defense, and security applications. The design of a compact (ca. 5x2.5x2") laser module that can withstand shock levels greater than 200G is discussed, in addition to a hand-portable, battery powered controller, equipped with a multi-function handpiece. Application to forensics including results for latent fingerprint detection and serology are presented.

6552-15, Session 3

Compact laser sources for laser designation, ranging and active imaging

L. Goldberg, U.S. Army Night Vision & Electronic Sensors Directorate

Recent NVESD advances in compact solid sate laser sources for laser designation, eye-safe range finding and active imaging will be described. Wide temperature operation of compact Nd:YAG laser was achieved by end pumping and use of multi-wavelength diode stacks. Such lasers enabled construction of fully operational 4.7 lb laser designator prototype generating 50 mJ pulse at 10-20 Hz PRF. Approaches for increasing the energy output of such compact sources will be presented. Eye-safe 1.5 um lasers based on low PRF (0.3 Hz) flash-pumped "Monoblock" lasers, have enabled compact "STORM" range finders that have been recently put into full-scale production to meet Army's current and future needs. For higher PRF applications, such as flash imaging, improvements in such lasers have been made through the use of diode end-pumping and unstable laser cavity designs. These approaches made it possible to achieve high electrical efficiency, PRF's in the 10-20 Hz range, wide temperature operation (-20 to +50 deg.C), and shortening of the Q-switched laser pulses to <2 ns.

Compared with bulk compact solid state lasers, fiber laser are characterized by lower pulse energy, higher PRF's, shorter pulses and higher electrical efficiency. These properties make them useful for high resolution LIDAR, free space optical signal transmission and interrogation. Several examples of fiber lasers suitable for these applications will be described.

6552-16, Session 4

Eyesafe diffraction-limited single-frequency 1 ns pulsewidth Er:YAG laser transmitter

R. C. Stoneman, R. Hartman, E. A. Schneider, C. G. Garvin, S. W. Henderson, Lockheed Martin Coherent Technologies

We report an eyesafe diffraction-limited single-frequency 1617 nm Er:YAG laser transmitter, developed for coherent laser radar applications. The transmitter utilizes a master oscillator / power amplifier architecture, enabling the production of high peak power output. The pulsed oscillator is Q-switched and cavity-dumped, resulting in a 1.1 ns pulsewidth. The pulsed oscillator is injection seeded by a commercial 1617 nm CW distributed feedback laser diode, resulting in single longitudinal mode output. The oscillator and amplifier are directly pumped into the Er:YAG laser upper state by commercial diode-pumped CW 1533 nm Yb,Er-doped fiber lasers. The injection-seeded pulsed oscillator produces an average output power of 2.1 W at 10 kHz pulse repetition frequency (PRF) with a pulsewidth of 1.1 ns (0.19 MW peak power) with a beam quality 1.1 times the diffraction limit. The oscillator has a slope efficiency of 47% in the CW mode, and a conversion efficiency of 80% from CW mode to injection-seeded pulsed mode. The power amplifier produces 10 W in the CW mode and 4.7 W in the pulsed mode at 10 kHz PRF with 1.1 ns pulsewidth (0.43 MW peak power). The Fourier transform of the heterodyne signal of the pulsed oscillator output has a width of 0.42 MHz, which is consistent with the transform limit of 0.40 MHz for a Gaussian pulse with the observed 1.1 ns pulsewidth of the heterodyne signal.

6552-17, Session 4

A 100mJ Q-switched 1645nm Er:YAG laser

S. D. Setzler, M. Francis, E. P. Chicklis, BAE Systems

Er:YAG lasers operating on the 'eyesafe' 4I13/2 → 4I15/2 transition are of growing interest. They are capable of operating at much higher average power than conventional Er:glass lasers, can produce higher diffraction-limited pulsed peak power than current fiber-based sources, and emit directly at eyesafe wavelengths (typically 1617 nm or 1645 nm) and need no nonlinear wavelength conversion. Resonant pumping, or direct excitation of the 4I13/2 lasing level, in a longitudinally pumped architecture has proven extremely effective. Common pump sources include 1470 nm diodes and 1533 nm fiber lasers. The latter are

generally used for cw pumping to produce efficient, moderate-average-power, repetitively Q-switched output. The former are generally used for operation in energy-storage mode when high peak pump power is usually needed.

We present results in which 1470 nm diode arrays are used in a pump-confined geometry. We generate 55 mJ of Q-switched output at 10 Hz from a 6-mm-long, 2-mm-diameter 0.5%Er:YAG rod with a 50%R output mirror. The pump diodes and focusing system launch ~210 W (peak) into the rod for a 7ms duration. The average Q-switched pulsewidth is 32ns (1.7 MW peak) and the measured beam quality is M2~1.2 with a 50%R. In a similar experiment we measured 26 mJ / 10 ns pulses (2.6 MW peak) at 10Hz from a shorter oscillator cavity. A two-pass longitudinally pumped slab amplifier has been used to amplify the 55 mJ oscillator output to over 100 mJ.

6552-18, Session 4

Experimental and modeling study of Er:YAG kinetics

H. P. Chou, D. O. Hogenboom, Textron Systems Corp.

Erbium doped YAG is an intriguing laser material which lases directly at 1645nm when pumped at either 1473nm or 1532nm, all of which are in the eye-safe band. However, a laser made from this material is not particularly straightforward to design. Er:YAG is a quasi-three-level system, which leads to strong temperature dependence. Perhaps more importantly, a strong up-conversion process, which is dopant concentration dependent, effectively produces a pump intensity dependence in the saturation intensity and other laser parameters. We present a detailed study of the absorption coefficient and the gain as a function of the pump intensity, dopant concentration and crystal temperature. The results of this study will allow us to optimally design the laser.

6552-19, Session 4

Latest developments in resonantly diode-pumped Er:YAG lasers

I. Kudryashov, D. Garbuzov, Princeton Lightwave Corp.; M. A. Dubinskii, Army Research Lab.

Er-doped laser materials are getting significantly more attention lately for “eye-safer” HEL applications due to recent successes in low-photon-defect resonantly diode-pumped Er:YAG lasers, but major scaling of these lasers with good beam quality is yet to be demonstrated. Very good, but arguably practical, results are obtained with fiber laser-pumped Er:YAG, but directly diode-pumped Er:YAG lasers are currently under development. Major development areas are power scaling, beam quality as well as overall conversion efficiency.

Here we report the results of our diode-pumped Er:YAG laser power scaling effort using the hybrid (stable-unstable) cavity, which resulted in highest, to our knowledge, Q-CW power of 130W with the beam quality of M2 = 1.28 in stable direction and M2 = 1.1 in unstable direction. Also reported are dramatic improvements in the overall conversion efficiency of a CW Er:YAG DPSSL achieved by implementing volume Bragg gratings for narrowing the InGaAsP-InP 10-diode bar stack pump spectrum in order to achieve the “in-line” pumping of Er3+. We used an Er(0.5%):YAG slab with dimensions 60x2.5x15 mm3 In-bonded to water-cooled copper heatsink for CW operation. With an optical path length for pumping radiation of 15 mm, only 37% of 1530 nm radiation was absorbed by the slab using direct output from the pump stack. With the volume Bragg grating between the pump diode stack and the Er:YAG slab, the absorption of the pumping radiation increased to 62%. As a result, the incident threshold power was reduced by a factor of 2.5 and laser efficiency was increased by a factor of 1.7. Obtained maximum CW power was increased from 31 W to 51 W, and is the record high CW power reported for the Er:YAG resonantly DPSSL, to the best of our knowledge.

6552-20, Session 4

Scalable ultra-low quantum defect Er lasers

K. Spariosu, M. Cashen, V. Leyva, R. A. Reeder, Raytheon Space and Airborne Systems

Ultra-low quantum defect operation Er lasers are discussed. Power scaling demonstration has shown promise for high efficiency Er:crystal laser operation.

6552-21, Session 4

Ultra-low photon defect diode-pumped cryo-cooled Er:YAG laser

M. A. Dubinskii, N. Ter-Gabrielyan, M. B. Camargo, L. D. Merkle, G. A. Newburgh, Army Research Lab.

We report what is believed to be the first ultra-low-photon-defect resonantly diode-pumped Er:YAG cryo-laser. Quasi-CW laser performance at 85°K in this first experiment was found to be 57% efficient (output versus absorbed, slope).

6552-22, Session 5

High efficiency, monolithic LMA fiber lasers and amplifiers operating at 1 micron and 2 micron wavelengths

B. N. Samson, Q. Wang, D. P. Machewirth, K. Tankala, M. O’Connor, A. Carter, G. Frith, Nufern

This paper summarizes current developments in monolithic (all-fiber) large mode area (LMA) fiber amplifiers operating in the 100W-1kW power regime. Some specific systems of interest include polarization maintaining, multistage fiber amplifiers optimized to amplify narrow linewidth (single frequency) signals from ~10mW to power levels \>100W by overcoming the stimulated Brillouin scattering (SBS) limitations of traditional fiber designs. We present experimental SBS threshold data as a function of various LMA fiber designs in conjunction with fiber length and temperature gradient together with a complete monolithic system designed to deliver ~200W at 1064nm with near diffraction limited beam quality. These systems will be the building blocks used in multi-kilowatt spectral and coherent beam combining experiments in the near future. These experiments are set to take place at various Government research labs such as AFRL. The adoption of monolithic fiber amplifier designs allows for robust, cost effective system architectures that are critical for the development of the next phase of the high power beam combining technology.

In addition, the problems associated with power scaling fiber technology at key eyesafe wavelengths (1.5 and 2 micron) will be reviewed, with particular emphasis on the new class of highly efficient Tm-doped LMA fibers and components. Progress on the doped fibers such as improved slope efficiency and beam quality, as well as the device optimization, will be presented along with the development of several key components leading to monolithic demonstrations at the ~100W power level at the 2 micron wavelength.

6552-23, Session 5

522 W spectrally beam combined fiber laser with near diffraction limited beam quality

T. H. Loftus, P. R. Hoffman, A. M. Thomas, M. A. Norsen, R. Royse, E. Honea, Aculight Corp.

We describe a three-channel, spectrally beam combined (SBC), 1- * m fiber laser that clearly illustrates the unique potential for fiber SBC to efficiently generate high power optical beams with near perfect beam quality. The laser features an SBC power combining efficiency of 93%, versatile master-oscillator, power-amplifier (MOPA) fiber channels that produce up to 260 W each of narrowband, polarized, and near-diffraction limited output. The SBC system currently produces 522 W of average power with a dispersed (non-dispersed) beam quality at 522 W of 1.18x (1.22x) diffraction limited and a signal to out-of-band ratio of \>

70 dB. To our knowledge, these results represent the best combination of output power and beam quality achieved by either spectral or coherent fiber beam combining to date. Moreover, and in contrast to coherently combined systems (wherein the near-field fill factor degrades the far-field irradiance), the output beam is a nearly perfect, single-mode Gaussian in both the near- and far-fields. Significant additional power scaling with similarly excellent system performance, either by increasing the individual channel powers or adding additional channels, appears feasible. For current demonstrations, the MOPA outputs are individually collimated and then spectrally multiplexed with a multi-layer dielectric diffraction grating. Grating tests at peak irradiances \> 1.5 kW/cm2 show negligible wavefront distortion, as confirmed by the excellent combined beam quality. Future efforts will focus on increasing the number of MOPAs and the individual MOPA output powers. Our latest progress toward achieving \> 1 kW SBC combined beams with near-diffraction limited beam quality will also be described.

6552-24, Session 5

Broadly tunable, high peak power, pulsed fiber laser system for mid-IR applications

V. V. Ter-Mikirtychev, J. B. Paul, J. J. Scherer, NovaWave Technologies, Inc.

A broadly tunable, mid-infrared fiber laser-based system has been demonstrated at room temperature. The laser system consists of two high peak power pulsed fiber lasers along with difference frequency generation (DFG) in Periodically Poled Lithium Niobate (PPLN). Both fiber lasers were operated with 100-200 ns pulse duration and a 20 kHz Pulse Repetition Rate. The first laser (Pump) was high peak power TEM00 Yb doped fiber continuously tunable in the 1050 - 1080 nm region with a bandwidth of <16 GHz, and produced up to 1 W of average power (0.5 kW of peak power, 50 * J/pulse). The second laser (Signal) was a fixed wavelength, TEM00 mode, 1556 nm Er fiber laser with line-width of <50 MHz and produced up to 150 mW of average power.

In a separate effort both lasers were combined into a single polarization maintained fiber using a fiber wavelength-multiplexer, and then coupled into a NovaWave Technologies commercial DFG conversion head to produce a rugged all-fiber-coupled assembly. By changing only the Pump laser wavelength, continuously tunable radiation in the spectral range 3300 - 3480 nm was generated with a maximum average power of 9 mW (2.25 W of peak power) when 1 micron fiber laser average power was 280 mW which was limited by a damage threshold of used fiber optic components. The demonstrated DFG conversion efficiency of 0.2 W/W2 (20%/W) is ~100 times higher than that of CW operation. By simultaneously changing the crystal temperature along with the Pump laser wavelength, the tuning range was increased to 3235 - 3545 nm (310 nm).

6552-25, Session 5

High peak power Yb-doped diode pumped fiber amplifier system

P. Madasamy, F. Kimpel, W. E. Torruellas, Fibertek, Inc.

We have developed an Yb-doped fiber amplifier system at 1.064 µm and achieved a peak power in excess of 1 MW with sub-1ns pulses at a repetition rate of 10 Kpps. Our approach involves a diode seed source amplified by a chain of fiber amplifiers with the fiber amplifier chain optimized to minimize ASE and nonlinear effects. We have implemented a hybrid modulation architecture for the first time where the direct modulation of seed diode laser and external electro-optic modulation are married together to generate clean 1 ns pulses without sacrificing efficiency. The seed diode laser is direct modulated with 10 ns pulses using a high current driver and passed through a first stage fiber amplifier operating in high gain/low signal regime. A 1ns pulse is carved out of the 10 ns pulse using a LiNbO3 Mach-Zehnder-Interferometer waveguide modulator. The pulse width and the repetition rate of the amplifier system can eventually be varied over a wide range from 0.1 ns to \>1 * s for the pulse width and 10 Kpps to 100Mpps for the repetition rate. The final stage high power amplifier produces an average output power of \>12.6 W at 1.064 µm for a pump power of 27.5 W when operated at 1ns pulses with a pulse repetition rate of 10 Kpps. For a repetition rate of 20 Kpps and 1 ns pulses, the system also produces 15.1 W average output power.

6552-26, Session 5

A novel side coupling technique for rugged all-fiber lasers and amplifiers

Y. Sintov, Y. Glick, Y. Nafcha, O. Katz, T. Koplowitch, R. Lavi, Soreq Nuclear Research Ctr. (Israel)

A novel side coupling technique between two multimode high NA fibers is described. The technique is used for efficiently pump fiber lasers and amplifiers by low brightness fiber coupled pump diodes. With the presented technique, identical multimode fibers with 0.46NA and core diameters extending from 125µm to 400µm, can be coupled together, and provide pump coupling efficiency of \>95%. Direct coupling to a rare-earth doped fiber is possible. In this configuration one fiber is used as the pump guiding fiber and the second fiber is the rare-earth doped double clad fiber. By utilizing the presented pump coupling technique, highly efficient, rugged and low cost short pulse and CW all-fiber lasers were implemented, with average output power extending to 300W and peak power of 600kW.

6552-27, Session 5

1-2um high average power fiber sources

D. V. Gapontsev, IPG Photonics Corp.

Active fiber devices continuously find more and more applications in different fields of business worldwide. Over recent years substantial progress was achieved in increasing an average power level of both lasers and amplifiers in mid-IR range. This presentation would provide a current overview of activities in this area done by IPG Photonics Corporation. Recent results in single frequency amplification, single and multimode CW and QCW power scaling at 1, 1.5 and 2um micron ranges would be described as well as some applications that had been enabled by these developments.

6552-28, Session 5

High peak power eye-safe coherent EYDFA laser source

Y. Chen, B. Matheson, W. E. Torruellas, Fibertek, Inc.; J. Faroni, N. Jacobson, K. Tankala, Nufern

Coherent Laser Radar is a versatile remote sensing tool, which can be applied to range-finding, target discrimination, vibrometric monitoring, air pollution monitoring, aircraft wake-vortex and clear-air turbulence analysis. A high power, highly efficient, near diffraction limited and highly reliable coherent laser source is one of the key elements of such a coherent monitoring system. With humans present, eye safe laser emission is required. Therefore a highly efficient fiber laser system based on a coherent Master-Oscillator followed by a chain of Erbium (EDFA) and Erbium co-doped with Ytterbium fiber amplifiers (EYDFA) is ideally suited for this application suite.

In this paper we are presenting advance architecture designs and experimental results on high peak power EYDFA system with different pulse widths at a wavelength of 1563nm. The system is constituted of three amplification stages, all based on Polarization-Maintaining fiber. A novel short-pulse (~1ns) and high current (1A) driver has been successfully developed to drive the DFB master oscillator. The seeded laser pulses are amplified by more than 50dB from 550pJ to \>70µJ pulse energy by the three stages at 10Kpps. The corresponding peak power is as high as 100kW. With 3ns and 100Kpps seeded pulses, 10W average power and over 30kW peak power have been achieved. With 500ns and 50Kpps, over 300W peak power has been experimentally demonstrated as well.

6552-30, Session 6

Performance enhancement and reduction of heat generation in Nd lasers

V. Lupei, Institute of Atomic Physics (Romania); N. A. Pavel, Institute for Molecular Science (Romania)

The enhancement of performances of the solid-state laser is essentially determined by the optimization of the partial efficiencies that characterize the flow of excitation inside the pumped laser material. In case of Nd laser, pumped currently in the strongly absorbing energy levels placed above the emitting laser level, a modality to improve the laser emission parameters and to reduce the generation of heat could be elimination of the parasitic upper quantum defect between the pump and the emitting level by pumping directly into the latter. In many laser materials, this could introduce complications owing to the weaker pump absorption in this level and increased doping concentration could be necessary, leading to enhanced self-quenching of emission. The paper discusses the manifestation of these processes in several classes of laser materials (garnets, vanadates, hexa-aluminates, borates and so on) and in various wavelength ranges of the Nd lasers (900 nm, 1060 nm, 1300 nm). It is shown that by a proper selection of the materials and of their characteristics such as the doping level, marked improvement of the laser parameters at the fundamental frequency or of the performances of the nonlinear devices using this radiation could be obtained. Moreover, the reduction of heat generation by pumping into the emitting level could be instrumental in scaling these lasers to higher power levels.

6552-31, Session 6

Room-temperature, near-IR fluorescence of high optical quality KTP

K. L. Schepler, Air Force Research Lab.; S. M. Hegde, Univ. of Dayton; R. D. Peterson, D. E. Zelmon, Air Force Research Lab.

Fluorescence due to impurities or defects in nonlinear frequency conversion crystals can be deleterious in secure communications applications where spectral purity and photon entanglement are needed. We have investigated room-temperature fluorescence in the 500-900 nm spectral region from high optical quality, polished and uncoated KTP (potassium titanyl phosphate) crystals purchased from three commercial vendors and representing four different growth processes. The crystals were all cut into 5-mm x 5-mm x 5-mm cubes with their dielectric principal axes along the cube edges. The pump source used was a tripled Nd:YAG laser operating at 355 nm with 7 mJ of energy per pulse having a 3-ns pulse width and 100-Hz pulse repetition rate. Samples from two vendors showed low fluorescence of similar magnitude, while samples from the third vendor showed an order of magnitude higher value in the peak fluorescence near 800 nm. In addition, all samples showed a weaker secondary fluorescence band peaking near 600 nm. Low fluorescence samples from one of the vendors also showed typical “gray tracking” at these pump radiation conditions. Vendor-proprietary growth processes clearly affect KTP operating properties. Efforts to investigate the origin of fluorescence in these materials and reduce their fluorescence are planned.

6552-53, Session 6

Architectural issues and designs in creating high energy fiber lasers

D. L. Sipes, Jr., Optical Engines

Fiber lasers create unique opportunities for designing high energy lasers. The distributed gain and heat deposition, and the flexible resonator provide the means for scaling to high powers. In addition and perhaps more valuable is the idea that fiber lasers allow the creation of an extensible architecture: an architecture where the individual components can be researched, designed, improved and replaced independently. In order to create sources at power levels over 10kW in volumes less than 1 cu. ft. weighing less than 50lbs at costs under $1 per Watt of laser output. Serious consideration first needs to be given to the underlying architecture of choice. In this presentation, several architectural constraints along with competing approaches will be presented. Preliminary results from high brightness fiber coupling designs and simulations will also be discussed.

6552-32, Session 7

Walk-off correction using AFB® similar nonlinear crystal composites

H. Lee, H. E. Meissner, Onyx Optics Inc.

Beam walk-off in uniaxial and biaxial crystals is a natural occurrence when the phase normal of the propagating electromagnetic wave deviates from the direction of the Poynting vector. Walk-off is a limiting factor for increasing conversion efficiency and for restricting the OPO tuning ranges.

The beam walk-off angle in nonlinear single crystals can be reversed by bonding similar non-linear crystals rotated by 180° with respect to each other. An even number of twisted twins of single crystals is formed that has negligible loss at the AFB(r) interfaces and is free of stress. Since no adhesives are employed and the bonding force consists primarily of Van der Waals attractive forces, there is no adverse contribution or absorption at the bond interface.

The theory of walk-off angles as function of orientation for uniaxial and biaxial crystals is derived and discussed. Correction of beam walk-off by producing an AFB(r) composite configuration results in more efficient frequency conversion and thereby allows the generation of higher power output of frequency converted radiation for a given input power. Beam correction is demonstrated experimentally for zinc germanium phosphide (ZGP) as representative of a uniaxial nonlinear crystal, and on biaxial crystals KTP and LBO. AFB(r) composites of ZGP with inactive ends of gallium phosphide have been produced in an effort to power scale a ZGP optical parametric oscillator for frequency conversion into the mid-IR range.

6552-33, Session 7

Recent progress in transition metal doped II-VI mid-IR lasers

S. B. Mirov, V. V. Fedorov, I. S. Moskalev, The Univ. of Alabama/ Birmingham

Recent progress in transition metal doped II-VI semiconductors (mainly Cr2+:ZnSe and ZnS) make them sources of choice when one needs a compact system with continuous tunability over 2-3.1um, output powers up to 2W, and high (up to 70%) conversion efficiency. The unique combination of technological (low-cost ceramic material) and spectroscopic characteristics (ultrabroadband gain bandwidth, high sigma taw product, and high absorption coefficients) make these materials ideal candidates for “non-traditional” regimes of operation such as microchip and multi-line lasing. This talk reviews these non-traditional Cr-doped mid-IR lasers as well as describes first Cr2+:ZnSe laser operating in a single longitudinal mode regime with a linewidth of 80MHz over a 120 nm tuning range around 2.5 µm with an output power up to 150 mW. This laser was used for Doppler limited resolution intracavity absorption spectroscopy of ro-vibrational transitions of the v3 and v1 bands of H2O. We also present results on Fe2+:ZnSe laser having potential to operate at room temperature over the spectral range extended to 3.7-5.1um. Transition metal doped II-VI media also hold potential for direct electrical excitation. The initial steps towards achieving this goal by studying Cr2+ ion excitation into the upper laser state 5E via photo-ionization transitions as well as via direct electrical excitation are also reported.

6552-34, Session 7

Raman scattering spectroscopy for explosives identification: trend to UV excitation

L. Nagli, Tel Aviv Univ. (Israel); M. Gaft, Laser Detect Systems, Ltd. (Israel)

Real time detection and identification of explosives at a standoff distance is a major issue in efforts to develop defense against so-called Improvised Explosive Devices (IED). Raman spectroscopy is

increasingly important technology for homeland defense applications. The appeals of this technique are in its remote non-destructive and fast sensing ability. While Raman spectra are available for most explosives it is only recently that this method has emerged as promising tool for trace level detection at standoff distance as well as method of luggage control in airports.

The main problem for Raman application is its weakness relatively to Rayleigh scattering and luminescence of a substrate or sample itself that in many cases may blur desired signal. Raman signal can enhanced strongly using (1/l)4 dependence of Raman cross section and even much higher enhancement at the vicinity of allowed electronic transition of the material. Deep UV excitation also strongly diminishes overlapping of the luminescence, which is placed at violet-blue spectral range due to Stock shift range while Raman lines are very close to excitation wavelengths.

LDS at present is developing a commercial system for remote detection of explosives traces using UV excitation. At the beginning of this R&D we find the lack of the absolute data of Raman scattering cross sections for many widely spread explosives. In this report we present results of our measurements of wavelength dependence of the Raman cross section in spectral range 620-248 nm for ANFO, RDX, TNT, UN and TENN explosives.

6552-36, Session 7

High-power, single-frequency, tunable, CW, Er-fiber laser pumped Cr2+:ZnSe laser

I. S. Moskalev, V. V. Fedorov, S. B. Mirov, The Univ. of Alabama/ Birmingham

We demonstrate, for the first time to our knowledge, an Er-fiber-laser-pumped, CW, high-power, single-longitudinal-mode Cr2+:ZnSe laser, potentially tunable over 2-3 µm spectral range. The laser is operating in a single longitudinal mode regime with a linewidth of 80 MHz over a 120 nm tuning range around 2.5 µm, and delivers up to 150 mW of output power. The laser design is very compact and is based on Kogelnik/ Littman cavity configuration with the total optical length of the folded cavity of 10 cm. The narrow-linewidth output spectrum can be quickly scanned over a 10 nm spectral range with a repetition rate of 200 Hz by a piezo-controlled tuning mirror which allows for an ultra-fast wavelength tuning of the output spectrum over a large number of absorption spectral lines of trace gases of interest. As a test experiment, we performed a Doppler-limited-resolution intra-cavity laser absorption spectroscopy of ro-vibrational transitions of the v3 and v1 bands of H2O with minimum detectable absorption coefficient of ~3x10-7 cm-1, which corresponds to 9 parts per billion by volume water vapor detection limit. The laser is currently in active stage of development and its further optimization will allow for full 2-3 µm fast tuning range and Watt-level output powers. This laser is being designed as a seeding source for an OPG-OPA-based, highly sensitive trace-gas photo-acoustic sensor system for real-time detection of gas traces of biological pathogens and explosives in the molecular fingerprint mid-IR spectral region of 2-10 µm.

6552-37, Session 8

Fiber-coupled diode laser systems for high-power and high-brightness applications

D. M. Grasso, S. D. Roh, N. P. Ostrom, B. O. Faircloth, Nuvonyx, Inc.

Extensive research and development has advanced semiconductor laser technology into a wide range of novel applications. High-power diode lasers are the workhorse of many industrial and military/defense applications, offering small size, high electrical to optical conversion efficiency, and high reliability. Despite these desirable traits, diode laser bars with a broad-area emitter geometry suffer from low brightness due to their poor beam quality. Previous results have shown that single-mode diode laser bars can dramatically improve the beam quality and coupling efficiency into an optical fiber. There is a desire to extend this improvement in laser performance at the bar level into next generation systems offering enhanced spectral and high-power characteristics.

In this work, we present the development of a suite of high brightness, fiber-coupled diode laser systems at Nuvonyx. The use of flared-ridge, single-mode waveguide emitters in these systems can lead to low output divergence of less than 3 mrad and 10 mrad in the fast and slow emitter axes, respectively. The largest unit demonstrates high continuous wave power in excess of 1.7 kW at a single wavelength out of a 400 micron diameter core fiber with numerical aperture value of 0.22. This represents a power density of \> 1.4 MW/cm^2, which is an order of magnitude improvement over other commercially available single wavelength, fiber-coupled, diode laser systems. Smaller systems with wavelength stabilization and beam combination will also be discussed. The enabling technology in these products is supported by key developments in micro and macro optics, diode laser packaging, and system architecture.

6552-38, Session 8

High brightness semiconductor lasers from 780-1064nm

P. T. Rudy, M. L. Osowski, R. M. Lammert, T. S. Stakelon, C. Panja, S. W. Oh, J. E. Ungar, QPC Lasers, Inc.

We present recent advances in high power semiconductor lasers in the 780 - 1064 nm wavelength range including high spectral brightness and spatial brightness. Data are presented which demonstrate edge emitter devices with internal gratings that narrow and stabilize the spectrum. Devices with high spatial brightness and high power performance are described as well. These devices have the potential to dramatically improve diode pumped systems and enable new direct diode applications.

6552-39, Session 8

High brightness semiconductor lasers at 1300-1600 nm and beyond

P. T. Rudy, M. L. Osowski, R. M. Lammert, C. Panja, S. W. Oh, T. S. Stakelon, J. E. Ungar, QPC Lasers, Inc.

We present recent advances in high power semiconductor lasers in the 1300 - 1600 nm wavelength range and beyond including high spectral brightness and spatial brightness. Data are presented which demonstrate edge emitter devices with internal gratings that narrow and stabilize the spectrum. Devices with high spatial brightness and high power performance are described as well. These devices have the potential to dramatically improve diode pumped systems and enable new direct diode applications.

6552-40, Session 8

Recent developments in high power 2.3 µm diode lasers

L. Shterengas, Stony Brook Univ.; J. G. Kim, Sarnoff Corp.; D. Westerfeld, G. L. Belenky, Stony Brook Univ.

The combination of atmospheric transparency, strong chemical spectral signatures, and invisibility to some night vision systems opens up many potential defense and security applications for mid infrared lasers. The GaSb based semiconductor diode lasers emitting at 2.3 µm described in this work can be used either directly in applications or as pump sources for solid state lasers. As pump sources, they offer improved quantum efficiency and lower heating compared to shorter wavelength diode lasers. Previously, we have demonstrated a record setting 10 watt continuous wave output power from a single 1 cm laser array bar.

This work describes our efforts to improve the efficiency and output power of these devices. We have demonstrated 0.7 watts continuous wave output power from a single 100 µm aperture, 1 mm cavity length laser diode, with half the threshold current density and higher external efficiency than our previous devices.

The reduced threshold current and improved efficiency result from a high (~1.7 %) compressive strain GaInAsSb/GaAlAsSb quantum well design. This design has resulted in a trebling of the differential gain and improved efficiency. We will discuss the effect of high strain on differential gain in GaSb based type-I heterostructure lasers.

6552-41, Session 8

High power wavelength-beam-combined diode arrays

M. Kanskar, V. Zhao, Alfalight, Inc.; B. Chann, R. L. Aggarwal, T. Y. Fan, MIT Lincoln Lab.

High brightness and high power diode lasers are very useful for pumping high power solid-state lasers such as fiber lasers and thin disk lasers that are potential high-energy sources for tactical use. Spatial brightness is very crucial for many solid-state laser pumping applications. We report on enhancing spatial brightness of laser diode arrays at the expense of spectral brightness. This is achieved by wavelength-beam-combining (WBC) of elements from a five-bar stack using a dispersive optical system which overlaps the beams in the near and far fields. We report on details of WBC technique and results of fiber-coupling combined beam to achieve high brightness 915 nm pump source.

6552-42, Session 8

Room temperature high power mid-IR diode laser bars for atmospheric sensing applications

S. Patterson, W. Dong, M. Grimshaw, P. Crump, nLight Corp.

Peak CW optical power from single 1-cm diode laser bars is advancing rapidly across all commercial wavelengths and the available range of emission wavelengths also continues to increase. Both high efficiency ~ 50% and \> 100-W power InP-based CW bars have been available in bar format around 1500-nm for some time, as required for eye-safe illuminators and for pumping Er-YAG crystals. There is increasing demand for sources at longer wavelengths. Specifically, 1900-nm sources can be used to pump Holmium doped YAG crystals, to produce 2100-nm emission. Emission near 2100-nm is attractive for free-space communications and range-finding applications as the atmosphere has little absorption at this wavelength. Diode lasers that emit at 2100-nm could eliminate the need for the use of a solid-state laser system, at significant cost savings. 2100-nm sources can also be used as pump sources for Thulium doped solid-state crystals to reach even longer wavelengths. In addition, there are several promising medical applications in this band, including dental applications such as bone ablation, apicoectomy, periodontal bony procedures, and medical procedures such as tissue ablation, skin welding and opthamology. Industrial applications include trace gas sensing and spectroscopy. We have extended our high performance 1500-nm material to longer wavelengths through careful optimization of design and epitaxial growth conditions and report CW output powers from single 1-cm diode laser bars of 37W at 1910-nm and 25W at 2070-nm. We review the developments required to reach these powers, latest advances and prospects for longer wavelength, higher power and higher efficiency.

6552-44, Poster Session

Time-dependent model of eye-safe erbium-doped YAG laser

B. Zandi, Army Research Lab.; J. B. Gruber, The Univ. of Texas at San Antonio; A. S. Nijjar, San José State Univ.; R. C. Lee, Georgia Institute of Technology; M. B. Camargo, MegaWatt Lasers, Inc.; J. O. White, Army Research Lab.

We have developed a time dependent model for the eye-safe laser emission at 1.6?m, representing transitions from the manifolds 4I13/2 to 4I15/2 of trivalent Er-doped YAG (Y3Al5O12). The model is based on a set of coupled first- order differential equations (rate equations) that describe the laser kinetics of this quasi-three level laser system. Also called zero-dimensional (0-D) equations, these equations are time only dependent with no spatial dimension dependency. The model is anchored to experimental results including the experimental Stark levels that are populated according to a Boltzmann distribution at room temperature. Emission cross section parameters are calculated using reciprocity methods from experimental absorption cross sections. A MATLAB code is written and the equations are solved numerically for output power and slope efficiency and threshold. The results are useful and predictive compared to the published experimental laser data. This model can be optimized for its parameters such as output coupler reflectivity, ion concentration, etc and for other hosts.

6552-45, Poster Session

Thermal lensing in high power solar pumped solid state lasers

S. Payziyev, ACADEMPRIBOR Scientific and Production Association (Uzbekistan)

The thermal lensing effect in Nd:YAG laser rods at pumping by concentrated solar flux of Big Solar Furnace of SPA "Physics-Sun"(Tashkent) is considered. For solution of the problem the computer model of the process was developed and the numerical experiments were performed.

6552-46, Poster Session

Dense spectral beam combining for high power laser applications

O. G. Andrusyak, I. V. Ciapurin, A. Sevian, College of Optics & Photonics/Univ. of Central Florida; V. I. Smirnov, OptiGrate; G. B. Venus, L. B. Glebov, College of Optics & Photonics/Univ. of Central Florida

Development of high-power laser systems capable of producing multi-kilowatt CW radiation has always been challenging mainly due to a problem of dissipating huge amount of heat produced during laser operation. To overcome the limit of ultimate power of a single laser unit, combining of multiple high-power laser beams using passive elements has been suggested. Volume Bragg gratings (VBGs) recorded in photo-thermo-refractive (PTR) glass have been successfully used for high-efficiency spectral beam combining (SBC) of high power laser radiation. Photosensitive PTR glass exhibits low absorption and scattering in the near-IR and excellent optical homogeneity comparable to the best commercial optical glasses.

The key parameter of SBC is spectral density which determines the number of channels that can be combined within a certain bandwidth, limiting the total output power of the system. We report experimental results of 5-beam SBC around 1064 nm with channel density exceeding 2 channels/nm. Reflecting VBGs have been designed following a recently developed multi-channel SBC optimization procedure and fabricated in PTR glass. SBC with absolute efficiency in excess of 93% and near-diffraction-limited output beam was demonstrated using these gratings. Initial results of kW-level SBC are discussed. We show how output power is scaled by increasing the channel count, and outline a pathway to multi-kW systems.

6552-47, Poster Session

1-W laser diode spectrally narrowed to 10 GHz

A. Gourevitch, G. B. Venus, L. B. Glebov, College of Optics & Photonics/Univ. of Central Florida

High power optical sources with narrow emission spectra are promising for a variety of applications such as optical pumping, gas detection, direct illumination, etc. Volume Bragg gratings (VBGs) manufactured in a photo-thermo-refractive (PTR) glass are highly selective spectral and/or angular filters. Robust VBGs with diffraction efficiency greater than 99% and high thermal, optical, and mechanical stability in high-power laser radiation have been demonstrated. The use of a reflecting VBG as an output mirror in an external cavity secures a narrowing the wide emission spectra of laser diodes within tens of picometers (the GHz range). This narrowing technique can be applied over a spectral range from the blue to mid-IR. Results of spectral narrowing of a single laser diode operating at 980 nm with a 2 nm FWHM emission spectrum by means of the VBG external cavity is presented. 1 W CW output power within 35 pm (10 GHz) spectral width has been achieved at spectral conversion efficiency better than 90%.

6552-48, Poster Session

The progress towards the transparent ceramics fabrication

Y. A. Barnakov, Z. W. Kabato, G. Zhu, Norfolk State Univ.

The present paper highlights the technological aspects of Nd:YAG transparent ceramics fabrication. The comprehensive analysis of the relationship between nanoparticles size, consolidation's techniques, sintering's parameters and optical quality of the product will be performed.

6552-49, Poster Session

Fast-tuning narrow-linewidth all polarization-maintaining fiber ring laser

Z. Meng, Y. M. Hu, Z. Hu, S. Xiong, C. Cao, National Univ. of Defense Technology (China)

Narrow-linewidth, linearly-polarized fibre ring lasers have attracted much research interests because of their potential applications in optical sensors and optical communications. Several methods have been investigated to suppress mode hopping and obtain stable single-frequency lasing. Previous work has demonstrated that a narrow-band reflection filter can be established in unpumped erbium-doped fibre (EDF), which acts as a saturable absorber in a ring cavity. The importance of using PM rather than SM unpumped EDF for enhancing stability has also been experimentally demonstrated. However, in practical hostile environments, the fluctuation of state-of-polarization in other SM fibres and devices in the laser cavity also induces the lasing mode hopping. This paper presents an all polarization-maintaining fibre ring laser with fast tunability, which is required to operate in some optical fibre sensor applications, such as phase generated carrier (PGC) technique.

The structure of the laser is a travelling-wave ring cavity, which includes an EDF amplifier, wavelength-division multiplexing (WDM) coupler, a circulator, a piezoelectric ring wrapped with PM fibre, a FBG, an unpumped EDF and a coupler. All of the polarization-maintaining fibre and devices can suppress the polarization instability effects on the mode hopping. With a 100mW pump power, the output power of the stable single-frequency laser is up to 5mW at 1536nm. The extinction ratio of the linearly-polarized output is 25dB, the SNR is larger than 60dB, the RIN is below -118dB/Hz and the linewidth is less than 1.0kHz. The fast tuning rates of the lasing optical frequency achieves ~50kHz with no noticeable power fluctuations, and the maximum tuning range is about 10MHz. This fibre laser has been used in an interferometric fibre sensor and the experimental results show the equivalent phase noise is approximately -107dB/Hz with 20m optical path difference between two arms.

6552-50, Poster Session

Fabrication of Nd:YAG transparent ceramics

Y. A. Barnakov, G. Zhu, M. Bahoura, M. A. Noginov, Norfolk State Univ.; J. Intrater, R. Radhakrishnan, T. S. Sudarshan, Materials Modification Inc.

We have fabricated several pieces of transparent Nd:YAG ceramics using various synthesis techniques. Nanopowder compacts were made by applying high pressure or by pressure-less sedimentation. In different experiments, the long-term sintering with low heating and cooling rates as well as short-term sintering with fast heating and cooling rates were used to fire green bodies. The sintered samples were characterized by means of optical spectroscopy and electron microscopy. Emission and absorption spectra as well as emission kinetics were similar to those in Czohralski grown Nd:YAG crystals. The samples were optically transparent, however, not of the laser quality yet. The comprehensive analysis of the influence of the sintering regime on the optical quality of the ceramics will be presented at the conference.

6552-51, Poster Session

Spectroscopic characterization of ceramic laser materials for high-performance solid-state lasers

V. Lupei, A. Lupei, C. Gheorghe, Institute of Atomic Physics (Romania); A. Ikesue, Poly-Techno Co., Ltd. (Japan)

The transparent polycrystalline ceramic materials activated with laser active ions are considered as possible substitutes for single crystals in construction of lasers. These materials consist of tightly packed, randomly-oriented crystalline grains with shallow grain boundaries and with very small volume density of intergrain pores and could be useful in case of the cubic materials, such as the garnets or sesquioxides. The fabrication temperature of the transparent ceramics is about 400 to 700 0C below the melt temperature of these materials. Besides evident technological (high production yield, better control, capability to produce very large laser active components) or economical (low cost, better use of the raw material, low energy consumption), the transparent ceramics show functional advantages such as large compositional versatility, higher doping concentration, controlled profile of the doping, from uniform over all the body of ceramic to gradient or steep change, improved mechanical or heat conduction properties and so on). Thus these materials could extend the performances of the existing solid-state lasers or enable tailoring of new laser systems. Nevertheless, the granular structure of ceramics rises problems concerning the variety, nature and the relative concentrations of the cationic sites, the distribution of the doping ions in these sites, the energy levels and the transition probabilities and the manifestation of the interactions between ions and energy transfer. The present paper discusses the use of high-resolution spectroscopy in solving these problems in case of garnets and sesquioxide laser ceramics produced by solid-state synthesis, with grains in the tens of micron range. Special accent is put on new laser materials that show prospect for improving the laser performance or for new laser emission schemes. It is inferred that from spectroscopic point of view these ceramics could substitute and extend the capabilities of these lasers.

6552-52, Poster Session

Development of robust solder processes for reliable high power bars enables 70-W on-off output at 50C case from passivated 8xx-nm bars hard soldered to CTE matched passively cooled heatsinks

J. Wang, M. DeFranza, A. L. Hodges, B. D. Vivian, C. Johnson, D. Wise, V. Liu, M. A. DeVito, R. J. Martinsen, J. Bell, nLight Corp.

Applications of conventional high power GaAs bars are limited by several

critical issues:

(1) failure of the indium solder joint at high temperature or on current cycling, (2) failure of the semiconductor due to facet failure (COD) and (3) the requirement of microchannel coolers for high power per-bar, which are complex and require highly skilled operators to use. We present results on a new class of products that eliminate all these issues. Using heatsinks that are expansion matched to GaAs enables the use of hard gold-tin solder, eliminating indium solder and allowing high temperature (\>50C case) operation. Expansion matching also eliminates stress in the solder joint and semiconductor, enabling reliable operation under demanding second-on, second-off operation. Application of high performance nXLT facet-passivation enables reliable 70W operation from a 30% fill factor bar, and the use of passively cooled (CS) heatsinks means complex, hard to use microchannels are unnecessary. High quality solder-joints are of critical importance for these applications to enable reliable high powers, and we present results of an experimental study to optimize this process, detailing key failure modes and how these are eliminated. We also present results of reliability study supporting 10000 hour operation under second-on second off conditions at temperatures up to 50C.

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6553-01, Session 1

Surface velocity phases of the seismic/acoustic ratio and buried landmines

J. M. Sabatier, G. M. Matalkah, G. Broussard, R. Lirette, C. McNeill, The Univ. of Mississippi

The seismic-to-acoustic transfer function (S/A) has been defined as the total normal particle velocity of the ground surface normalized by the surface acoustic pressure as measured by either a geophone or laser Doppler vibrometer (LDV) and a microphone. This is a complex quantity that describes the magnitude and phase of the grounds surface velocity relative to the phase of the total pressure at the surface due to an incident sound field. The phases of the ground's surface particle velocity for both off-target and on-target locations offer contrast to aid in the detection of mines. In raw, unprocessed images of the magnitude and phase of the ground's surface particle velocity as a function of frequency, the strongest contrast image for the magnitude appears at a lower frequency than for the phase contrast image. Simple harmonic oscillator models of the soil/mine system suggest that one look for the zero crossing in the phase response for pixels over the mine as detection criteria. However, both particle velocities measured in field tests and plane wave, elastic layered models of the ground's phase response show many phase zero crossings for off-target or background locations, thus precluding zero crossings as a stand alone indicator for the presence of a mine. Also, models and field measurements show that the complex velocity response of the ground becomes spatially more random as the frequency increases. For frequencies above the mine resonance, both coupled oscillator and plane wave acoustic models show the phase of the soil particle velocity changes slowly between the first resonance and first anti-resonance of the soil/mine system. In this study, an acoustical landmine stimulant that has a high "Q" relative to most landmines is used to study the phases on and off target.

6553-02, Session 1

Adaptive CFAR detection algorithm for acoustic-seismic landmine detection

G. M. Matalkah, M. Matalgah, J. M. Sabatier, The Univ. of Mississippi

Constant False Alarm Rate (CFAR) detection algorithms based on the maximum likelihood ratio test of Neyman and Pearson have been extensively dealt with in the literature and found to be giving satisfying results in a broad variety of target detection technologies. In this work, a CFAR algorithm is derived for acoustic-seismic landmine detection and applied to high frequency-resolution spectral images of magnitude and phase of ground's surface particle velocity. The algorithm is based on the experimentally justified assumptions that the magnitude of the complex-valued velocity spectrum follows a Rayleigh distribution and that the phase, independently from the magnitude, follows a uniform distribution. Based on the assumptions of magnitude and phase distributions, statistical parameters are estimated from the large number of samples provided by high frequency-resolution images (order of 1-Hz). Estimated parameters of background and potential target regions are used to set a maximum likelihood ratio test against a particular threshold value. The algorithm is adapted to select the background-dependent threshold value such that the test maintains a constant false alarm rate. Results of applying the algorithm to images of different types of background are shown and expression for the probability of false alarm is derived.

6553-03, Session 1

Direct mechanical landmine excitation with LDV surface measurements

S. S. Bishop, U.S. Army Night Vision & Electronic Sensors Directorate; P. Tsopelas, J. A. Judge, J. F. Vignola, The Catholic Univ. of America

Remote acoustic or seismic forms of excitation for laser Doppler vibration mine detection are seen as low false alarm rate detection strategies. A more recent approach now under investigation includes a close-in direct mechanical excitation through a prodder or probe. In this research we report on simple laboratory measurements of the TS-50, VS-50, PMN and VS1.6 landmines undergoing direct mechanical excitation through various probing techniques while measuring the mine's pressure plate vibration through a laser Doppler vibrometer. Excitation mechanism consisted of a supported mechanical shaker at the aft end of a steel rod or a piezoelectric at the contacting tip of the rod. We determine natural modes frequencies, damping coefficient, stiffness and mobility transfer function. Additionally, we report on the ground surface response when the excited landmine is buried flush and at various depths in dry and.

6553-05, Session 1

Basic experiments on seismo-acoustic waves, interacting with subsurface cylindrical voids and ground-surface sensors

T. G. Muir, R. Mack, J. M. Sabatier, The Univ. of Mississippi

Cylindrical voids near the earth's surface may include man-made tunnels, drain pipes, and conduits. Their location and monitoring is of interest in law enforcement, as well as in agricultural and civil engineering. A wide variety of Seismo-acoustic waves appear to offer several different means for detection and monitoring, both passive and active. A 12 inch. diameter, concrete pipe, buried in soil at a depth of 8 feet, and used for roof drainage in an urban environment, was utilized to experimentally examine this hypothesis. Three scenarios were sequentially examined in the 100 to 500 Hz band, all with sensors deployed in patterns on the ground surface (and in the drain pipe, for monitoring), as follows: 1) the detection of sound emitted by an upwardly oriented loudspeaker, inserted some 20 ft. into the pipe, 2) a vertical shaker source made to contact the top crest of the pipe at the same lateral location, and 3) a moveable, ground-surface shaker. In each case, seismo-acoustic waves were detected, in surface patters, with tri-axial seismometers. The loudspeaker and shaker in the pipe primarily generated vertically polarized body waves, while the surface shaker also reflected transversely polarized shear waves, all in characteristic patterns that will be discussed in the paper. Refraction appeared to affect all of the propagating waves. The orientation of the drain pipe could be determined from the sensed wave pattern on the surface, and its depth from pulse-echo measurements from the surface shaker, provided a representative geo-acoustic model for the overlying soil is available, or is measured. [Work supported by the U.S. Department of Agriculture and the U.S. Army Research Office.]

6553-06, Session 2

Effects of magnetic soil on metal detectors: preliminary experimental results

Y. Das, Defence Research and Development Canada (Canada)

In a series of previous papers, analytical results dealing with the effects of soil electromagnetic properties on the performance of induction metal detectors were reported. In this paper experimental data are provided to verify some previously reported results. The time-domain

response of a magnetic soil half-space and a small metallic sphere situated in air as well as buried in the soil were measured using a purpose-designed system based on a modified Schiebel AN19/2 metal detector. As in the previous work, the sphere is chosen as a simple prototype for the small metal parts in low-metal landmines. The soil used was Cambodian ''laterite" with dispersive magnetic susceptibility, which serves as a good model for soils that are known to adversely affect the performance of metal detectors. The metal object used was a sphere of diameter 0.0254~m made of 6061-T6 aluminum. Experimental data is in good agreement with theoretical predictions. Data also show that for the weakly magnetic soil used in the experiments, the total response of the buried sphere is the sum of the response of the soil and that of the sphere placed in air. This finding should simplify the prediction or measurement of response of buried targets as one can separately measure/compute the response of an object in air and that of the host media and simply add the two. This simplification may not be possible for soils that are more strongly magnetic.

6553-07, Session 2

Toward a model for predicting the magnetic susceptibility of bedrock regolith

B. J. Harrison, New Mexico Institute of Mining and Technology; R. L. Van Dam, Michigan State Univ.; J. M. H. Hendrickx, New Mexico Institute of Mining and Technology

One of the Department of Defense's (DOD) most pressing environmental problems is the efficient detection and identification of unexploded ordinance (UXO) without the need to exhume large numbers of non-UXO. In regions of highly magnetic soils, magnetic and electromagnetic sensors often detect large anomalies that are of geologic origin adding significantly to remediation costs. Up to 30 % of the magnetic anomalies identified during remediation of the Kaho 'olawe firing range were of geologic origin. Most rock types contain iron and their magnetic susceptibility is determined predominantly by the amount and form of iron oxides present. The susceptibility of the most magnetic iron oxides (magnetite, maghemite) is approximately a factor 500-1,000 higher than that of the most common iron oxides (goethite, hematite). Therefore, it crucial to understand the spatial distribution of different iron oxides so that predictive models for magnetic susceptibility can be developed. When rocks weather, the amount and form of the oxides change producing concomitant changes in the magnetic susceptibility. The type of iron oxide found in the weathered rock or regolith is a function of the duration and intensity of weathering, as well as the original content of iron in the parent material. The rate of weathering is controlled by rainfall and temperature; thus knowing the climate zone, the amount of iron in the lithology and the age of the surface will allow us to predict the amount and forms of iron oxide in the regolith.

We have compiled analyses of the types and amounts of iron oxides from soils over a wide climate range, from semi arid grasslands, to temperate and tropical forests. We find there is a predictable range of iron oxide type and magnetic susceptibility according to the climate zone, the age of the soil and the amount of iron in the unweathered regolith.

6553-08, Session 2

Estimating soil's effective magnetic susceptible from EMI data

I. Shamatava, Dartmouth College; B. E. Barrowes, U.S. Army Engineer Research and Development Ctr.; F. Shubitidze, Dartmouth College; K. A. O'Neill, U.S. Army Engineer Research and Development Ctr.; K. Sun, J. P. Fernández, Dartmouth College

EMI responses from magnetically susceptible soils can cause significant problems for magnetometers and electromagnetic induction sensors, in terms of both decreased probability of detection and increased probability of false alarm. However, in most existing approaches to buried metallic object discrimination, the object of interest is assumed to be embedded in a medium with the same electromagnetic properties as free-space. Any influence of the background medium is assumed to have been removed by pre-processing or filtering before the data are submitted to an inversion routine. Most existing techniques for calculating the soil and geological effects, which include the half-space earth model and equivalent dipole layer models, have almost exclusively neglected the surface roughness of the soil. In addition, these techniques are limited to the use of one dimensional or layered Earth models. Such models are incapable of capturing the electromagnetic induction effects associated with the soil surface roughness pervasive in field environments. We characterize the response from a rough soil surface so that it can be predicted, or so that it can at least be accounted for during data processing. The characterizing of soil's EMI response requires knowledge of its magnetic susceptibility. To date the soil's magnetic susceptibility is measured using very small amounts (as little as 15 mg) of soil, which for many soils does not yield the effective magnetic susceptibility required to predict the effects of the soil on the state of the art EMI sensors such as the GEM3 and the EM63.

The main objectives of this paper are to develop a new algorithm for mapping the soil's effective magnetic susceptibility using handheld EMI sensors at varying elevations, in both the TD and the FD, and to perform Monte-Carlo modeling of random rough soil surfaces in order to establishing a statistical relationship between surface roughness and signal characteristics. The numerical algorithm will be tested against measured data for a variety of soil types. Finally, to aid in UXO discrimination under realistic field conditions, the algorithm will combine these soil calculations with current the state of the art EMI modeling techniques to separate and account for the soil response within UXO classification algorithms.

6553-09, Session 2

Evaluation of the Geonics EM-63 time-domain metal detector/discriminator

L. S. Riggs, Auburn Univ.; B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr.

The EM-63 Manufactured by Geonics Ltd. of Mississauga, Ontario, Canada is a time-domain electromagnetic induction metal detector/ discriminator. It consists of a 1m X 1m transmitter coil and three 21 inch X 21 inch coaxially stacked receiver coils. The bottom receiver coil lies in the plane of the transmitter coil while the middle/top coil is 12/24 inches above the plan of the transmitter coil. The transmitter current waveform rises exponentially to around 15 Amperes and then falls to zero in a linear ramp in approximately 100 microseconds. The circuitry used to generate the transmitter current as well as other interesting transmitter current waveform characteristics shall be discussed. The input impedance characteristics of the receiver coils have been measured and a model of their electrical characteristics shall be presented. Furthermore, the frequency response characteristics of the receiver coil preamplifier have also been measured and will be presented. The EM-63 has been used to measure a variety of test objects including three copper loops with fast, medium, and slow time constants as well as two different ferrous cylinders and a ferrous sphere. This data shall be presented in light of the sensor's ability to discriminate among unexploded ordnance (UXO) and between UXO and metallic clutter. Concluding, the paper will compare the performance of the EM-63 to metal detectors/discriminators sold by other manufactures.

6553-10, Session 2

Broadband electromagnetic induction sensor

W. R. Scott, Jr., G. D. Larson, Georgia Institute of Technology

In recent years, advanced electromagnetic induction (EMI) sensors have been shown to be capable of discrimination between buried landmines and various metal clutter. The detectors accomplish this by utilizing a broad range of frequencies or a broad range of measurement times in conjunction with advanced signal processing. For these advanced EMI sensors to be effective, they must accurately, repeatably, and quickly measure the response of a buried target. This is difficult because the sensor must operate with bandwidths greater than 100 to 1 while accurately measuring signals that are more than 80dB smaller than the direct coupling between the coils on the EMI sensor. In order to accomplish this, the EMI sensor must be very cleverly designed to

account for the coupling between the transmit and receive coils and for the secondary effects such as the resonances in the coils.

In most EMI sensors, the coupling between the coils is handled by one of two methods. In time-domain sensors (pulsed induction), the coupling between the coils is mostly removed by time gating. In frequency domain sensors, the coupling is typically removed by using a quadrapole receive coil which minimizes the mutual inductance between the coils. The quadrapole coils are formed in several ways, but they all have the disadvantage of being less sensitive to deeply buried targets and having a complicated detection zone when compared to a dipole receive coil.

A prototype EMI sensor is developed that uses simple dipole transmit and receive coils along with a bucking transformer to cancel the coupling between the coils. The results of laboratory and field experiments using this sensor are presented. These results show that the sensor can distinguish between landmines and many types of clutter.

6553-11, Session 3

Inferring the location of buried UXO using a support vector machine

J. P. Fernández, Dartmouth College; B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr.; K. D. Paulsen, I. Shamatava, F. Shubitidze, K. Sun, Dartmouth College

The identification of unexploded ordnance (UXO) using electromagnetic induction sensors involves two essentially independent steps: Each anomaly detected by the sensor has to be located fairly accurately, and its orientation determined, before one can go on and try to find size/shape/composition properties that identify the object uniquely. The dependence on the latter parameters is linear, and can be solved for efficiently using for example the Normalized Surface Magnetic Charge model. The location and orientation, on the other hand, have a nonlinear effect on the measurable scattered field, making their determination much more time-consuming and thus hampering the ability to carry out discrimination in real time. In particular, it is difficult to resolve for depth when one has measurements taken at only one instrument altitude.

In view of the difficulties posed by direct inversion, we propose using a Support Vector Machine (SVM) to infer the location and orientation of buried UXO. SVMs are a method of supervised machine learning: the user can train a computer program by feeding it features of representative examples, and the machine, in turn, can generalize this information by finding underlying patterns and using them to classify or regress unseen instances. In this work we train an SVM using measured-field information, for both synthetic and experimental data, and evaluate its ability to predict the location of different buried objects to reasonable accuracy. We explore various combinations of input data and learning parameters in search of an optimal predictive configuration.

6553-12, Session 3

Buried metalic object identification by EMI sensor

M. Sezgin, TÜBITAK Marmara Research Ctr. (Turkey)

Electromagnetic Induction (EMI - Metal detector) sensors have wide application areas for buried metallic object searching, such as detection of buried lines, pipes, mine and mine like-targets, etc. In this paper, we studied the identification of buried objects utilizing metal detector. We considered unique signatures of objects in the test data set, than we performed classification process.

6553-13, Session 3

Performance of a four-parameter model for landmine signatures in frequency domain wideband electromagnetic induction detection systems

E. Fails, Duke Univ. Chapter; P. A. Torrione, L. M. Collins, Duke Univ.

This work explores possible performance enhancements for landmine detection algorithms using frequency domain wideband electromagnetic induction, WBEMI. A pre-existing four parameter model for conducting objects based on empirically collected data for UXO (Miller et al. IEEE TGARS, 2001) is discussed, and its application for accurately modeling landmine signatures is considered. Certain model features are also introduced to exploit the coupling effects between the conducting shape responses. Discrimination of mines versus clutter based on the extracted model parameters is considered. Furthermore, this work will compare the effectiveness of discrimination based on the four parameter model to a matched subspace landmine detection algorithm discussed previously (Torrione et al., SPIE, 2002). Different pre-processing approaches will be discussed and compared. Experimental results using data from government run test sites will be presented.

6553-14, Session 3

A combined NSMC and Pole series expansion approach for UXO discrimination

F. Shubitidze, Dartmouth College; B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr; I. Shamatava, J. P. Fernández, K. Sun, Dartmouth College

The detection and remediation of UXO on military ranges still continues to be the number one military environmental problem. The UXO detection and discrimination activities conducted at DoD and DoE sites using current state-of-the-art technologies often yield unsatisfactory results due mainly to the inability to discriminate between UXO and non-hazardous items. Innovative discrimination and classification techniques that can reliably distinguish between hazardous UXO and non-hazardous metallic items are required. There are a wide range of different inverse scattering methodologies (single and double dipole models, the standardized excitation approach (SEA), the NSMC model, and etc) currently being used or are in development for discriminating UXO from non-UXO items. In order to utilize these inverse approaches, first the buried object's location and orientation have to be inverted. Inverting for these parameters are the most time consuming and difficult phase of the inversion process, particularly when two or more objects are simultaneously present in the sensor's field of view, which usually is the case in real field conditions. The secondary magnetic field that is measured by the receiver must have origins/sources, i.e. they are produced by a certain type of source such as induced eddy currents or dipoles. These sources are distributed non-uniformly inside the scatterer. There are some particular points, named "scattered field singularities" (SFS), were most sources are located.

The main objective of this paper is to combine the normalized surface magnetic charge (NSMC) method and a pole series expansion method to determine the SFS points from the measured magnetic field, and thereby to find a buried object's location and orientation without solving a time consuming inverse problem. The NSMC method has been developed previously and is a robust model for predicting the EMI responses of various objects. This method is applicable to any combination of magnetic or electromagnetic induction data for any arbitrary 3-D object or set of objects. In this paper, the EMI responses will first be collected at a planar measurement surface. Then the NSMC model, which distributes magnetic charge on a surface conformal to, but not coincident with the measurement surface, will be used to extend the actual measured EMI magnetic field above the data collection surface to generate spatially distributed data. Then the pole series expansion model will be employed and tested with the goal of localizing the scattered fields' origins. Once the objects' locations and orientations are determined, the EMI inverse scattering problem simplifies to determining the amplitudes of the NSMC. Finally, the total NSMC will be used for object classification. The proposed technique will be tested against real data with different signal to noise ratios.

6553-15, Session 3

NSMC for UXO discrimination in cases with overlapping signatures

F. Shubitidze, Dartmouth College; B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr.; I. Shamatava, K. Sun, J. P. Fernández, Dartmouth College

Discrimination of Unexploded Ordnance (UXO) from non-UXO items continues to be a challenging problem. The high costs of excavating all geophysical anomalies are well known and are one of the greatest impediments to efficient clean-up of UXO contaminated lands at DoD and DoE sites. Recent field activities from the UXO standardized test site have shown that existing modeling and inversion technologies, which are based on a simple dipole model approximation, have difficulty dealing with overlapping responses from closely spaced targets. In order to provide effective and reliable discrimination in these situations, new methodologies for multi-object inversion are required. These new algorithms should implement more accurate and physically complete EMI forward modeling algorithms.

In this paper the normalized surface magnetic charge model (NSMC) is presented for discriminating objects of interest, such as UXO, from innocuous items, in cases when UXO electromagnetic induction (EMI) responses are contaminated by signals from other objects or magnetically susceptible ground. The NSMC model is designed for genuine discrimination and is a physically complete, fast, and accurate forward model for EMI scattering. In physical reality, there are no magnetic charges, i.e. no isolated magnetic monopoles. However, they can serve as a useful and legitimate mathematical fiction. Because the field produced by the magnetic charges constitute an analytic solution to the governing EMI equation outside the scatterer, we can use ficticious magnetic charges to generate real secondary magnetic fields. In the NSMC, the overall EMI inverse problem can be summarized as follows: first, for a given primary magnetic field the secondary magnetic field at selected points outside the object is recorded, and second, the scattered field information is used to distinguish an object of interest from innocuous items. To connect the scattered field to its source, we require a forward model, which the processing uses to infer source parameters. Ideally these parameters are invariant even so that they constitute distinguishing characteristics of the object. In the NSMC formulation that is presented here, the source-field connection is parameterized in such a way that fulfills this requirement, at the same time being extremely efficient computationally. To illustrate the applicability of the NSMC algorithm, we processed and analyzed blind test data, which were collected at the Cold Regions Research and Engineering Laboratory facility from objects buried under different soil types, some of which were magnetically susceptible. In these cases, signals from nearby buried objects frequently overlapped.

6553-16, Session 4

An assessment of the fundamental performance of GPR against buried landmines

D. J. Daniels, ERA Technology Ltd. (United Kingdom)

GPR has achieved success against buried landmines in particular design configurations (handheld). There are however fundamental limitations in terms of propagation parameters, proximity to the ground surface, ground topography and bandwidth of operation. This paper discusses these limitations with reference to stand off landmine detection and with reference to published results establishes basic operating parameters within which GPR can operate successfully.

6553-17, Session 4

Obstacle avoidance and concealed target detection using the Army Research Lab Ultra-Wideband Synchronous Impulse Reconstruction (UWB SIRE) forward imaging radar

L. H. Nguyen, D. C. Wong, M. A. Ressler, F. Koenig, B. Stanton, G. M. Smith, J. P. Sichina, K. A. Kappra, Army Research Lab.

The U.S. Army Research Laboratory (ARL), as part of a mission and customer funded exploratory program, has developed a new low-frequency, ultra-wideband (UWB) synthetic aperture radar (SAR) for forward imaging to support the Army's vision of an autonomous navigation system for robotic ground vehicles. These unmanned vehicles equipped with an array of imaging sensors will be tasked to help detect man-made obstacles such as enemy minefields and booby traps, as well as other natural obstacles such as ditches, quagmires, and bodies of water. The ability of UWB radar technology to help detect concealed objects has been documented in the past and could provide an important obstacle avoidance capability for autonomous navigation systems, which would improve the speed and maneuverability of these vehicles and consequently increase the survivability of the U.S. forces on the battlefield.

One of the goals of the radar is the ability to collect and process data at combat pace in affordable, compact, and lightweight package. To achieve this, the radar is based on the synchronous impulse reconstruction (SIRE) technique where we employ relatively slow inexpensive analog-to-digital (A/D) converters to sample the wide bandwidth of the radar signals.

This paper will describe an experiment conducted this summer at Aberdeen Proving Ground (APG), Maryland. The purpose of the experiment is to support phenomenological studies of the backscatter from positive and negative obstacles for autonomous robotic vehicle navigation, as well as the detection of concealed target of interest to the Army. In this paper we briefly describe the UWB SIR radar and the test setup in the experiment. We will also describe the signal processing and the forward image techniques used in the experiment. Finally, we will present imagery of positive obstacles such as barriers, concertina wires, mines, as well as negative obstacles such as ditches.

6553-18, Session 4

Fusion of disturbed soil feature for down-looking ground-penetrating radar mine detection

E. M. Rosen, E. Ayers, Institute for Defense Analyses

For vehicle-mounted down-looking ground penetrating radar (DLGPR) systems, the largest response is due to the radar reflecting off of the ground. Most DLGPR algorithms remove the ground bounce response as a first pre-processing step. The remaining subsurface response is then used to detect buried mines. It was observed that the ground bounce response over recently buried mines differs from the surrounding undisturbed soil. This suggests an approach in which the ground bounce response could be used to enhance buried mine detection performance. In this paper, we describe a technique for fusing the GPR ground bounce response with the GPR subsurface response to enhance mine detection performance. The technique is applied to data collected by a wide bandwidth impulse radar over buried mines in various soil conditions.

6553-19, Session 4

Improvements based on ground penetration radar field evaluations in Angola

F. Navish III, U.S. Army Night Vision & Electronic Sensors Directorate

The U.S. Army Research, Development and Engineering Command (RDECOM), Communications-Electronics Research Development and Engineering Center (CERDEC) Night Vision and Electronic Sensors Directorate (NVESD) Humanitarian Demining (HD) Research & Development Program focuses on developing, testing, demonstrating, and validating new technology for immediate use in humanitarian demining operations around the globe. The HD team provided funding and guidance to NIITEK Inc., for development of a prototype system called Mine Stalker, a relatively light-weight, remote-controlled vehicle outfitted with the NIITEK ground penetrating radar (GPR), detection algorithms, and a marking system. Individuals from the HD team, NIITEK Inc, and the non-governmental organization (NGO) Meschen Gegen Minen (MgM) participated in a field evaluation of the Mine Stalker in Angola in October - November 2005. Improvements to the first generation Mine Stalker are based on the Angola field evaluation and recommendations from an annual humanitarian demining requirements workshop of various NGOs and mine action centers from all over the world. The HD team and NIITEK identified hardware and software improvements to the first generation Mine Stalker for further field evaluations that will occur in Angola, Cambodia, or Somaliland in the spring / summer of 2007.

6553-20, Session 4

Preliminary measurements of ruffled water surface, snow, and bare soil microwave reflective and emissive characteristics polarization and correlative features by polarimetric, combined scatterometer-radiometer system of 15GHz

A. K. Arakelyan, A. A. Arakelyan, A. K. Hambaryan, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia); S. F. Clifford, CIRES

In this paper preliminary results of simultaneous and spatially coincident, microwave polarimetric measurements of a water surface, snow, bare soil and vegetation will be presented. Measurements include the microwave reflective (radar backscattering coefficient) and radiothermal emission (brightness temperature) characteristics at 15GHz. The observations were made by a Ku-band, polarimetric, combined radar-radiometer system from a stationary platform of 6m height. The main characteristics of the microwave sensor are:

Central Frequency - ~15GHz;

Radar Pulse duration - 25ns

Radar pulse power - 70mW

Radar receiver's bandwidth - ~40MHz;

Radiometer receivers bandwidth - ~800MHz;

Parabolic antenna with a beamwidth - ~70;

Radar receivers noise factor - ~2dB;

Radiometer receiver's noise factor - ~250K;

Radar channel's sensitivity at 1s- ~0.1dB;

Radiometer Channel's sensitivity at 1s- ~0.15K.

The principal advantages of this unique device are its spatio-temporally combining of microwave active-passive channels of observation under the condition of short range sensing (at the observation distance ~5m) at the far field condition for sensing.

The methodology of experimental performance, field calibration of the measuring system, and the measured data will be discussed. Relationships between the intrinsic properties of a perturbed water surface, snow cover, bare soil, and vegetation and their respective radar backscattering coefficients and brightness temperatures will be determined under various conditions of observation (angle of incidence and polarization). We will also determine the correlation between variations of the water surface, snow, bare soil and vegetation's radar backscattering coefficients and brightness temperatures due to changes in the observed medium's structure: its roughness parameters, depth, density, and ground cover. The effects of changes in the air temperature, biomass and moisture will also be considered.

6553-21, Session 4

Preliminary measurements of ruffled water surface microwave reflective and emissive characteristics results of spatio-temporally combined, microwave active-passive of bare and vegetated soil, snow and water surface at 5.6 GHz

A. K. Hambaryan, A. K. Arakelyan, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia)

In this paper preliminary results of simultaneous and spatially coincident, microwave, polarimetric measurements of a water surface, snow, bare soil and vegetation will be presented. Measurements include the microwave reflective (radar backscattering coefficient) and radiothermal emission (brightness temperature) characteristics at 5.6GHz. The observations were made by a C-band, polarimetric, combined radar-radiometer system from a stationary platform of 6m height. The main characteristics of the microwave sensor are:

Central Frequency - 5.6GHz;

Radar Pulse duration - 25ns

Radar pulse power - 50mW

Radar receiver's bandwidth - ~40MHz;

Radiometer receivers bandwidth - ~600MHz;

Parabolic antenna with a beamwidth - 50;

Radar receivers noise factor - ~2dB;

Radiometer receiver's noise factor - ~150K;

Radar channel's sensitivity at 1s- ~0.1dB;

Radiometer Channel's sensitivity at 1s- ~0.1K.

The principal advantages of this unique device are its spatio-temporally combining of microwave active-passive channels of observation under the condition of short range sensing (at the observation distance ~5m) at the far field condition for sensing.

The methodology of experimental performance, field calibration of the measuring system, and the measured data will be discussed. Relationships between the intrinsic properties of a perturbed water surface, snow cover, bare soil, and vegetation and their respective radar backscattering coefficients and brightness temperatures will be determined under various conditions of observation (angle of incidence and polarization). We will also determine the correlation between variations of the water surface, snow, bare soil and vegetation's radar backscattering coefficients and brightness temperatures due to changes in the observed medium's structure: its roughness parameters, depth, density, and ground cover. The effects of changes in the air temperature, biomass and moisture will also be considered.

6553-22, Session 4

ICA analysis of polarization data in microwave X band region for detection of shallow buried non-metallic dummy landmines without explosives.

K. C. Tiwari, D. Singh, M. Arora, Indian Institute of Technology Roorkee (India)

Detection of buried landmines and estimation of depth by modeling layered media is a complex and computationally intensive task. With the advent of satellites which can provide data in various polarizations, it has increasingly become relevant to investigate methods which can be used for the purpose of landmine detection using various polarization techniques. In this paper, ICA (Independent component analysis) has been applied on image data obtained in two polarizations and investigated for detection of dummy landmines without explosives. The data for the purpose was generated through lab experiments in HH and VV polarizations in microwave X band region (10 GHz, 3 cm) using dummy landmines (without explosives) buried at different depths in dry sand. ICA attempts to produce statistically independent components from the mixed input signals. First, the data in each polarization was calibrated, normalized and then convoluted using a 5x5 convolution filter. The convoluted data in two polarizations was then processed through FastICA algorithm and Otsu's thresholding applied on the independent components produced for landmine detections. Detections were attempted using Otsu's thresholding without processing the data through FastICA algorithm also. It was found that the thresholding of the independent components produced most accurate results. The backscatter intensity calculated for the pixels detected as landmine using ICA is being further processed for shape and depth analysis.

6553-23, Session 5

Multisensor, multi-environment learning for underwater object classification

J. R. Stack, F. J. Crosby, Naval Surface Warfare Ctr.; Y. Hue, L. Carin, Duke Univ.

The purpose of this research is to appropriately share information between similar classification tasks during the learning process and to appropriately apply relevant, previously learned information to new, similar classification tasks. Consider a set of similar underwater sensors operating over a variety of environments where some environments posses similarities. It is expected that information gained by one sensor in one environment is relevant to performing classification given a similar sensor in another, similar environment. By jointly learning multiple classification tasks in a Bayesian framework, a common hierarchical prior is employed to enforce sharing of information between tasks. For each task, the prior distribution is drawn from a Dirichlet process, which is non-parametric and automatically determines the number and grouping of similar tasks. Therefore, similar tasks share a common, jointly learned prior distribution while disparate tasks possess different prior distributions. When faced with learning a new, previously unseen task, this same framework facilitates the appropriate sharing of previously learned information to the new task. This produces improved performance over both learning the new task given only the new data (because the training data set is significantly expanded) and learning the new task using all data equally (because the new classifier is not forced to generalize to all previous tasks). The proficiency of this technique is demonstrated on simulated data and on data from multiple sidescan sonars operating from various unmanned underwater vehicles in a variety of environments.

6553-24, Session 5

Underwater magnetic gradiometer for magnetic anomaly detection, localization, and tracking

S. Kumar, D. C. Skvoretz, M. J. Ebbert, S. L. Bennett, A. Tzouris, Quantum Magnetics, Inc.; G. S. Sulzberger, J. T. Bono, G. I. Allen, T. R. Clem, Naval Surface Warfare Ctr.

GE Security and the Naval Surface Warfare Center, Panama City (NSWC-PC) have collaborated to develop a magnetic gradiometer, called the Real-time Tracking Gradiometer or RTG, that is mounted inside an unmanned underwater vehicle (UUV). The UUV-RTG will be part of a buried mine hunting platform being developed by the United States Navy. The UUV-RTG has been successfully used to make test runs on mine-like targets buried off the coast of Florida. We will present a general description of the system and latest results describing system performance. We will also describe how such a system can be used for other applications, including those in the area of Homeland Security. This program has been supported by the United States Office of Naval Research.

6553-25, Session 5

Dynamic tree segmentation of side-scan sonar imagery

J. T. Cobb, Naval Surface Warfare Ctr.; K. C. Slatton, Univ. of Florida; G. J. Dobeck, Naval Surface Warfare Ctr.

Side-scan sonar images of the sea floor contain rich spatial information that varies widely depending on survey location, sea state, and sensor platform-induced artifacts. Prior to applying an automatic target recognition scheme to find sea mines, the sonar image is usually segmented to better localize target regions and reject environmental and platform-induced clutter. This paper presents a method for sonar image segmentation using graphical models known as dynamic trees (DTs). A DT is a mixture of simply-connected Bayesian networks (BNs) where the leaf nodes of each BN are assigned the value of the corresponding image pixel. The DT segmentation task is to find the best BN mixture that represents the underlying data. A Monte Carlo sampling method is used to determine the maximum a posteriori (MAP) DT quad-tree formulation for each sonar image. Segmentation results from several images are presented and discussed.

6553-26, Session 5

Underwater target classification using the wing BOSS and Bayesian sampling-based decision fusion

N. S. Wachowski, M. R. Azimi-Sadjadi, Colorado State Univ.

One of the most challenging tasks in underwater mine hunting is that of detecting and classifying mine-like objects, especially when the objects in question are buried or resting on the bottom. This is due to the fact that reverberation, artifacts and secondary returns tend to make analysis of the acoustic backscattered returns difficult. One way to effectively deal with this problem is to utilize multiple looks of an object to make a more informed classification decision. Incorporating multiple aspects in the decision-making process effectively allows more information to accumulate about an object, which in turn yields better classification results in varied environmental and operating conditions. One way of implementing a classification scheme involving multiple aspects is through the use of a Bayesian sampling-based system. In this framework, a Gibbs sampler is used as a method for decision-level fusion by iteratively sampling the full conditional distributions of the decision parameters until they converge to a distribution specified by the joint posterior probabilities of the given parameters. This method will be tested against previous multiple aspect fusion methods on a recently collected database that consists of sonar returns from various buried or proud mine-like and non-mine-like objects in different operating and environmental conditions. This data set was collected in June 2006 by a wing Buried Object Scanning Sonar (BOSS) system. Features are extracted from the data using canonical correlation analysis between multiple sonar pings are then classified using Bayesian inference tools. Results will be presented in terms of correct classification rate for each object and general performance of the system in relation to the various operating and environmental conditions encountered.

6553-27, Session 6

Automated sea mine detection, classification, and fusion in high-resolution sonar imagery

G. J. Dobeck, Naval Surface Warfare Ctr.

Since 1995, the Office of Naval Research has sustained a significant research effort in the area of automated sea-mine detection and classification (D/C). The thrust of this effort was five-fold: (1) reduce false alarms that slow mine clearance operations, (2) dramatically speed up post mission analysis so that the location of mines are reported to command and control in a timely fashion, (3) reduce the workload of operators who must look at volumes of sensor data, (4) increase probability of detection and classification against stealthy mines hidden in the complex littoral environment, and (5) supply robust real-time D/C algorithms for the MCM autonomous underwater vehicle (AUV) systems being developed to keep humans and assets out of harms way. Since 2000, real-time D/C algorithms have been developed and successfully implemented on severall small AUV's, which carry side-scan sonars. The current R&D focus is on developing real-time D/C for AUV's for long-range, high-resolution synthetic aperture sonars or long-range, broadband synthetic aperture sonars.

This paper will present an overview of automated D/C processing that has been developed since 2000 for high-resolution side-looking sonar imagery. This includes improvements in (1) normalization of sonar imagery, (2) D/C algorithms, and (3) Algorithm Fusion, the combining of multiple D/C algorithms. Results from recent exercises will be given. Finally the paper will present the current technical approaches being pursued regarding ONR's new focus on buried-mine D/C, principally using multi-spectral and multi-aspect data from broadband synthetic aperture sonars.

This work was sponsored by the Office of Naval Research (ONR 321OE, ONR 32MIW).

6553-28, Session 6

Nonlinear feature fusion of processing strings for automated sea-mine classification in HF and BB SAS imagery in shallow water

T. Aridgides, M. F. Fernández, Lockheed Martin Corp.

An improved sea mine computer-aided-detection/computer-aided-classification (CAD/CAC) process¬ing string has been developed. The overall CAD/CAC processing string consists of pre-processing, subimage adaptive clutter filtering (SACF), normalization, detection, feature extraction, optimal subset feature selection, feature orthogonalization, classification, and fusion processing blocks. The range-dimension SACF is matched both to average highlight and shadow information, while also adaptively suppressing background clutter in each subimage portion. For each detected object, features are extracted and processed through an orthogonalization transformation, enabling an efficient application of the optimal log-likelihood-ratio-test (LLRT) classification rule, in the orthogonal feature space domain.

The classified objects of 3 distinct processing strings are fused using the classification confidence values as features and "M-out-of-N", LLRT-based or Fisher Discriminant-based fusion rules. The utility of the overall processing strings and their fusion was demonstrated with new high-resolution HF and BB SAS imagery data, collected from a difficult shallow water environment. The processing string detection and classification parameters were tuned and the string classification performance was optimized, by appropriately selecting a subset of the original feature set. Three significant fusion algorithm improvements were made. First, a nonlinear 2nd order (Volterra) feature LLRT fusion algorithm was developed. Second, a Box-Cox nonlinear feature Fisher Discriminant Ratio fusion algorithm was developed. The Box-Cox transformation consists of raising the features to a to-be- determined power. Third, a repeated application of the subset feature selection/ feature orthogonalization/Volterra feature LLRT fusion block was utilized.

Multiple ways of fusing the output of the processing strings were investigated, including: fusing the HF and BB outputs of each string and then fusing the resultant outputs, fusing the HF outputs and BB outputs of the 3 strings and then fusing the combined outputs, or fusing the HF and BB of all 3 strings at one. It was shown that cascaded Volterra feature LLRT fusion of the CAD/CAC processing strings outperforms the "M-out-of-N", baseline LLRT and Box-Cox feature Fisher-based algorithms, yielding significant improvements over the best HF or BB single CAD/CAC processing string results, and providing the capability to correctly call the majority of mine targets while maintaining a low false alarm rate. Additionally, a separate investigation illustrated the robustness of cascaded Volterra feature fusion, since the algorithm yielded similar performance with a training and a test set, while in both cases the fusion algorithm was trained on the training set only.

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6553-29, Session 6

Impact of image decimation and quantization on the performance of sonar computer-aided detection/computer-aided classification (CAD/CAC) algorithms

C. M. Ciany, W. C. Zurawski, Raytheon Co.

Raytheon has extensively processed high-resolution sonar images with its CAD/CAC algorithms to provide real-time classification of mine-like bottom objects in a wide range of shallow-water environments. The algorithm performance is measured in terms of probability of correct classification as a function of false alarm rate, and is impacted by variables associated with both the physics of the problem and the signal processing design choices. Some examples of prominent variables pertaining to the choices of signal processing parameters are image resolution (i.e., pixel dimensions), image normalization scheme, and pixel intensity quantization level (i.e., number of bits used to represent the intensity of each image pixel). Improvements in image resolution associated with the technology transition from sidescan to synthetic aperture sonars have prompted the use of image decimation algorithms to reduce the number of pixels per image that are processed by the CAD/CAC algorithms, in order to meet real-time processor throughput requirements. Additional improvements in digital signal processing hardware have also increased the quantization level with which the image data can be converted from analog to digital format. This study examines the CAD/CAC algorithm performance for multiple types of decimation algorithms and various quantization levels, using a wide range of at-sea data from previous test exercises.

6553-30, Session 6

Coherent-based feature extraction for detection and classification of underwater objects from sonar imagery

M. R. Azimi-Sadjadi, J. D. Tucker, Colorado State Univ.

Detection and classification of underwater objects in sonar imagery is a complicated problem due to the various factors such as variations in operating and environmental conditions, presence of spatially varying clutter, variations in target shapes, compositions and orientation. Moreover, bottom features such as coral reefs, sand formations, and the attenuation of the sonar signal in the water column can totally obscure a mine-like object. In this paper a new coherent-based feature extraction method for high-resolution sonar imagery is developed using canonical correlation analysis. Canonical coordinate decomposition allows us to quantify the changes between the returns from the bottom and any target activities in sonar images and at the same time extract useful features without the need to perform separate detection and anomaly feature extraction. These features can be used for simultaneous detection and classification of mine-like and non-mine-like objects. Moreover, in situations where any visual analysis or verification by human operators is required, the detected/classified objects can be reconstructed from the coherent features. Test results of the proposed methods on a dataset of underwater side-scan sonar images provided by the Naval Surface Warfare Center in Panama City, FL will be presented. This database contains synthesized targets in real images varying in degree of difficulty and bottom clutter. Results illustrating the effectiveness of the canonical correlation analysis as a coherent change detection tool will be presented in terms of probability of detection, false alarm and correct classification rates for various density of clutter.

6553-31, Session 7

Image processing of landmines

D. J. Daniels, R. Allan, S. Jennings, ERA Technology Ltd. (United Kingdom)

Surface laid and buried landmines may be detected by visual and IR cameras. This paper considers the issues involved with processing images from trials and examines the performance of a suite of pre processing and image recognitions algorithms.

6553-32, Session 7

HYDRUS simulations of surface temperatures

J. Kleissl, Univ. of California/San Diego and New Mexico Institute of Mining and Technology; J. M. H. Hendrickx, New Mexico Institute of Mining and Technology; J. Simunek, Univ. of California/Riverside

Remotely sensed temperatures of the earth's surface are an important determinant of the partition of the available solar energy into sensible heat flux and evapotranspiration (ET). In this manner, Landsat and MODIS thermal infrared bands provide crucial input for the Surface Energy Balance Algorithm for Land (SEBAL), which can be used to generate spatial maps of ET and soil moisture. These maps facilitate the prediction of mine detection capabilities.

To examine surface temperature evolution, a soil heat and water transfer model (HYDRUS-1d) is coupled to an atmospheric surface layer scheme. Idealized simulations are carried out for different soils, initial soil moisture conditions, and atmospheric flow properties (stability, surface shear stress). From the simulation results, the coupling between soil properties, surface temperature, and sensible heat flux is examined.

6553-33, Session 7

Assessments of phenomenologies for multi-optical mine detection

S. K. Sjökvist, M. S. G. Uppsäll, D. Letalick, Swedish Defence Research Agency (Sweden)

The objective of this paper is to present the Swedish land mine and UXO detection project "Multi Optical Mine Detection System", MOMS, and the research carried out so far. The goal for MOMS is to provide knowledge and competence for fast detection of mines, especially surface laid mines, by the use of both active and passive optical sensors. During 2006 the activities have mainly been focused on assessments of the different phenomenologies for mines and UXOs from a sensor perspective. The overall analysis and preliminary results are presented and discussed.

6553-34, Session 7

A revised model for the spectral signature of disturbed soil and its potential exploitation for mine detection

E. M. Winter, Technical Research Associates, Inc.

Disturbed soil is an indicator of military operations and detection of disturbed soil can be an important tool for the detection of buried mines. In this paper we will concentrate on the phenomenology of disturbed soil as observed in the LWIR portion of the spectrum. The principal observable associated with disturbance of dirt surfaces is that the spectral contrast in the vicinity of 9.2 micrometers is reduced in disturbed areas relative to undisturbed surfaces. The original theory developed by the University of Hawaii is that the signature of the disturbed soil is due to the reststrahlen signature of quartz, and the difference between disturbed and undisturbed soil is caused by fine particles clinging to the larger soil particles. Laboratory measurements have documented that the depth of the reststrahlen emissivity feature is directly related to the size of the silicate minerals in the soil, principally quartz. New observations made with the University of Hawaii AHI LWIR hyperspectral sensor by the U. S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate, backed up by a re-examination of data taken previously, have created a new picture that extends the original theory. The relative depth of the two reststrahlen spectral features at 8.25 and 9.2 micrometers is different in measurements of disturbed and undisturbed soil. This effect correlates well with spectral measurements on quartz particles of different sizes. This new observation is important because if the spectral effect were simply an attenuation of the basic background signature, disturbed soil could not be distinguished from linear mixtures of background and vegetation. These new findings show that we are detecting the fine particles directly, which means that the disturbed soil has a unique spectrum and can be separated from mixtures of blackbody vegetation and undisturbed soil. To verify this behavior, we examined measurements previously made at a variety of locations and on a wide variety of soil types made with LWIR hand held spectrometer and airborne measurements. The results of the analysis of these measurements and their impact on the design of detection algorithms will be presented.

6553-35, Session 8

Buried mine detection in airborne imagery using co-occurrence texture features

S. Tiwari, S. Agarwal, Univ. of Missouri/Rolla; A. H. Trang, U.S. Army Night Vision & Electronic Sensors Directorate

In the recent past, airborne minefield detection has increasingly been explored, due to its capability for low-risk standoff detection and quick turnaround time. Significant research efforts have focused on the detection of surface mines and few techniques have been proposed specifically for buried mine detection. Although reasonable performance has been achieved for surface mine detection, detection performance for buried mines is far from satisfactory. In this paper, we propose an algorithm for buried mine detection in multi-spectral and single-band MWIR imagery based on the texture features using gray-level co-occurrence matrices (GLCM). Based on the analysis of raw GLCM features extracted from the imagery, composite features are tailored for improved discrimination of buried mine signature. RX algorithm is used for anomaly detection on the different feature images obtained from the aforementioned discriminatory features. These anomaly detector responses are combined into modalities adapted for improved detection and reduced false alarms. The proposed method is completely unsupervised, and being based on co-occurrence matrix features, is largely invariant to illumination changes in the images. We present detection performance results for the proposed method and compare it with the existing methods for buried mine detection. We also present results showing the improvement in the detection performance achieved by the fusion of the texture feature-based detection and simple RX anomaly detection over raw images. Results for both multi-spectral and single-band MWIR imagery are presented.

6553-36, Session 8

Multiclassifier buried mine detection using MWIR images

B. Ling, Migma Systems, Inc.; A. H. Trang, US Army RDECOM CERDEC NVESD

The fundamental challenges of buried mine detection arise from the fact that the mean spectral signatures of disturbed soil areas that indicate mine presence are nearly always very similar to the signatures of mixed background pixels that naturally occur in heterogeneous scenes composed of various types of soil and vegetation. In our previous published work, we demonstrated that MWIR images can be used to effectively detect the buried mines. Here, we further improve our existing method by fusing multiple buried mine classifiers. For each target chip extracted from the MWIR image, we scan it in three directions: vertical, horizontal, and diagonal to construct three feature vectors. Since each cluster center represents all pixels in its cluster, the feature vector essentially captures the significant thermal variation of the same target chip in three directions. In order to detect the buried mines using our variable length feature vectors, we have applied Kolmogorov-Smirnov (KS) test to discriminate buried mines from background clutters. Since we built one KS-based classifier for each directional scan, for the same target chip, there will be a total of three classifiers associated with vertical, horizontal, and diagonal scans. In our system, these three classifiers are applied to the same target chip, resulting in three independent detection results. Therefore, we further fuse them using our optimization-based fusion method without imposing any assumptions of their underlying statistical distributions. Test results using actual MWIR images have shown that our system can effectively detect the buried mines in MWIR images with low false alarm rate.

6553-37, Session 8

Processed infrared images of plastic and metallic landmines in an Argentine project

E. H. Castro, H. A. Abbate, Univ. de Buenos Aires (Argentina) and Instituto de Investigaciones Científicas y Técnicas de las FFAA (Argentina); M. Costanzo, Instituto de Investigaciones Científicas y Técnicas de las FFAA (Argentina); M. E. Mejail, J. Gambini, J. C. Jacobo Berllés, J. M. Santos, P. Borensztejn, Univ. de Buenos Aires (Argentina)

A great development of technologies for the detection of buried landmines took place worldwide in the last years. In Argentina, a project for the development of an autonomous robot with sensors for landmines detection was recently approved by the Science and Technology National Agency. Within this project we are studying the detection of landmines by infrared radiation. Metallic and plastic objects with landmines shape and dimension were buried at different depths from 1 to 5 cm in soil with and without grass. Periodic natural warming by solar radiation or artificial warming by means of electric resistances or flash lamps were applied. Infrared images were obtained in the 8-12 micrometers spectral band with a microbolometer camera. The IR images were processed by different methods to obtain a good definition of the buried objects. After this, a B-Spline method was applied to detect the targets contours and determine shape and dimensions of them so as to distinguish landmines from other burid targets. We are looking for a landmine simple and fast detection method , with detection capability of metallic and plastic landmines and an acceptable false alarm rate which would be reduced when applied with other detection methods as GPR and electromagnetic induction. We present processed images and contours found by B-spline method, and results obtained to distinguish buried landmines from other buried objects.

6553-38, Session 8

Landmine detection using B-spline deformable contours in IR images

M. E. Mejail, J. Gambini, M. E. Buemi, E. H. Castro, H. A. Abbate, J. C. Jacobo Berllés, P. M. Borenstjn, J. M. Santos, Univ. de Buenos Aires (Argentina)

Presently, the number of landmines planted around the world totalizes more than 110 million and, far from slowing down, the landmine

production planting rate is, at least, one order of magnitude higher than the rate at which they are removed.In this work a technique to detect buried landmines using boundary detection in IR images, is presented. The buried objects have different temperature than the surrounding soil.

We find the object contours by means of an algorithm of B-Spline deformable curves.

Under a statistical model, regions with different temperatures can be characterized by the values of the statistical parameters of these distributions.

Therefore, this information can be used to find boundaries among different regions in the image.

The B-Spline approach has been widely used in curve representation for boundary detection, shape approximation, object tracking and contour detection.

Contours formulated by means of B-Splines allow local control, require few parameters and are intrinsically smooth.

The algorithm consists in estimating the parameters along lines strategically disposed on the image. The true boundary is found when the values of these parameters vary abruptly on both sides.

A likelihood function is maximized to determine the position of such boundaries.

We present the experimental results, which show the behavior of the detection method, according to the buried object depth and the elapsed time from the cooling initial time.

The obtained results exhibit that it is possible to recognize the shape of the objects, buried at different depths, with a low computational effort.

6553-39, Session 8

A novel patterned and unpatterned minefield detection in cluttered environments using Markov marked point process

A. H. Trang, T. Broach, T. E. Smith, U.S. Army Night Vision & Electronic Sensors Directorate; S. Agarwal, Univ. of Missouri/Rolla; P. Regalia, The Catholic Univ. of America

The current minefield detection approach is based on a sequential processing employing mine detection followed by minefield detection. The mine detection module is a combination of local anomaly detector and false alarm rejection. The potential targets located by the anomaly detector include natural as well as man-made anomalies that contrast themselves from the background. False alarm reduction works by selecting/rejecting targets based on some pre-specified criteria like shape and color features of the target signature. However, target signature changes with time; so they are different under different environment conditions, are affected by background characteristics and change with time of the day or seasons. Therefore, the current approach does not work robustly under different backgrounds and environment conditions. Moreover, the performance of the current approach degrades dramatically in the presence of high density of false alarms. The aim of this research will be to advance the state of the art in detection of both patterned and unpatterned minefield in high clutter environments. The proposed method seeks to combine false alarm rejection module and the minefield detection module of the current architecture by spatial-spectral clustering and inference module using a Markov Marked Point Process formulation. The approach simultaneously exploits the feature characteristics of the target signature and spatial distribution of the targets in the interrogation region. The method is based on the premise that most minefields can be characterized by some type of distinctive spatial distribution of “similar” looking mine targets. The minefield detection problem is formulated as a Markov Marked Point Process (MMPP) where the set of possible mine targets is divided into a possibly overlapping mixture of targets. The likelihood of the minefield depends simultaneously on feature characteristics of the target and their spatial distribution. A framework using “Belief Propagation” is developed to solve the minefield inference problem based on MMPP. Preliminary investigation using simulated data shows the efficacy of the approach. Limited results with available airborne minefield data are also presented.

6553-86, Session 8

Trial of a vehicle-mounted UK electro-optic countermine sensor system as part of a UK/US collaborative program

R. M. Deas, N. A. Playle, K. Long, Defence Science and Technology Lab. (United Kingdom)

A Project Arrangement (PA) for Countermine Capabilities for Medium/ Future Forces has been entered into by the UK and US Governments. The PA is a joint research programme into a ground-based system for the detection and countering of land mines on military routes. The objective of the program is to jointly develop and then evaluate a demonstration system prototype. The work involves both MoD and DoD organizations as well as industrial organizations in both the UK and US in a fully collaborative program that pools and shares all information produced.

This project was established as a three phase programme. Phase 1 identified candidate technologies of the appropriate Technology Readiness Level. Phase 1 established the User requirement and conducted Operational Analysis based on generic sensors. The PA is currently in Phase 2 which is de-risking the technologies from Phase 1, with trials occurring in both the UK and US. A UK trial was completed in October 2005 where two US vehicle mounted sensor systems and one UK vehicle mounted sensor system were trialled. The UK sensor system is described herein and consisted of three Electro-Optic (EO) sensors that covered the visible, medium wave infra-red (IR) and long wave IR bands. The set-up of the UK trial site and the development of the UK EO sensor system are discussed. Analysis of trial data and preliminary research on the feasibility of fusing data from the EO sensors are presented.

6553-82, Poster Session

Influence of environmental conditions in fate and transport of ERCs in a physical 3D model: spatial and temporal assessment effects in a sandy soil

A. A. Anaya, I. Y. Padilla, Univ. de Puerto Rico Mayagüez

Chemical, biological, canine, and Infra Red detections of buried explosive devices (BEDs) rely on the presence of explosive related chemicals (ERCs) near the soil-atmospheric surface. ERCs distribution near this surface and their relation to the location of explosive devices are controlled by the fate and transport processes. A physical experimental work in a multidimensional soil-atmospheric physical system was developed to generate accurate data and information on spatial and temporal effect due to environmental factors on the fate, transport and detection of ERCs near soil surfaces. The system incorporates a rainfall simulator, variable light (visible and Ultra Violet spectrum), temperature and relative humidity components, and a 3D SoilBed capable of simulating several boundary and initial conditions. Experiments demonstrate that non-reactive solutes are highly influenced by variation in hydraulic, advective, and dispersive processes induced by changes in environmental conditions, however great impacts for reactive and semi-volatile solutes such as ERCs were observed. Fate and transport were affected by variations in sorptive, gas transport, and degradation processes. These Fate and Transport processes were integrated through numerical modeling, Hydrus 2D code, to develop the spatial and temporal concentration distributions of these chemicals under different environmental conditions.

In the same way an air ERCs measurement system was developed using xad-2 resin. These air and water ERCs concentrations, solutes’ behavior, and water and air pressure data obtained from physical models, allowed the characterization and quantification of mass transfer, sorptive, diffusive, advective, and reactive transport processes of ERCs in soils.

6553-83, Poster Session

Vapor sampling of ERCs for environmental assessment in atmospheric and soil settings

D. Acevedo, A. A. Anaya, O. Carrasquillo, I. Y. Padilla, Univ. de Puerto Rico Mayagüez

The existence of explosive related chemicals (ERCs) near the soil-atmospheric and other surfaces depend on their fate and transport characteristics within the environmental settings. Consequently, detection of ERC in environmental matrices is influenced by conditions that affect their fate and transport. Experimental work to study the fate and transport behavior of ERCs relies on proper temporal and spatial sampling techniques. Because the low vapor pressure of these chemicals and their susceptibility to adsorption and degradation, vapor concentrations in environmental matrices are very low. Depending on the environmental conditions, the amount of samples that can be withdrawn for analysis is also limited. It is, therefore, necessary to develop sampling technologies that can provide quantitative measures of ERC concentrations in limited sampling environments

This paper presents experimental work conducted to develop a sampling technique to quantify vapor concentrations of low vapor-pressure ERCs in environmental setting having limited sampling volumes. Vapor sampling volumes and efficiencies are quantified in variably-saturated soils, and near soil-atmospheric and vegetative surfaces.

6553-84, Poster Session

Angular and intensity dependence of NQR remote explosive detection

G. Ota, H. Itozaki, Osaka Univ. (Japan)

Landmine detection needs remote sensing, because explosives are buried under the ground, so that transmitting and receiving antennas should be away from explosives. In order to design the arrangement of these antennas, angular and intensity dependence of NQR signal from powder explosive were investigated. The NQR signal excited from a single direction emitted mainly forward and backward along the excitation direction and was weakly emitted to the direction perpendicular to the excitation direction. This result helps to design arrangement of a transmitting and receiving antenna. The adequate excitation field intensity to excite a sample away from the antenna was also investigated. A remote detection requires much stronger field to excite a sample away from the antenna to realize the same excitation condition as the chemical analysis using the sample in an antenna coil. The excitation field intensity dependence of NQR signal was studied and the existence of the minimum field intensity to excite the maximized NQR signal was obtained. This result helps to design the transmitter for the NQR landmine detector.

6553-85, Poster Session

Physical modeling of 2,4-DNT gaseous diffusion through unsaturated soil

A. Torres, I. Y. Padilla, Univ. de Puerto Rico Mayagüez

Detection of buried explosives devices (BEDs) through chemical sensing is influenced by factors affecting the transport of chemical components associated with that device. Explosive-related chemicals, such as 2,4-dinitrotolune (DNT), are somewhat volatile and their overall transport is influenced by vapor-phase diffusion. Gaseous diffusion depends on environmental and soil conditions. The significance of this mechanism is greater for unsaturated soil, and increases as water content decreases. Other mechanisms, such as sorption and degradation, which affect the overall fate and transport may be more significant under diffusion transport due to the higher residence time of ERCs in the soil system. Gaseous diffusion in soil is measured using a one-dimensional physical model (1-D column) to simulate the diffusion flux through soil under various environmental conditions. Samples area obtained from the column using solid phase microextraction (SPME) and analyzed with a Gas Chromatograph (GC). Initial results suggest lower diffusion coefficients than previously reported. Results also show the formation of degradation by-products in the vapor phase. Temporal concentrations distributions are simulated with several equations to estimate the best diffusion model that apply.

6553-40, Session 9

Real-time airborne hyperspectral imaging of landmines

T. A. Ivanco, S. B. Achal, ITRES Research Ltd. (Canada); J. E. McFee, Defence Research and Development Canada (Canada); C. D. Anger, ITRES Research Ltd. (Canada)

DRDC Suffield and Itres Research Ltd. have jointly investigated the use of visible and infrared hyperspectral imaging (HSI) for surface and buried land mine detection since 1989. These studies have demonstrated reliable HSI detection of surface-laid mines, based on their reflectance spectra from airborne and ground-based platforms. All commercial HSI instruments can collect and store image data at aircraft speeds, but analyse the imagery off-line after returning to base. Although useful for humanitarian demining, it is unacceptable for military countermine operations. We are developing a hardware system with algorithms that can process the raw hyperspectral data in real-time to detect mines. The algorithms perform radiometric correction of the raw data, then apply the mine classification algorithms to the corrected data, referencing a spectral signature library. The classification results are stored and displayed in real-time, that is, within a few frame times of the data acquisition. We demonstrated such real-time mine detection for the first time from a slow moving land vehicle in March 2000. This paper will describe an improved system which can achieve real-time detection of mines from an airborne platform, with its commensurately higher data rates. The system is presently compatible with the Itres visible/near infrared hyperspectral (casi) and short wave hyperspectral (sasi) families of imagers. Experiments to detect mines from an airborne platform in real-time were conducted at DRDC Suffield in October 2006. The results of these experiments will be described.

6553-41, Session 9

A thermal hyperspectral imager (tasi) for buried landmine detection

S. B. Achal, ITRES Research Ltd. (Canada); J. E. McFee, Defence Research and Development Canada (Canada); T. A. Ivanco, C. D. Anger, ITRES Research Ltd. (Canada)

DRDC Suffield and Itres Research have collaborated to investigate the use of hyperspectral imaging (HSI) for surface and buried land mine detection since 1989. Visible/near infrared (casi) and short wave infrared (sasi) families of imagers have been developed which have demonstrated reliable HSI detection of surface-laid mines, based on their reflectance spectra, from airborne and ground-based platforms. However, they have limited ability to detect buried mines. Thermal infrared (TIR) HSI may have the capability to detect buried mines. Disturbance of quartz-bearing soils has been shown to measurably change their TIR emissivity spectra due to mixing of surface/subsurface soil (restrahlen band intensities vary with particle size). Some evidence suggests that the effect can persist months after the visible disturbance has disappeared. Carbonates and other materials exhibit similar TIR spectral features and heat flow anomalies caused by buried mines can also be measured in the TIR band. There are no commercially available TIR hyperspectral imagers available that are suitable for mine detection. The very few possibly suitable imagers are one-of-a-kind research instruments, dedicated to internal programs and not available for the general mine detection community. They also have a narrow field of view and are very expensive. We have developed a TIR hyperspectral imager (tasi) based on a novel optical design and a cooled MCT focal plane array. The instrument has been designed with landmine detection in mind. First light images were obtained in summer 2006 and the prototype instrument was completed in fall 2006. The design of the instrument and a comparison with design alternatives in the context of mine detection requirements will be discussed. Preliminary images will be presented.

6553-42, Session 9

Development of a terrain surface model for optical property computation

J. M. Cathcart, D. Cash, B. Remesch, Georgia Institute of Technology

In this paper we discuss our efforts to develop a digital hyperspectral signature model for terrain features. These efforts focused on developing models for the optical and infrared properties of soils and vegetation features. A detailed geometric model of the particulate soil surface is combined with radiative transport algorithms to compute emissive and reflective properties of terrain surfaces. These models support analysis of environmental effects on terrain signatures, signature generation to support object detection algorithm development, and terrain clutter characterization. Environmental effects modeled and studied include soil particle size distributions, moisture level, and soil constituents. Particle size and moisture are shown to impact these optical properties; the impact on detection of subsurface objects such as landmines will be discussed. A discussion of the terrain modeling approach, the underlying analytical basis, and results from the model computations will be presented.

This work is supported under a grant from the Army Research Office.

6553-43, Session 9

Methods for determining best multispectral bands using hyperspectral data

E. M. Winter, Technical Research Associates, Inc.

Over the years several methods have been used to determining the best bands for a visible near IR multi-spectral sensor. The most popular method, the committee method, places scientists with differing opinions on the phenomena and the sensor mission in one room, and a compromise set is developed. To avoid this, there have been several methods to automate this selection process. We have developed a method to examine hyperspectral data to find the best multi-spectral band set (whether 3, 4, 5 or 6 bands) based on the background, on the premise that, with the target unknown, the band set that best separates the background materials is the best. We start with a hyperspectral data set of a background area without any targets. We then run a program for determining the spectral endmembers. Any endmembers that look like they are due to sensor artifacts or an anomalous point on the ground (junk) are discarded from the list. The resulting hyperspectral endmembers are then input to an exhaustive search program. The goal of the exhaustive search is to find a set of N (say 4) multi-spectral bands that maximizes the spectral angles between all of the endmembers. Thus, at each trial the multi-spectral bands are made by binning the hyperspectral (to four bands in this case) and the spectral angles calculated between endmembers 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4 etc. The endmembers in each case have been binned to four multi-spectral bands. We save the average of these spectral angle calculations. After examining often millions of combinations, the multi-spectral band set that maximizes the spectral separation is judged to be the best. We have applied this method to the selection of multi-spectral bands sets for several sensors.

6553-44, Session 9

SPICE: a sparsity promoting iterated constrained endmember extraction algorithm with applications to landmine detection from hyperspectral imagery

A. Zare, P. D. Gader, Univ. of Florida

Endmembers of hyperspectral images are spectral signatures that characterize distinct materials in a scene. Endmember extraction is useful for landmine detection in several ways: endmembers can represent spectral signatures of mines or conditions indicative of mines, endmembers can represent spectral signatures of material that can confused with mines such as bushes etc. Endmembers can also represent background conditions that may affect mine detection. A variety of algorithms exist for endmember identification. These algorithms suffer from the property that the number of endmembers needs to be known in advance. In this paper, an automated algorithm for identifying the correct number of endmembers in an image is described.

Evey pixel in a hyperspectral image is assumed to be a weighted average of endmembers. The weights in the weighted average are referred to as the abundances. The abundances are between zero and one and sum to one. If all the abundances associated with a particular endmember are zero, then that endmember can be discarded. We proposed the method of sparsity promoting priors to force the abundances associated with redundant or meaningless endmembers to be zero. Specifically, an existing algorithm developed by Berman et al.referred to as the Iterated Constrained Endmember (ICE) algorithm has been modified to incorporate sparsity promoting priors on the abundance terms. It is shown that inclusion of the sparsity promoting term can be incorporated into the Quadratic Programming approach proposed in ICE to find endmembers. Experiments are described using both real and synthetic data sets that indicate that SPICE can effectively remove redundant and meaningless endmembers. Applications to landmine detection with real hyperspectral data are described.

6553-45, Session 10

Handheld standoff mine detection system (HSTAMIDS) operational field evaluation in Cambodia

R. C. Doheny, Office of Assistant Secretary of Defense; S. P. Burke, R. Cresci, P. Ngan, C. E. Walk, U.S. Army Night Vision & Electronic Sensors Directorate

The Humanitarian Demining Research and Development Program of the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD), under the direction of the Office of Assistant Secretary of Defense for Special Operations and Low-Intensity Conflict (OASD SO/LIC), and in partnership with HALO Trust, conducted an extended operational in-country field evaluation of the Handheld Standoff Mine Detection System (HSTAMIDS) in Cambodia. The primary objectives were to demonstrate the performance and suitability of the U.S. Army's newest handheld multi-sensor mine detector, the HSTAMIDS in minefield operations and to collect data and information, to the performance of the metal detector being used by local demining organizations and also to assess the performance of deminers using the HSTAMIDS after limited experience and training.

6553-46, Session 10

MINEHOUND: transition to production

D. J. Daniels, P. Curtis, N. Hunt, ERA Technology Ltd. (United Kingdom)

The UK Department for International Development (DfID), in collaboration with the German Foreign Ministry (Auswärtiges Amt), contracted ERA Technology of the UK to carry out extensive field trials in Cambodia, Bosnia and Angola of an advanced technology, dual sensor, and hand-held landmine detector system called MINEHOUND(tm). This detector combines a metal detector with a Ground Penetrating Radar (GPR). As a result of extremely successful trials MINEHOUND(tm) has been productionised by ERA Technology and Vallon GmbH for release in late 2006. This paper describes the transition to production of the detector

6553-47, Session 10

The development of the hand-held dual-sensor ALIS

M. Sato, K. Takahashi, Tohoku Univ. (Japan)

We are developing a new hand-held land mine detection dual-sensor (ALIS) which is equipped with a metal detector and a GPR. ALIS is equipped with a sensor tracking system, which can record the GPR and Metal detector signal with its location. It makes possible to process the data afterwards, including migration. The Migration processing drastically increase the quality of the imaging of the buried objects.

For the sensor tracking system, we have used a ground control points, but in the new system, we do not need any standard mark on the

ground. Also, the impulse GPR system was replaced by a step-frequency GPR system, which increased the quality of the GPR data sets.

ALIS demonstration were held in Afghanistan in December 2004 and other countries in 2005. We will summarize the evaluation tests. After some demonstrations and evaluation, we received many useful suggestions. Using these advises, we have modified the ALIS and it is now more easy to use.

In this paper, we will describe the latest characteristics of the ALIS and summarize its operation.

6553-48, Session 10

The evaluation test of hand-held dual-sensor ALIS in Croatia and Cambodia

M. Sato, K. Takahashi, A. G. Gorriti, Tohoku Univ. (Japan)

We are developing a new hand-held land mine detection dual-sensor (ALIS) which is equipped with a metal detector and a GPR. ALIS is equipped with a sensor tracking system, which can record the GPR and Metal detector signal with its location. It makes possible to process the data afterwards, including migration. The Migration processing drastically increase the quality of the imaging of the buried objects.

Evaluation test of ALIS have been conducted several test site. In January 2006, one-month evaluation test was conducted in Croatia, and in October-December 2006, two-month evaluation test will be conducted in Croatia. Since the dual-sensor is a new landmine detection sensor, and the conventional evaluation procedure developed for metal detectors cannot directly be applied for the dual sensor.

In this paper, we will demonstrate the operation performance of ALIS in different soil condition and discuss the new evaluation procedure for dual sensors.

6553-49, Session 10

Test and evaluation of Japanese GPR-EMI dual-sensor systems at Benkovac Test Site in Croatia

J. Ishikawa, Japan Science and Technology Agency (Japan) and Tokyo Denki Univ. (Japan); K. Furuta, Tokyo Denki Univ. (Japan); N. Pavkovic, Ctr. for Testing Development and Training (Croatia)

This paper presents an experimental design and evaluation results of a trial that were carried out from 1 February to 9 March 2006 using real PMA-1A and PMA-2 landmines at the Benkovac test site in Croatia. The objective of the Croatia-Japan joint trial is to evaluate dual sensor systems, which use both a ground penetrating radar (GPR) and an electromagnetic inductive (EMI) sensor. A comparative trial was also carried out by Croatian deminers using an existing EMI sensor, i.e., a metal detector (MD). The trial aims at evaluating differences in performance between dual sensors and MDs, especially in terms of discrimination of landmines from metal fragments and extension of detectable range in the depth direction. Devices evaluated here are four kinds of prototypes of anti-personnel landmine detection systems developed under a project of the Japan Science and Technology Agency (JST), the supervising authority of which is the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The prototypes provide operators with subsurface images and final decision whether a shadow in the image is a real landmine or not is left to the operator. This is similar to the way that medical doctors find cancer by reading CT images. Since operators' pre-knowledge of locations of buried targets significantly influences the test results, three test lanes with different soils have been designed to be suitable for blind tests. The results showed that the dual sensor systems have a potential to discriminate landmines from metal fragments and that probability of detection for small targets in mineralized soils can be improved by using GPRs.

6553-50, Session 11

Automated calibration methods for robotic multisensor landmine detection

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Both force protection and humanitarian demining missions require efficient and reliable detection and discrimination of buried anti-tank and anti-personnel landmines. Widely varying surface and subsurface conditions, mine types, and placement, as well as environmental regimes challenge the robustness of the automatic target recognition process. In this paper, we will present applications of target recognition software modules created for the U.S. Army Nemesis detection platform for variable environmental conditions and mine types. Nemesis is an unmanned rubber-tracked vehicle-based system designed to eradicate a wide variety of anti-tank and anti-personnel landmines for humanitarian demining missions. The detection system integrates advanced ground penetrating synthetic aperture radar (GPSAR) and electromagnetic induction (EMI) arrays, highly accurate global and local positioning, and on-board target detection/classification software on the front loader of a semi-autonomous UGV. We present the results of new systematic calibrations to adapt system parameters and target recognition software for site specific conditions such as soil electromagnetic properties, surface conditions and variability, temperature, and target types. Automated procedures were developed to account for frequency dependent dielectric permittivity, reflectivity, and penetration depth for the GPSAR. Analysis of the variability in soil moisture, surface roughness, and layering revealed the influence on GPSAR ground and array coupling, directivity functions, and effective antenna footprints. We also considered the effects of mineralized soil and ferrous clutter for EMI data collected in a controlled test pit and describe enhanced time-domain processing from multiple coil configurations. The results have implications not only for calibration of system data acquisition parameters, but also for tuning of automatic target recognition detection and discrimination algorithms.

6553-51, Session 11

Imaging of buried targets using seismic and ground-penetrating radar data

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It is unlikely that any single sensor will be able to reliably detect subsurface targets such as landmines and tunnels with a reasonable false alarm rate in all environmental conditions. The reason for this is that the soil is a complex, lossy, and very inhomogeneous media. Many of the inhomogeneities in the soil such as layering, moisture variations, rocks, roots, etc. can cause a sensor to give false alarms. The loss in the soil can also be very problematic for certain types of soil. If there is prohibitive attenuation of the waves due to the loss in the soil, the sensors will perform very poorly.

In this work both multi-static and multi-modal systems are investigated in an effort to improve the ability to reliably detect subsurface targets. The multiple "look" angles provided by a multi-static sensor may enhance target features. The use of multiple sensors to sense a broad range of physical properties will make the system applicable to a broader range of soil properties.

An experimental system has been developed to collect co-located seismic and ground penetrating radar (GPR) data for a variety of subsurface targets such as landmines and tunnels. Currently the GPR is multi-static while the seismic system is bi-static. The data from these experiments is used to investigate the potential of inversion algorithms that use the multi-static and/or the multi-modal nature of the data. Methods for enhancing the signatures of the buried objects are also investigated.

6553-52, Session 11

Visual cues for landmine detection

J. J. Staszewski, Carnegie Mellon Univ.; A. Davison, Army Research Lab.

Landmines remain a major threat to US ground forces and their mission capability. Although recently deployed handheld landmine detection equipment (AN/PSS-14) substantially improves countermine capability, the threat is not eliminated. Military history suggests that visual perception of the terrestrial information produced by landmine burial represents an approach that can supplement landmine detection via handheld technology and holds potential to increase detection rates and reduce the hazard of the task. Anecdotal evidence argues to the contrary. Testing this controversial hypothesis first requires a detailed empirical description of the optically available information produced by landmine emplacement and the manner in which such information changes with time and naturally varying weather conditions. The objective of the study is to systematically acquire needed objective, foundational knowledge on which training could be based. The key questions are (1) what visible cues resulting from mine burial can reveal their locations and (2) how does this information change over time in the natural environment? This presentation will present initial findings from a study that buried demilitarized landmines whose sizes and shapes cover the range of mines found in the operational environment. Trained and experienced personnel emplaced the mines according to Army doctrine in a secure test site at Fort Leonard Wood. Equipment for time-lapse photography recorded high-resolution images of the ground surface where the mines were buried to document the effects of naturally varying weather upon the terrestrial cues and patterns that mine burial produced. In additional to presentation of the images of the soil surface signatures, qualitative descriptions of the visual features of the signatures that generated by an expert tracker and a pair of soil scientists will be summarized and presented.

6553-53, Session 11

NATO-SCI-133 guides for planning and reporting tests of countermine equipment

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NATO Task group SCI-133 on “Countermine Technologies” under the NATO RTO (Systems Concepts and Integration) panel, has the goal to identify the technologies of mine detection (close-in detection and remote detection) and mine neutralization (breaching, route clearing, area clearance) which provide the best short, medium and long-term potential in countermines operations. A brief overview of the activities will be given.

The main focus of the paper will be the work of the NATO RTO SCI-133 working group on test and evaluation procedures for landmine-detection/neutralisation and mechanical clearance equipment. In test reports, incomplete descriptions of test procedures and lack of clear definitions of test parameters make interpreting test results difficult. SCI-133 prepared a list of issues that should be addressed in test reports of landmine-detection equipment. The guide also gives references to documents containing relevant definitions. The presentation is in the form of a checklist of questions to be answered when designing, conducting, and reporting on test and evaluation efforts.

6553-54, Session 11

An investigation into landmine neutralisation techniques for a vehicle-mounted countermine system

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This paper will review landmine neutralisation and marking systems and assesses how they can be down-selected for incorporation into a technology demonstrator system. The aim will be to illustrate detection, marking and route clearance capabilities against various anti-tank mines.

A technology comparison matrix was constructed to allow the down selection of technologies according to defined criteria. The matrix captures information from a top-level review of a broad range of neutralisation and marking techniques both currently in use and in development. The methodology developed for technology down selection allows filtering of technologies using the matrix and is flexible enough to take into account differing operational scenarios and requirements. The results of an initial sub-system down-selection using this methodology are shown.

The requirements for the final technology down selection with respect to the overall system concepts are discussed. The application of this technique for down selecting technologies/methods in a broader system context is highlighted.

6553-55, Session 12

Transport of explosive related chemicals from a point source

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The transport of explosive related chemicals (ERCs) near their source is strongly influenced by characteristics of the source. Although it is often assumed that sources of ERCs, such as landmines and other IEDs, release these chemicals at a constant rate, they vary temporally depending on the environmental conditions.

The effect of point sources on the fate and transport of 2,4,6 Trinitrotoluene (TNT) and 2,4 Dinitrotoluene (DNT) in soil, water and air are studied in 1D and 2D columns subject to variable environmental conditions. ERC concentrations and environmental conditions are quantified temporally and spatially to determine the behavior of the source and the subsequent effect of fate and transport. A temporal function of the source is developed and applied to fate and transport models, which are used to further describe the behavior of these chemicals in environmental setting. Preliminary results indicate that dissolution and volatilization of TNT and DNT from a point source are rate-limited and depend on the environmental matrix (water, soil, air) and condition. Differences are observed for different flow, soil, light, and temperature conditions.

6553-56, Session 12

Adsorption coefficients for TNT on soil and clay minerals

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To understand the adsorption process of TNT on soil and clay minerals is essential to determine the fate and transport mechanisms of buried landmines. In this research, soil samples from horizons Ap and A from Jobos Series at Isabela, Puerto Rico were studied. The mechanical method was used to separate the clay fraction from the other soil components. Using the hydrometer method the particle size distribution for the soil horizons was obtained. Physical and chemical characterization studies such as cation exchange capacity (CEC), surface area, percent of organic matter and pH were performed for the soil and clay samples. A complete mineralogical characterization of clay fractions using X-ray diffraction analysis reveals the presence of kaolinite, vermiculite, goethite, hematite, gibbsite and quartz. In order to obtain adsorption coefficients (Kd values) for the TNT-soil and TNT-clay interactions high performance liquid chromatography (HPLC) was used. The adsorption process for TNT-soil was described by the Langmuir model. The higher adsorption was observed in Ap horizon. On the other hand, the Freundlich algorithm described the adsorption process for TNT-clay. The affinity and relative adsorption capacity of the clays for TNT were higher in the A horizon. These results suggest that adsorption by soil organic matter predominates over adsorption on clay minerals when significant soil organic matter content is present. It was found that, properties like cation exchange capacity, surface area, type of exchangeable cations and clay minerals present in the clay fractions are important factors in the adsorption of clayey soils.

6553-57, Session 12

Development of a multiscale packing methodology for evaluating fate and transport processes of explosive-related chemicals in clayey soils

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Detection of organic compounds (TNT, DNT, and related substances) derived from landmines sources is influenced by fate and transport processes, which are affected by interrelated environmental, soil, and landmine source factors. It is, therefore, necessary to develop a physical experimental platform that will generate accurate data and information on these processes. For this reason, a multi-scale investigation has been developed to systematically characterize and quantify the effects of environmental factors on the fate and transport behavior of ERCS in variable-saturated soils.

This work focuses on the development of methodologies that yield soil packing characteristics for clayey soils similar to those found in the field and that can be reproduced across physical models of different scales and dimensions. Prototype acrylic columns and tanks of different scales and dimensions were used to test different packing methods. The methods used include: gravity-driven sedimentation packing; vibration packing; induced settling; infiltration; and inverse infiltration. These methods were evaluated under different water contents, including dried, field water contents, field capacity water content, and the water contents at plastic and liquid limits. The systems were evaluated for consistent bulk density, porosity, and capacity of flow. Preliminary results exhibit satisfactory values for bulk density ranging from 1.2-1.4 g/cm3 for all methods. Settling under plastic state has yield the best results so far since capably reproduce the conditions found in the field.

6553-59, Session 12

Effect of environmental parameters on the chemical signature of TNT in soil

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As part of a large research program aiming to the development of chemical sensor for detecting land mines, we have studied the fate and transport of TNT subject to different ambient parameters. The space and temporal concentration profiles of TNT, and its degradation compounds have been measured using soil tanks. The following ambient parameters were controlled to emulate environmental factors: water content, temperature, relative humidity, and uv-vis radiation. A series of soil tanks were kept under controlled conditions for longer than a year and sampled periodically at the surface. After several months, all tanks were sampled vertically and disposed of. Chromatographic techniques (GC-μECD) with direct injection were used for the analysis of the samples. Of particular interest is the presence of several degradation compounds, as time evolves, responding to the ambient parameters imposed. The vertical concentration profiles of the several chemicals found, gives an interesting view of the degradation process as well as of the transport mechanisms. The results agreed with our computer simulations, and are being used to validate previous numerical analyses.

6553-60, Session 13

False alarm reduction during landmine detection

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The average time for landmine detection may be significantly reduced by combining initial and available rapid scanning devices with Quadrupole Resonance detectors. QR works as a verifier or confirmation unit with the potential to remarkably reduce false alarms. This is of particular importance for demining, as currently hundreds of clutter items are found before uncovering a single landmine.

Significant technical and scientific advances have resulted in the fabrication of QR landmine detectors in compact, power-efficient configurations. The development work is focused on baseline sensitivity increase, as well as the achievement of high detection performance under field conditions.

6553-61, Session 13

Research and development of humanitarian landmine detection system by a compact discharge-type fusion neutron source

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Described are research and development on an advanced anti-personnel landmine detection system by using a compact discharge-type fusion neutron source called IECF (Inertial-Electrostatic Confinement fusion). The present detection system is effective to all-plastic mines, in particular, by detecting neutron-captured gamma-rays of specific energies by nitrogen atoms to identify landmine explosives, as well as backscattered neutrons to identify hydrogen anomaly.

Unlike beam-target type fusion neutron sources, the IECF neutron source is based on beam-gas and beam-beam colliding fusion reactions, thus, it has advantages of long lifetime because of much less heat load on the target and less sputtering yield, as well as robustness, safe and easy operation, all of which are essential for the practical landmine detection application.

We have developed an extremely compact IECF device with a titanium getter pump as the main exhaust pump to endure the vibration when it is installed at automobile. The developed IECF neutron source employs double jacket chambers (20 and 30 cm in diameter, respectively) for water cooling, which enables CW operation with a high discharge power of more than 6 kW, yielding neutrons of 10^7 /sec. At the same time, the 5 cm thick water coolant is found to be effective in reflecting 2.45 MeV neutrons downward through a thinner water jacket installed at the bottom. Also a BGO/NaI(TI)-combined scintillation detector has been developed for detection of neutron-captured gamma-rays by nitrogen atoms in the explosives. Experiments with a landmine simulant have shown promising features for the landmine detection.

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6553-62, Session 13

Development of NQR explosive detector in Japan

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NQR (Nuclear Quadrapole Resonance) detector of explosives is under development in Japan for clearing landmines in countries after the civil war such as Afghanistan. Normal coil and SQUID (Superconducting Quantum Interference Device) were used to detect week NQR signals from explosives under the ground remotely. The HMT (hexamethylenetetramin) is raw material of RDX. It was used for fake material for our research on NQR explosive detection. Angular dependence of NQR radiation from HMT powder was investigated. Strong resonance signal was found to be emitted forward and back to the transmitting antenna from the sample. This radiation is of the same pattern as a dipole antenna.

In order to obtain strong signals, the following investigations has been done. NQR properties such as T1 and T2* of RDX and TNT were studied. They are needed to design and optimize pulse sequence. Pulse sequences of SORC and SLSE have been adopted to detect NQR signals from RDX and TNT, respectively. A Q-switch was also used to shorten blank time between the transmission excitation pulse and the NQR detection time.

Environmental noise was removed by using a first order gradiometer, which functioned well in the field test. Two systems have been developed for the field test of explosive detection. One is a handheld type and another is a sensor head type which is attached to a robot arm. Both detectors were evaluated by detecting buried real explosives under the ground.

6553-63, Session 13

Portable LIBS and Raman spectroscopy standoff chemical analysis system

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A combination of the trace element detection capability of Laser-Induced Breakdown Spectroscopy (LIBS) with Raman complex compound analysis to identify minerals promises to provide unprecedented specificity in chemical identification from a standoff distance. We present a new hybrid LIBS and Raman Spectroscopy standoff element, mineral, and isotope analysis system that offers a deployable instrument suitable for robotic missions in terms of in situ measurements, resolution, bandwidth, compact size, low cost, and ruggedness. A proof-of-concept tabletop (0.012 cubic meter sensing head; 0.03 cubic meter power supply) prototype has been developed and capability of up to 25 meters was demonstrated. Detection and identification of inorganic, organic and mineral samples, including compounds associated with origins of life, has been demonstrated. Compounds related to buried explosives were also detected, and the capability to differentiate between explosives and similar compounds (such as fertilizers) was demonstrated. A compact, pulsed laser is used as the excitation laser for both LIBS and Raman spectroscopy. A single nonimaging multipurpose telescope assembly directs the laser beam away and to collect the radiation emanating from the microplasma, and the Stokes shifted spectra by means of a holographic element that eliminates the Rayleigh scattered laser light from the analysis signal. A miniature integrated multiband spectrometer (MIMS) analyzes the spectrum of the radiation collected by the nonimaging telescope subsystem, with a spectral resolution of <0.1nm. Chemical fingerprinting software accurately identifies elements and compounds from measured LIBS and Raman spectra.

6553-64, Session 13

Femtosecond laser-induced breakdown spectroscopy and femtosecond laser mass spectrometry of explosives

Y. Dikmelik, C. McEnnis, J. B. Spicer, Johns Hopkins Univ.

We use femtosecond and nanosecond laser-induced breakdown spectroscopy (LIBS) to detect trace amounts of TNT and RDX deposited on aluminum and glass substrates. We have observed emission from CN molecules as the marker for the explosives with femtosecond LIBS. In contrast, the signals for nanosecond LIBS of explosives are dominated by emission from the elemental constituents of the explosives. Emission lines from the elements in the substrates are also observed with both femtosecond and nanosecond excitation and they are examined in terms of the optical properties of the substrate in response to the femtosecond and nanosecond time scales of the excitation processes. Optical microscope images of the ablated explosives will be shown for femtosecond and nanosecond laser excitation. Fragmentation studies by femtosecond laser mass spectrometry were performed to help interpret LIBS results and revealed molecular cluster formation with masses higher than the mass of the explosive molecules.

6553-65, Session 13

Development of HPLC-SPME methodology for detection of nitro-explosives

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Solid phase microextraction (SPME) has been coupled with liquid chromatography to widen its range of application to nonvolatile and thermally unstable compounds, generally limited for SPME-GC. A method for analysis of nitroaromatic explosives and its degradations products was developed using SPME and high performance liquid chromatography with ultraviolet detection (HPLC-UV), introducing a modified interface that ensured accuracy, precision, repeatability, high efficiency, unique selectivity and high sensitive to detection and quantification of explosives from surface soil samples and increased chromatographic efficiency. A pretreatment step was introduced for the soil samples which extracted the target compounds into an aqueous phase. Several parameters that affect the microextraction were evaluated such as: fiber coating, absorption and desorption time and stirring rate. The effect of NaCl concentration on analyte extraction and the role of various solvents on SPME fiber were also evaluated. Carbowax-templated resin (CW-TPR) and polydimethylsiloxane-divinylbenzene (PDMS-DVB) fibers were used to extract the analytes from the aqueous samples. Explosives were detected at parts per million concentrations. This study demonstrates that SPME-HPLC is a very promising method of analysis of explosives from aqueous samples and has been successfully applied to the determination of nitroaromatic compounds, such as TNT.

6553-66, Session 14

Managing landmine detection sensors: results from application to AMDS data

M. P. Kolba, L. M. Collins, Duke Univ.

Previous work by the authors using information-based sensor management for static target detection has utilized a probability of error performance metric that assumes knowledge of the number of targets present in a grid of cells. Using this probability of error performance metric, target locations are estimated as the N cells with the largest posterior state probabilities of containing a target. In a realistic application, however, the number of targets is not known a priori. The sequential probability ratio test (SPRT) developed by Wald is therefore implemented within the previously developed sensor management framework to allow cell-level decisions of “target” or “no target” to be made based on the observed sensor data. Using these cell-level decisions, more traditional performance metrics such as probability of detection and probability of false alarm may then be calculated for the entire region of interest.

The resulting sensor management framework is implemented on a large set of data from the U.S. Army’s autonomous mine detection sensors (AMDS) program that has been collected using both ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors. The performance of the sensor manager is compared to two different direct search techniques, and the sensor manager is found to achieve the same Pd performance at a lower cost than either of the direct search techniques. Furthermore, uncertainty in the sensor performance characteristics is also modeled, and the use of uncertainty modeling allows a higher Pd to be obtained than is possible when uncertainty is not modeled within the sensor management framework.

6553-67, Session 14

Landmine-detection prescreeners based on feature-level fusion of SAR and HSI data

K. I. Ranney, Army Research Lab.

Many automatic target detection (ATD) algorithm suites include a prescreener as an initial link in their processing chains. It assists the downstream algorithms by eliminating many potential false alarms while still retaining a large percentage of the objects of interest, thereby allowing for greater specialization by the downstream algorithms. Many such prescreeners have been implemented for individual sensors-for example the constant false alarm rate detectors of radar systems or the RX (Reed-Xiaoli) detection algorithms of hyperspectral imaging (HSI) systems.

In this paper we examine straightforward methods for fusing the outputs from synthetic aperture radar (SAR) and HSI prescreeners to create a multi-sensor prescreening algorithm. We begin by examining the sensor phenomenology for a specific operational scenario, and we incorporate this phenomenological information into both the individual sensor prescreener designs and the final fusion algorithm design. We describe how the SAR and HSI prescreener detects are associated with one another prior to fusion. Finally, we discuss several fusion methodologies-a polynomial-based detector, a Dempster-Shafer based detector, and a Bayesian detector based on an assumption of independence. The final results are compared with those obtained using a single sensor.

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6553-68, Session 14

Confidence level fusion of edge histogram descriptor, hidden Markov model, and spectral correlation feature

D. K. C. Ho, Univ. of Missouri/Columbia; P. D. Gader, Univ. of Florida; H. Frigui, Univ. of Louisville; J. N. Wilson, Univ. of Florida

This paper focuses on the confidence level fusion among several promising detectors for the vehicle-mounted ground penetrating radar landmine detection system. The detectors considered includes Edge Histogram Descriptor (EHD), Hidden Markov Model (HMM) and Spectral Correlation Feature (SCF). These detectors are feature based and they operate at the alarm locations declared from a pre-screener that may potentially contain landmine targets. These detectors perform quite well individually, and the purpose of fusion is to improve further the detection results.

EHD is a time-domain based algorithm that generates the edge features for detection. HMM is also a time-domain based algorithm that uses the positive and negative edges from an alarm signature together with time-sequencing information of the edges to perform detection. SCF is a frequency domain based technique that distinguishes landmine target with false alarm by examining the energy density spectrum estimated at the alarm location.

The fusion technique considered in this paper is based on the Mahalanobis distance measure. In particular, we collect the confidence values from the individual detectors at each alarm location to form a vector, compute the mean vector and the covariance matrix of them for the landmine targets and as well as for the false alarms. Given a vector of confidences from the individual detectors at an alarm, we compute its Mahalanobis distance from the mean vector of false alarms and that from the mean vector of landmines. The fused confidence is the difference between them. Experiments were conducted to evaluate the proposed fusion technique using the data measured from 4 different test sites with over 1500 landmine encounters. Preliminary results show that the proposed fusion technique reduces the false alarm rate by 16% at 90% probability of detection, and by 22% at 95% probability of detection, when comparing to the result of the best individual detector.

6553-69, Session 14

Context-dependent fusion for landmine detection with ground-penetrating radar

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In this paper, we present a novel method for fusing the results of several landmine detectors. The detectors considered include Edge Histogram Descriptor (EHD), Hidden Markov Model (HMM), Spectral Correlation Feature (SCF), the Feature-based rules Order statistics and Adaptive whitening (FOWA), and Texture Feature Classification Method (TFCM). The above detectors use different types of features and different classification methods.

The proposed fusion method, called Context-Dependent Fusion (CDF) is motivated by the fact that the relative performance of different detectors can vary significantly depending on the mine type, geographical site, soil and weather conditions, and burial depth. The training part of CDF has two components: context extraction and algorithm fusion. In context extraction, the features used by the different detectors and other additional features that describe the background characteristics are pooled. A novel clustering algorithm is then used to partition the training signatures into groups of similar signatures, or contexts, and to identify the relevant features within each context. The algorithm fusion component assigns an aggregation weight to each detector in each context based on its relative performance within the context. To test a new signature using CDF, each detector would extract its set of features and assigns a confidence values. Then, the features are used to identify the best context, and the aggregation weights of this context are used to fuse the individual confidence values.

Preliminary results on large and diverse Ground Penetrating Radar data collections show that the context extraction part of CDF can identify meaningful and coherent clusters. For instance, most contexts group signatures based mainly on geographical sites and mine/clutter types. Our initial experiments have also indicated that the context-dependent fusion outperforms all individual detectors and other methods that use a global fusion.

6553-70, Session 14

Use of the Borda count for landmine discriminator fusion

J. N. Wilson, P. D. Gader, Univ. of Florida

The Borda Count was proposed as a method of ranking candidates by combining the rankings assigned by multiple voters. It has been studied extensively in the context of its original use in political elections and social choice-making. It has recently seen use in machine learning and in ranking web searches, but few of its formal properties have been extensively investigated. In this paper, we describe both supervised and semisupervised learning systems that employ the Borda Count as their underlying bases. We analyze the strengths and weaknesses of the technique in the context of landmine discrimination. We discuss and evaluate methods for algorithm fusion using several weighted Borda Count methods and show how they affect algorithm fusion performance.

6553-88, Session 14

Land mine detection applying holographic neural technology (HNeT)

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Provided is a summary of Holographic Neural Technology (HNeT) and its application in detection of land mines using airborne SAR imagery. Tests were performed for three mine types (RAM, M20, VS1.6) located within variable indigenous background clutter (bare dirt, short/tall grass). This work has been performed as part of the Wide Area Mine Detection (WAAMD) Program at the U.S. Army Night Vision and Electronic Sensors Directorate in Fort Belvoir, VA. The ATR algorithm applied was Holographic Neural Technology (HNeT); a neuromorphic model based upon non-linear phase coherence/de-coherence principles. The HNeT technology provides rapid learning capabilities and an advanced capability in learning and generalization of non-linear relationships. Described is a summary of the underlying HNeT technology and the methodologies applied in the training of the neuromorphic system for mine detection using target images (land mines) and back-ground clutter images. Provided also is a summary description of the software tools applied in the development of the mine detection capability.

Performance testing of the mine detection algorithm separated target training and testing sensor image sets by airborne sensor depression angle and surface ground condition indigenous to site location (Countermine Alpha, Yellow Sands). Detection performance was compared in the analysis of complex versus magnitude sensor data. Performance results from independent test imagery indicated a reasonable level of clutter rejection, providing \> 50% probability of detection at a false detection rate < 10-3/m2. A description of the test scenarios applied and performance results for these scenarios are summarized in the conclusion of the report.

6553-71, Session 15

Segmentation of labeled GPR data for improved training

L. Carin, Duke Univ.

The signatures of landmines and clutter are typically a strong function of environmental conditions. It is therefore important to select the training data wisely, such that it is matched to the environment of interest. In the work presented here we employ non-parametric statistical techniques, based on the Dirichlet process, to cluster features extracted from GPR data. The algorithm is applied to sequential features of interest to HMM-based classification, as well as non-sequential features. The formulation yields a framework in which the data are segmented without requiring a priori knowledge of the number of data clusters. After clustering, the training data are pruned, such that those clutter-like mine signatures and mine-like clutter signatures are removed from the training set. Typical results are presented based on data measured by the NIITEK system, with encouraging performance demonstrated.

6553-72, Session 15

Ground bounce tracking for landmine detection using a sequential Monte Carlo method

L. Tang, P. A. Torrione, L. M. Collins, Duke Univ.

Given their ability to detect landmines with low metal content, ground penetrating radar (GPR) has received more and more attention. To locate the potential landmines accurately, the ground bounce (GB) signature, which is a major source of interference in the 3D data collected by the GPR system, is generally removed during the pre-processing process. A Sequential Monte Carlo method is proposed to model the locations of the GB signature, which is caused by the dielectric discontinuities between soil and air. The GB location at each down-track/cross-track position is treated as the hidden state in a stochastic Bayesian system. As the data arrive scan by scan along the down-track direction, its posterior distribution is approximated by a set of samples with associated weights. Those samples are propagated through the system evolution model in a predictive stage, which includes a deterministic component of the system dynamics and a random component associated with process noise. The prediction is refined with the new observation in a weight update stage by evaluating the likelihood of each sample. An initial training step sets parameters adaptively to accommodate different ground and weather conditions. The feature associated with the GB signature is updated with the arrival of new data. The prior distribution for a given location is predicted by propagating information from its two most recent neighbors, which enforces a 2D continuity constraint on the estimated ground surface. The algorithm is verified utilizing real data and improved landmine detection accuracy is achieved compared with other ground tracking algorithms.

6553-74, Session 15

Feature learning for a hidden Markov model approach to landmine detection

X. Zhang, P. D. Gader, Univ. of Florida; H. Frigui, Univ. of Louisville

Hidden Markov Models (HMMs) have been shown to be useful tools for landmine detection and discrimination using Ground Penetrating Radar (GPR). HMMs are used to build stochastic models of the characteristics of the GPR signals acquired as the sensor passes over a landmine. The stochastic models are built using sequences of feature vectors computed from the GPR signals. The performance of HMMs, as well as other feature-based methods, depends not only on the design of the classifier but on the features. Traditionally, algorithms for learning the parameters of classifiers have been intensely investigated while algorithms for learning parameters of the feature extraction process have been much less intensely investigated. In this paper, we describe experiments for learning feature extraction parameters in the context of using hidden Markov models for landmine detection.

The classification and feature learning parameters of HMMs are trained using a Minimum Classification Error approach that uses gradient descent to minimize a logistic loss function of difference of mine and non-mine models. Feature extraction algorithms are parametrized using Ordered Weighted Averaging operators. Features are initialized by clustering subwindows selected from landmine and non-landmine signatures. The magnitude of the Fourier transform is used to provide shift invariance. Morphological thinning operations are performed generate minimal representations of feature elements.

Results are shown for a large dataset of GPR measurements that were acquired over a 4 year period at several geographic locations and several different environmental conditions.

6553-75, Session 15

Visual detection, recognition, and classification of surface-buried UXO based on soft-computing decision fusion

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In this paper, we have addressed the problem of visual inspection, recognition, and discrimination of UXO based on computer vision techniques and introduced three complimentary color, texture, and shape classifiers. The proposed technique initially enhances an image taken from an UXO site and removes terrain background. Next, it applies a blob detector to detect the salient objects of the environment. The UXO classification begins with a perceptive color classifier that classifies the found salient objects based on their color hues. The color classifier attempts to differentiate and classify the color of salient objects based on the color hue information of some known UXO objects in the database. A color ranking scheme is applied for ranking color hue likelihood of the salient objects in the environment. Next, an intuitive texture classifier is applied to characterize the surface texture of the salient objects. The texture signature is used to disjointedly discriminate objects whose surface texture properties matching the priori known UXO textures. Lasting, an intuitive Object Shape Classifier is applied to independently arbitrate the classification of the UXO. Three soft computing methods were developed for robust decision fusion of three UXO feature classifiers. These soft computing techniques include: a statistical-based genetic algorithm, a hamming neural network, and a fuzzy logic algorithm. In this paper, we present details of the UXO feature classifiers and discuss the performance of three decision fusion methods for fusion of results from the three UXO feature classifiers. The main contributing factor of this work is toward designing an ultimate fully-automated tele-robotic system for UXO classification and decontamination.

6553-87, Session 15

Soil compensation techniques for the detection of buried metallic objects using electromagnetic sensors

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Magnetic soils are a major source of false positives when searching for landmines or unexploded ordnance (UXO) with electromagnetic induction sensors. In adverse areas up to 30% of identified electromagnetic (EM) anomalies are attributed to geology. The main source of the electromagnetic response is the magnetic viscosity of the ferrite minerals, such as magnetite and maghaemite. The EM phenomena that give rise to the response of magnetically viscous soil and metal are fundamentally different. The viscosity effects of magnetic soil can be accurately modelled by assuming a ferrite relaxation with a log-uniform distribution of time constants. The EM response of a metallic target is due to eddy currents induced in the target and is a function of the target's size, shape, conductivity and magnetic susceptibility. In this presentation, we consider different soil compensation techniques for time domain and frequency domain EM data. For both types of data we exploit the EM characteristics of viscous remnantly magnetized soil. These techniques will be demonstrated on time domain and frequency domain data collect on Kaho'olawe Island, Hawaii and the former Waikaloa Maneuver Area on the Island of Hawaii. A frequency domain technique based on modeling a negative log-linear in-phase and constant quadrature component was found to be very effective at suppressing false-alarms due to magnetic soils.

6553-76, Session 16

Image segmentation techniques for improved processing of landmine responses in ground-penetrating radar data

P. A. Torrione, L. M. Collins, Duke Univ.

As ground penetrating radar sensor phenomenology improves, more and more advanced statistical processing approaches become applicable to the problem of landmine detection in GPR data. Most previous studies on landmine detection in GPR data have focused on the application of statistics and physics based pre-screening algorithms, new feature extraction approaches, and improved feature classification techniques. In the typical framework, pre-screening algorithms provide spatial location information of anomalous responses in down-track / cross-track coordinates, and feature extraction algorithms are then tasked with generating low-dimensional information-bearing feature sets from these spatial locations. However in time-domain GPR, a significant portion of the data collected at pre-screener flagged locations may be unrelated to the true anomaly responses - e.g. ground bounce response, responses either temporally “before” or “after” the anomalous response, etc. The ability to segment the information-bearing region of the GPR image from the background of the image may thus provide improved performance for feature-based processing of anomaly responses. In this work we will explore the application of Markov random fields (MRFs) to the problem of anomaly/background segmentation in GPR data. Preliminary results suggest the potential for improved feature extraction and overall performance via application of image segmentation approaches prior to feature extraction.

6553-77, Session 16

Landmine with ground-penetrating radar using discrete hidden Markov models with symbol dependent features

H. Frigui, O. Missaoui, Univ. of Louisville; P. D. Gader, Univ. of Florida

In this paper, we propose an efficient Discrete Hidden Markov Models (DHMM) for landmine detection that rely on training data to learn the relevant features that characterize different signatures (mines and non-mines), and can adapt to different environments and different radar characteristics. Our work is motivated by the fact that mines and clutter objects have different characteristics depending on the mine type, soil and weather conditions, and burial depth. Thus, ideally different sets of specialized features may be needed to achieve high detection and low false alarm rates.

The proposed approach includes three main components: feature extraction, clustering, and DHMM. First, since we do not assume that the relevant features for the different signatures are known a priori, we proceed by extracting several sets of features for each signature. Then, we apply a clustering and feature discrimination algorithm to the training data to quantize it into a set of symbols and learn feature relevance weights for each symbol. These symbols and their weights are then used in a DHMM framework to learn the parameters of the mine and the background models. Preliminary results on large and diverse ground penetrating radar data show that the proposed method outperforms the basic DHMM where all the features are treated equally important.

6553-78, Session 16

Landmine discrimination using the Kullback-Leibler distance

J. N. Wilson, Univ. of Florida

In this study, we look at application of the Kullback-Leibler distance to classification in landmine discrimination. We explore the relationship between the information theoretic concepts of the Kullback-Leibler divergence and mutual information with special attention to the asymmetry of the typical formulation of the Kullback-Leibler distance. We consider two different approaches to using the Kullback-Leibler distance as a classifier, one that applies to the density distribution of landmine electromagnetic induction signatures, and another that treats those signatures themselves as probability density functions. Finally, we show cross-validation results of applying these techniques to a large collection of actual landmine data.

6553-79, Session 16

Application of a modified FFT approach to the subsurface imaging problem

Y. A. Gryazin, Idaho State Univ.

In previous publications (Y.A. Gryazin, M.V. Klibanov and T.R. Lucas, J. Comput. Phys., 158(2000), pp. 98-115 and Proc. of The International Society of Optical Engineering (SPIE), “Detection and Remediation Technologies for Mines and Minelike Targets IV” 3710 (1999), pp. 875-886) authors developed an effective approach for the solution of a forward subsurface imaging problem based on the combination GMRES method and a carefully chosen preconditioner, the solution of which was found using Fast Transform Method. But in the case of 3-D Helmholtz equation such algorithm becomes less effective due to the necessity of the solution of many 2-D problems by direct method and the effect of the replacement in the preconditioner the boundary conditions of third kind with Dirichlet or Neumann type. In this presentation, we consider a modified FFT based 3-D preconditioner that utilizes the same boundary conditions as the original discretized operator and requires the solution of the set of 1D problems. The results are compared to the application of GMRES and FFT combination. The extended problem of solving Helmholtz equation for many frequencies is also considered. Numerical results for realistic ranges of parameters in soil and mine-like targets are presented.

6553-80, Session 16

Development of processing algorithm for HSTAMIDS: status and field test results

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The Region Processing Algorithm (RPA) has been developed by the Office of the Army Humanitarian Demining Research and Development (HD R&D) Program as part of improvements for the AN/PSS-14. The effort was a collaboration between the HD R&D Program, L3-CyTerra Corporation, University of Florida, Duke University, and University of Missouri. RPA has been integrated into and implemented in a real-time AN/PSS-14. The subject unit was used to collect data and tested for its performance at three Army test sites within the United States of America. This paper describes the status of the technology, and its most recent test data.

6553-81, Session 16

CA-CFAR detection against K-distributed clutter in GPR

Y. Bahadirlar, M. Sezgin, TÜBITAK Marmara Research Ctr. (Turkey)

In the first part of the study the background signals of B-scan frames from a pulse GPR is statistically investigated. It is shown that the background signals residual of a removing process of the dominant GPR signals due to air-to-ground interface have K-Distributed statistics. The form and scale factors of K-Distributions are estimated using the higher order fractional moments. The clutter signals from three different soils have revealed different from factors. The form factor of K-Distribution could generally differentiated three soils. In the second part of the study the receiver loss of CA-CFAR (Cell Averaging-Constant False Alarm Rate) detector is calculated using a numerical method and the Monte-Carlo simulations. The loss is also related to the K-Distribution factors in the simulations. Time series with statistical properties similar to those from the real measurements are obtained using SIRV (Spherically Invariant Random Vectors) and employed in the Monte-Carlo simulations. In the third part of the study effectiveness of CA-CFAR detector on B-scan frames is analyzed by estimating the Receiver Operating Characteristics (ROC) of the detector. High detection probabilities of buried objects at relatively low SNR data are obtained by the CA-CFAR detector.

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6554-01, Session 1

The challenges of stand-off explosive detection

B. L. Shoop, U.S. Military Academy

There has been a significant amount of research focused on developing trace detection techniques for high explosives for people and vehicles. There remains a similar urgent need for stand off detection of high explosives in the complex environment in which the military operates. A wide variety of analytical chemical methods have been or are being applied to this problem. This review outlines the relevant explosive signatures, the challenges associated with the complex operational environment, and surveys a number of approaches comparing detection limits, speed of analysis, and portability.

6554-02, Session 1

Micromachined microfluidic chemiluminescent system for explosives detection

Y. S. Park, H. S. Hewage, D. P. Neikirk, E. V. Anslyn, The Univ. of Texas at Austin

Result will be reported from efforts to develop a self-contained micromachined microfluidic detection system for the presence of specific target analytes under the US Office of Naval Research Counter IED Basic Research Program. Our efforts include improving/optimizing a dedicated micromachined sensor array with integrated photodetectors and the synthesis of chemiluminescent receptors for nitramine residues. Our strategy for developing chemiluminescent synthetic receptors is to use quenched peroxyoxalate chemiluminescence; the presence of the target analyte would then trigger chemiluminescence. In a slightly different system we have recently verified this concept by measuring the light signal, triggered by the presence of stimulant for Sarin and Soman, with a silicon photodiode. Preliminary results are encouraging as we were able to measure large photo-currents from the reaction. We have also fabricated and demonstrated the feasibility of integrating photodiodes within an array of micromachined silicon pyramidal cavities. One particular advantage of such approach over a conventional planar photodiode would be its collection efficiency without the use of external optical components. Unlike the case of a normal photodetector coupled to a focused or collimated light source, the photodetector for such a purpose must couple to an emitting source that is approximately hemispherical; hence, using the full sidewalls of the bead's confining cavity as the detector allows the entire structure to act as its own integrating sphere. At the present time, our efforts are concentrating on improving the signal-to-noise ratio by reducing the leakage current by optimizing the fabrication sequence and the design.

6554-03, Session 1

Landmine detection using hyperspectral imaging

J. E. McFee, Defence Research and Development Canada (Canada); C. D. Anger, S. B. Achal, T. A. Ivanco, ITRES Research Ltd. (Canada)

Airborne hyperspectral imaging has been studied since the late 1980s as a tool to detect minefields for military countermine operations and for level I clearance for humanitarian demining. Hyperspectral imaging employed on unmanned ground vehicles may also be used to augment or replace broadband imagers to detect individual mines. This paper will discuss the ability of different optical wavebands - the visible/near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) - to detect surface-laid and buried mines. The phenomenology that determines performance in the different bands will be discussed. Hyperspectral imagers have usually been designed and built for general purpose remote sensing applications and often do not meet the requirements of mine detection. The DRDC mine detection research program has sponsored the development of VNIR, SWIR and TIR instruments specifically intended for mine detection. The requirements for such imagers will be described, as well as the instruments. Some results of mine detection experiments will be presented. To date, reliable detection of surface-laid mines in non-real-time, independent of solar angle, time of day and season has been demonstrated in the VNIR and SWIR. Real-time analysis, necessary for military applications, has been demonstrated from low speed ground vehicles and recently from airborne platforms. Reliable, repeatable detection of buried mines has yet to be demonstrated, although a recently completed TIR hyperspectral imager will soon be tested for such a capability.

6554-04, Session 1

Stand-off Raman instrument for detection of bulk organic and on-organic compounds

S. K. Sharma, A. K. Misra, P. G. Lucey, Univ. of Hawaii at Manoa

There is a need for stand-off technologies capable of detecting bulk organic and inorganic compounds that can be used for making liquid explosives. We have designed and tested a portable stand-off gated-Raman system that is capable of detecting organic and inorganic bulk chemicals at stand-off distances to 100 m during day and night time. Utilizing a single 532 nm laser pulse (~25 mJ/pulse), Raman spectra of several organic and inorganic compounds have been measured with the portable Raman instrument at a distance of 10 m in a well-illuminated laboratory. Raman spectra, obtained during a very short period of time (1.1 micro second), from organic compounds such as acetone, benzene, cyclohexane, 2-propanol, naphthalene, and inorganic nitrates. We have also measured the Raman spectra of these materials in a variety of glass and plastic containers with the 532 nm pulsed laser excitation and accumulating the spectra with 600 laser shots (30 sec integration time) at 100 m with good signal-to-background ratio. Possible applications of the stand-off Raman system for Homeland security and environmental monitoring will be discussed.

6554-05, Session 1

SERS substrates: a sensitive system for detection and identification of explosive material and chemical agents in liquid and vapor phase

C. M. Netti, H. M. Stanford, R. Johnson, R. Tailor, P. G. Hargraeves, Mesophotonics Ltd. (United Kingdom)

There is an urgent need to develop a more reliable and sensitive field-based system to detect and quantify explosive and chemical-threat material for Homeland Security and Military applications. We have recently developed a system for Surface-Enhanced Raman Scattering (SERS) detection of explosives and chemical agent simulants, comprising of a robust, portable SERS reader and Klarite substrates, which have a unique proprietary sensing architecture.

In this work, we will discuss the rapid and sensitive detection of common explosive materials in both liquid and vapour phase sampling scenarios. Furthermore, we will illustrate the ability of the system to identify and discriminate between these compounds by their unique SERS fingerprint.

Further work centred on the use of this SERS system to detect various chemical agent simulants in liquid or vapour phase. Clear, distinct SERS spectra fingerprints were rapidly detected allowing both their detection and identification.

Data on the detection of explosives and chemical agent simulants will be discussed in the context of the unique structure of the Klarite SERS surface. Manipulation of the architecture of the sensing surface will allow further refinement of the system, improving sensitivity and the discrimination between threat materials.

6554-06, Session 1

Matrix effects and design considerations for quartz-bound Au nanoparticle SERS substrates in chemical and biological detection

E. V. Ni, W. N. Radicic, U.S. Military Academy; A. W. Fountain III, U.S. Army RDECOM ECBC

Surface Enhanced Raman Spectroscopy (SERS) spectral analysis and spatial characterization of quartz-bound Au nanoparticle substrates to improve analytical sensitivity and limits of detection. SERS enhancement is significantly affected not only by a substrate's surface morphology but also laser-analyte orientation as well as matrix effects caused by non-analyte and non-metal substrate components. The use of Au hydrosols to fabricate better performing SERS substrates to detect chemical and/or biological agents has been an area of active and widespread research, but to date, the impact of matrix effects from spectral interferers introduced during fabrication on analytical sensitivity and limits of detection is not well understood. Experiments varying the depth of collection (observation) volume with respect to R6G on the substrate show high variability in analyte signal to noise ratios (S/N) well as high variability in background due to matrix effects from varying influences of the substrate's non-metal components. Of the many post-fabrication design factors affecting quartz-bound Au nanoparticle SERS substrate performance, characterization of matrix effects caused by changes in observation volume depth near the analyte-substrate interface will improve analytical sensitivity and limits of detection.

6554-07, Session 2

Field test results of standoff chemical detection using the FIRST

C. C. Carter, T. S. Spisz, P. K. Murphy, Johns Hopkins Applied Physics Lab.; A. Vallières, M. Chamberland, Telops, Inc. (Canada)

The FIRST, a commercial hyperspectral imager developed by Telops, features high sensitivity in a compact and robust package. This sensor provides hypercubes of spectral radiance of up to 320x256 pixels at 0.35µrad spatial resolution over the 8-12 µm spectral range at user selectable spectral resolutions of up to 0.25cm-1. The measurements are converted into "chemical maps" by the use of powerful algorithms using both spatial and spectral information.

The FIRST has been used at several field tests for the standoff detection and identification of chemicals. During these tests, the sensor is usually operated at 4 cm-1 of spectral resolution and the image size is tailored according to the scene, which gives a temporal resolution of a few seconds, enough to produce videos of chemical dissemination.

Algorithms based on a combination of clutter-matched filters and spectral angle mapper have been developed and used to process the measured data. The algorithms combine sub-band selection to minimize the correlation between the spectral signatures in the library and careful selection of the thresholds to reduce the level of false alarms. The output of the algorithms is the image of the clouds superimposed on the broadband thermal image.

JHU/APL has developed a processing approach that adapts to different backgrounds, yields high probability of detection of select gases in either emission or absorption, yields low probability of false alarm, and performs well in the presence of "hot" pixels. The algorithm combines background/noise suppression techniques, spectral detection techniques, such as the spectral angle mapper and the matched filter, and automatic adaptive threshold techniques.

This paper will present the successful standoff detection and identification of various chemical compounds using a variety of field measurements. Videos of chemicals dissemination will be presented, with some of them including mixture of 2 different chemicals.

6554-08, Session 2

Design of CATSI EDM: a passive standoff chemical warfare agent detector

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With the constant menace of terrorist attacks with warfare agents, the community needs reliable detection systems. The CATSI EDM system, designed for the Canadian Forces, offers unmatched performances for standoff chemical detection and identification. This sensor is based on high resolution Fourier Transform Spectrometer technology and has a unique feature that performs automatic background rejection. Its wide coverage combined with its high sensitivity and large étendue makes of it a very powerful tool for homeland security applications.

This paper presents the conceptual approach for the optics, mechanics, thermal management and the main functionalities. Performance results obtained with the sensor during its integration are also presented.

6554-09, Session 2

Wide-area hyperspectral chemical plume detection using an asymmetric model

D. S. Rosario, Army Research Lab.; J. M. Romano, U.S. Army Armament Research, Development and Engineering Ctr.

This paper presents a novelty using an asymmetric model for hyperspectral (HS) image analysis and processing examples for several applications, including standoff chemical plume detection at a nadir look.

The application of this model has significant performance advantage over conventional models because, in essence, its application answers a different statistical question. Let a reference sample X and a test sample Y denote two random samples of unknown distributions. Conventional techniques are designed to answer whether Y and X belong to the same class (Question 1), whereas our asymmetric model answers whether Y belongs to one of the classes in X (Question 2). We argue in this presentation that techniques developed to answer Question 2 are more effective suppressing the scene background, because remotely sensed natural scenes contain abundant transitions of different regions, i.e., a sample X belonging to two or more classes is often compared to a homogeneous sample Y belonging to one of the classes in X.

The state of the art techniques can not appropriately handle local transitions of different regions, and as a result pixels near such transitions are often declared local anomalies. These unfortunate declarations have a negative impact obscuring the presence of genuine local anomalies elsewhere in the scene, e.g., an anomalous chemical plume, personnel under CC&D. Our asymmetric approach was designed to answer Question 2, without assuming a priori the underlying distributions of input samples, but under the null hypothesis it converges to a known distribution. Experimental results will be shown using HS imagery.

6554-10, Session 2

Detection of simulants and degradation products of chemical warfare agents by vibrational spectroscopy

S. P. Hernández-Rivera, O. Ruiz, L. Pacheco-Londoño, O. M. Primera-Pedrozo, W. Ortiz, Y. M. Soto-Feliciano, D. E. Nieves, Univ. de Puerto Rico Mayagüez

Recent terrorist attacks have motivated to focus the attention to the possibility of use of chemical agents by terrorist organizations as threats against troops and/or civilians. The anticipation of future attacks requires a wide array of detection capabilities for range of potential deployment scenarios. Several techniques have been employed to detect and identify chemical agents including HPLC/MS, GC/MS, IMS, Infrared Spectroscopy, Raman Spectroscopy, among others.

Vibrational spectroscopy has the advantage that provides chemical information; it is non-destructive, requires little sample treatment and has the potential for remote sensing. This work was focused in the measurement of spectroscopic signatures of Chemical Warfare Agent Simulants (CWAS) and degradation products of chemical agents using vibrational spectroscopy for the generation of spectroscopic libraries. The chemical studied were: DMMP, DIMP, 2-CEES, 2-BAET, 1,4-thioxane, thiodiglycol sulfoxide, dihexylamine, cyclohexylamine, among others. Raman microscopy experiments were performed at different excitation wavelengths that spanned from NIR at 1064 and 785 nm to the VIS at 532, 514.5 and 488 nm and even the deep ultraviolet region at 244 nm. For the compounds studied the optimum excitation lines were 488 nm and 532 nm with a laser power of 25 mW. Among the most prominent bands were at these incident wavelengths were located ca. 652 and 1444 cm-1. Fourier Transform Infrared Spectroscopy in liquid and gas phase and Fiber Optics Coupled-Grazing Angle Probe-FTIR (FOC-GAP-FTIR) were used to characterize the spectroscopic signature of target threat agents. The surface experiments were performed at detection levels of about 1 µg/cm2 suggest that limits of detection (LOD) achievable could be as low as nanograms/cm2. Characterization of compounds by vibrational spectroscopy and the early stages of the transition from the lab based experiments to remote detection experiments will be presented.

6554-11, Session 2

Improvments on standoff differential reflectometry

A. M. Fuller, C. Schoellhorn, R. E. Hummel, P. H. Holloway, Univ. of Florida

It is shown that traces of 2, 4, 6-Trinitrotoluene (TNT) display strong and distinct structures in differential reflectograms, near 420 nm and 250 nm. These characteristic peaks are not observed from moth balls, nail polish, starch, soap, paper, aspirin, polystyrene, polyester, or fertilizer, to mention a few substances which may be in or on a suitcase. This exclusivity implies an ideal technique for explosives detection in mass transit and similar locations. The described technique for detection of TNT is fast, inexpensive, reliable, portable, and does not require contact with the surveyed substance. Moreover, a standoff instrument with the capability to detect from a distance of one meter has been developed. Further optimization should allow larger detection distances. Other explosives such as RDX, HMX, nitroglycerin, and PETN have also been investigated and demonstrate similar, but unique, characteristic spectra. The technique utilizes UV light reflected from two spots on the sample surface yielding a differential reflectogram of the sample corresponding to the absorption of the sample.

6554-12, Session 3

Infrared, near-infrared, and visible spectroscopy of sarin

M. W. P. Petryk, Defence Research and Development Canada (Canada)

The infrared, near-infrared, and visible regions of the absorption spectrum of the nerve agent sarin (isopropyl methylphosphonofluoridate) are reported. Experimental data are compared with simulated spectral profiles which have been calculated using ab initio methods with no recourse to experimental data. The applications of these two complimentary approaches to remote sensing are addressed.

6554-13, Session 3

Operational characteristics of LWIR AOTF-based multispectral imager

N. B. Singh, Northrop Grumman Corp.; M. S. Gottlieb, D. R. Suhre, Carnegie Mellon Univ.; D. A. Kahler, D. J. Knuteson, A. Berghmans, B. Wagner, J. Hedrick, J. J. Hawkins, Northrop Grumman Corp.

Northrop Grumman has designed, developed and demonstrated an acousto-optic tunable filter- (AOTF) based hyperspectral imager to cover the visible to long wavelength infrared (LWIR) spectral region. System concepts have been developed with high efficiency, resolution, and thoughput. We have experimentally demonstrated the performance of these systems in the near-IR to LWIR spectral region for threat objects of interests. We developed and used TeO2, Tl3AsSe3, Hg2Cl2 and Hg2Br2 crystal-based AOTFs for Near-IR, Mid- and LWIR wavelengths. Our objectives are to advance the performance level of state-of-the-art AOTF imagers and provide a path for teleoperated systems suitable for robots and other platforms for space and airborne applications. In order to increase the efficiency and transparency range for LWIR AOTF-based imagers we are developing imagers based on new high efficiency materials and unique designs. These materials have a large optical transparency range from 0.40 to 30 µm and a high acousto-optic figure of merit. The results on the growth of crystals, AOTF fabrication, and system design and performance are presented. The results of the optical system designs developed and tested for reducing AOTF aberrations, and producing pixel limited resolution are also presented.

6554-14, Session 3

Investigations of quantum cascade laser sources for a MEMS-scale photoacoustic sensor

D. A. Heaps, P. M. Pellegrino, Army Research Lab.

Photoacoustic spectroscopy is a useful monitoring technique that is well suited for trace gas detection. A sensitive differential photoacoustic method for trace gas measurements is proposed. The technique also possesses favorable detection characteristics when the system dimensions are scaled to a micro-system design. The objective of present work is to incorporate two strengths of the Army Research Laboratory (ARL), Interband Quantum Cascade Laser (ICL) source development and chemical and biological sensing into a monolithic micro-electromechanical systems (MEMS) photoacoustic trace gas sensor. This work also investigates a novel tunable Quantum Cascade Laser (QCL) as a source that adds selectivity to the measurements. Previous data have show that reducing the size of the photoacoustic cell can produce a very sensitive sensor using a CO2 laser. Recent work has shown that with a MEMS photoacoustic cell and using an ICL as the source a detection limit of sub-parts per millions for Dimethyl Methyl Phosphonate (DMMP) a precursor to a nerve agent is obtained. These studies involve the incorporation of an ICL source operating at about 3.45 µm. These experiments have directing the creation of a modified MEMS photoacoustic sensor from the current design.

6554-15, Session 3

Stand-off detection using coherent backscattered spectroscopy

A. W. Schill IV, P. M. Pellegrino, Army Research Lab.; B. R. Arnold, L. A. Kelly, Univ. of Maryland/Baltimore County

Intense laser pulses may be used for stand-off detection of energetic materials. Coherent backscattered spectroscopy offers a tremendous advantage over other spectroscopic detection techniques in that it uses stimulated emission from the sample to produce a coherent, directional beam back to the detection platform. The characteristics of the backscattered beam depend largely on the intensity and pulse width of the laser source as well as the concentration and photo-physical characteristics of the target molecule. Different target molecules will exhibit different backscattered emission signals, allowing differential detection of energetic materials in the vapor phase. Because to the highly directional nature of the coherent backscattered beam, detection limits in the vapor of less than 1 ppm at ranges up to 100 meters can be anticipated.

6554-16, Session 3

The feasibility of a nano-inertial measurement unit using chemistry to record position

M. E. Tanner, J. Protz, Duke Univ.

Traditional micro-fabricated inertial measurement devices like MEMS accelerometers, MEMS gyroscopes, and MEMS integrated IMUs consist of two principle components: (1) a micromechanical structure

that responds to inertial forces and deforms in a way that can be measured electronically by, for example, changing the height of a gap, and, thus, its capacitance; (2) an analog or digital computing device that integrates the electronically sensed acceleration to yield velocity and position, and then records this information for later use. These two components must be replicated in some fashion in a “nano” version of the same devices, specifically a nano-IMU is considered. The proposed approach combines an inertially-sensitive nano-structure or nano fluid/structure system with a micro- or nano- sized chemical reactor that functions as an analog computer. This paper will outline the feasibility of using a cantilever-controlled valve or an inertially responsive fluid flow to feed catalyst into a first order chemical reaction. The concentration of the resulting product then provides a measure of position. The proposed approach to the development of a “nanoIMU” would allow the benefits of existing MEMS IMU technology to be applied to an even broader array of applications by enabling the development of a new class of geospatially-sensitive drugs and materials and has application in a variety of military, intelligence, and commercial activities, including targeted-drug delivery for cancer therapy or localized pain-blocking, and the tagging, tracking, and locating of individuals of special interest.

6554-17, Session 4

Biological substance characterization in water matrices with Raman microspectroscopy

R. E. Jabbour, A. Tripathi, U.S. Army Edgewood Chemical Biological Ctr.; P. J. Treado, M. P. Nelson, ChemImage Corp.; J. L. Jensen, A. P. Snyder, U.S. Army Edgewood Chemical Biological Ctr.

UV-VIS spectroscopy provides relatively little biological information compared to the rich spectral data and information content in the infrared (IR) region. A parallel technology to IR detection is Raman spectroscopy. Potable water sources are vital for the military community. Raman spectroscopy is applied to biological substances in distilled and tap water matrices. A confocal ChemImage Falcon II Raman microscope was used. The incident laser radiation was 532 nm. Laser power between 50-350 mW was evaluated to interrogate spores and vegetative cells of Bacillus subtilis and E. coli cells to prevent “burnout” tendencies to the bacteria. The Raman technique was investigated by plotting spectra of six organisms and five proteins in principal components (PC) dataspace. A PC plot of factors 1-3-4 produced adequate separation between each biological substance cluster of points. Distilled and tap water matrices were investigated for spectral contamination properties to that of the biological sample. A drop of sample was dried at time zero, and multiple slides were produced and monitored for 7 days to document the ageing effects. Replicate spectra of the 5 minutes, 5 hours, and 1, 2, and 7-day suspensions of colonies from the same agar plates were performed in both water matrices. Each bacterium produced a separate cluster of points where the ageing effects were essentially in a random fashion within each bacterial cluster. No systematic trend was observed for young to old cultures in a cluster of the same bacterial points or for tap and distilled water matrix preparations.

6554-18, Session 4

Detection and identification of a water mixture of E. coli cells and B. subtilis spores with Raman chemical imaging microscopy

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Raman chemical imaging microscopy (RCIM) was utilized to discriminate between biological substances with Raman spectral database identification. Biological mixtures introduce a more difficult challenge. A confocal ChemImage Falcon II Raman microscope and a 532 nm laser were used for biological sample method. In the single particle mode, each detector pixel collected the scattered radiation from a 61 x 61 micron section in the field of view to minimize multiple particle presence in a pixel. The 500-1700 cm-1 spectral region was scanned. Water sample suspensions were investigated for determining the presence of multiple types of bacteria. Suspensions of E. coli cells and Bacillus subtilis spores were mixed together in different ratios. In the bright field view, both bacteria were observed. Raman spectral imaging was used, and each pixel was an independent detector. All points in principal components dataspace belonged to a bacterial spore, cell, debris, or the blank microscope slide. The Raman spectra provided the detailed differentiation characteristics for the qualitative pseudo-color bacterial cell images. Different biological substances yield different Raman spectral patterns of peaks. The Raman spectra of the selected colored features from the RCIM were compared to that in the database for matching and identification purposes. Polystyrene beads of known diameter(s) were also added to the bacterial suspensions as a reference. It is believed that this is the first instance that this method has been reported for the visual differentiation of bacterial species by RCIM.

6554-19, Session 4

Spectroscopic characterization of biological agents using normal Raman and surface-enhanced Raman spectroscopies

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Bioterrorism and its potential for mass destruction has been subject of increasing international concern. Only modest microbiologic skills are needed to produce and effectively use biologic weapons. Production costs are low and aerosol dispersal equipment from commercial sources can be adapted for biologic weapon dissemination. It increased interest in the application of several physicochemical analytical techniques for the rapid detection and identification of microorganisms. Raman spectroscopy and Surface Enhanced Raman Scattering (SERS) requires a minimum of sample allows fast identification of microorganisms. The use of this technique for characterizing the spectroscopic signatures of these agents and their stimulants has recently gained considerable attention due to the fact that these techniques can be easily adapted for standoff detection from considerable distances. The techniques also show high sensitivity and selectivity and offer near real time detection duty cycles. This research focuses in laying the grounds for the spectroscopic differentiation of Staphylococcus spp., Pseudomonas spp., Bacillus spp., Salmonella spp., Enterobacter aerogenes, Proteus mirabilis, Klebsiella pneumoniae, and E. coli, together with identification of their subspecies. In order to achieve the proponed objective, protocols to handle, cultivate and analyze the strains have been developed. Spectroscopic similarities and marked differences have been found for Spontaneous or Normal Raman spectra and for SERS using silver nanoparticles have been found. The use of principal component analysis (PCA), discriminate factor analysis (DFA) and a cluster analysis were used to evaluate the efficacy of identifying potential threat bacterial from their spectra collected on single bacteria. The DFA from the bacteria Raman spectra show a little discrimination between the diverse bacterial species however the results obtained from the SERS demonstrate to be high discrimination technique. The spectroscopic study will be extended to examine the spores produced by selected strains since these are more prone to be used as Biological Warfare Agents due to their increased mobility and possibility of airborne transport. Micro infrared spectroscopy as well as fiber coupled FTIR will also be used as possible sensors of target compounds.

6554-20, Session 4

Rapid, multiplexed, high-sensitivity detection of biowarfare agents by surface plasmon resonance enhanced common path interferometry

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Real time monitoring of biowarfare agents for military and civilian protection remains a high priority for homeland security and battlefield readiness. Available devices have sensitivity adequate for BWA detection, but the detection modules have limited periods of

deployment, require frequent maintenance, employ single-use disposable components, and have limited multiplexing capability. Surface Plasmon Resonance(SPR) Common Path Interferometry (CPI) is a label-free, high sensitivity biomolecule interaction measurement technology that allows multiplexed real-time measurement of biowarfare agents, including small molecules, proteins, and microbes. The technology permits continuous operation in a field deployable detection module of an integrated BWA monitoring system. SPR-CPI measures differences in phase shift of reflected S and P polarized light (under TIR conditions) at a surface, caused by changes in refractive index induced by biomolecular interactions within the evanescent field at the TIR interface. The measurement is performed on a discrete 2-dimensional area functionalized with biomolecule capture reagents in a microarray format, allowing simultaneous measurement of up to 100 separate analytes. Since the optical beam spans the entire area of the transducer array, optical scanning is not required, enabling a highly robust BWA monitoring solution. Output consists of simultaneous voltage measurements proportional to the phase differences resulting from the refractive index changes, is automatically processed and displayed graphically or delivered to a decision making algorithm, enabling a fully automatic field-deployable detection system capable of integration into existing modular BWA detection systems. Proof-of-concept experiments on surrogate models of anticipated BWA threats have demonstrated utility, and efforts are in progress for full development and deployment of the device.

6554-21, Session 4

A study of spore identification from diffraction data

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Some recent studies have focused on the spectral signature of spores for their identification (e.g. Alupoaei et al, Biosensors and Bioelectronics 19, 893-903, 2004). While this is a promising approach, an alternative is to apply image recognition or classification techniques to the diffraction pattern of a spore. Typical refractive indices of spores range from 1.38 to 1.51 during activation from the spore to the vegetative state and sizes can double from ~ 0.37 to 0.6 microns (e.g. Katz et al, CLEO CThC3, p 1575, 2005). This puts a spore or vegetative cell in the Mie scattering regime and one can fit its precise size and shape to a simple scattering model of this type. Scale and rotation invariant measures of targeted features isolated from the diffracted intensity can be defined and once generated from real data, referenced to a look-up table for particle identification. While there may be particles of no interest having a similar size and index range in the air sample that flows through the optical scattering system, when combined with wavelength diversity, additional features should permit a more precise identifier to be defined in principle. A typical spore will contain a spore coat, exosporium, cortex and core wall each of which will have slightly different optical properties at different wavelengths, depending on their complex refractive indices. We will present an analysis and preliminary experimental results that examine the effectiveness of this approach in a practical system and discuss the optimal set of wavelengths required.

6554-22, Session 4

Noninvasive forward-scattering system for rapid detection, characterization, and identification of bacterial colonies

B. P. Rajwa, B. Bayraktar, P. P. Banada, K. Huff, E. Bae, A. K. Bhunia, E. D. Hirleman, J. P. Robinson, Purdue Univ.

The latest specter of terrorism is driving the development of new, sophisticated detection systems for biowarfare agents. One of the greatest challenges in the response to biological attacks is rapid recognition of the agent involved. Only a few current technologies available allow diagnostics to be performed in the field. The other serious issue is the cost of biodetection technology. Most current systems are based on the use of PCR or antibody-based techniques. We believe that these approaches are overly complicated and expensive. Additionally, traditional methods for pathogen identification require complicated sample preparation for reliable results. Herein, we report development of a noninvasive optical forward-scattering system for automated and rapid identification of bacterial colonies grown on solid surfaces. The presented system includes application of computer-vision and pattern-recognition techniques to classify scatter pattern formed by bacterial colonies irradiated with laser light. A laser scatterometer equipped with a high-resolution CCD chip and application of Zernike moments, Tchebichef moments, and Haralick texture descriptors for pattern characterization allows for a very high recognition rate. Fisher's criterion has been used for feature selection to decrease the training time of machine-learning systems. An algorithm based on support-vector machines was used for classification of patterns. Low error rates determined by cross-validation, reproducibility of the measurements, and robustness of the system prove that the proposed technology can be implemented in automated devices for detection and classification of pathogenic bacteria.

6554-23, Session 4

Compact chamber for the spectroscopic analysis of fluorescent aerosols

B. J. Déry, Univ. Laval (Canada) and Defence Research and Development Canada (Canada); J. Simard, Defence Research and Development Canada (Canada); R. Vallée, Univ. Laval (Canada); G. Roy, H. Lavoie, S. Buteau, Defence Research and Development Canada (Canada)

A compact chamber was developed for the dissemination of biological aerosols. The chamber, measuring 110 cm in length, was designed according to short-range lidar principles, and will be used to simulate open-air releases of aerosols. Measurements, carried out by light-induced fluorescence (LIF) techniques, will be correlated with spectroscopic data obtained with a long-range lidar system owned by Defence Research and Development Canada (DRDC). The chamber allows complete control over environmental factors, such as humidity, pressure and temperature, thus facilitating the creation of trustworthy reference bases for the remote sensing of bio-aerosols. Studies will also include the influence of growth stage, stress and growth media on the emission spectra of various biological aerosols.

6554-24, Session 4

Developments in on-the-fly biomarking: a new method to rapidly identify chemical and biological aerosols

M. B. Hart, H. Lin, J. Deich, C. D. Merritt, J. D. Eversole, Naval Research Lab.

We report on the advances made in the basic research to label specific chemical or biological aerosols on-the-fly using an electrospray technique. Fluorescent biomarkers that have been created for specific targets, and that produce a detectable change in emission characteristics only upon binding, will be used to coat all aerosols in an air stream. Aerosols with appropriate receptors will be labeled in this manner, allowing them to be identified in near real-time using a simple laser-induced fluorescence technique. In effect, an immunoassay is quickly performed on the surface of single chemical or biological particles as they flow in an air stream, labeling specific ones for rapid, single-particle interrogation and identification among a diverse and dynamic background. This method permits the use of solutions containing mixtures of different biomarkers to simultaneously identify multiple types of chemical or biological aerosols. Some issues that are currently being investigated include the kinetics of biomarker surface binding to an aerosol in flight and the control of charged aerosols for efficient single particle interrogation.

6554-25, Session 4

Extinction and backscatter cross sections of biological materials

M. E. Thomas, M. B. Airola, C. C. Carter, N. T. Boggs, Johns Hopkins Applied Physics Lab.

Aerosol backscatter and extinction cross-sections are required to model and evaluate the performance of both active and passive detection systems. A method has been developed by which begins with

laboratory measurements of thin films and suspensions of biological material to obtain the complex index refraction of the film from the UV to the LWIR. Using that result with particle size distribution and shape information as inputs to T-matrix calculations yields the extinction cross-section and backscatter cross section as a function of wavelength. These are important inputs to the lidar equation.

In a continuing effort to provide validated optical cross-sections, measurements have been made on a number of high purity biological species in the laboratory as well as measurements of material released at recent field tests. The resulting observed differences aid in distinguishing between intrinsic and extrinsic effects, which can affect the characteristic signatures of important biological aerosols. A variety of biological aerosols are examined.

6554-26, Session 4

Field testing results and ambient aerosol measurements using a dual-wavelength fluorescence excitation and elastic scatter-based biosensor

V. Sivaprakasam, A. L. Huston, H. Lin, J. D. Eversole, P. Falkenstein, A. Schultz, Naval Research Lab.

A bioaerosol sensor based on dual wavelength fluorescence excitation and multiple wavelength elastic scattering - has been developed and characterized for classifying micron-sized bioaerosols on the fly. We have been able to successfully classify different types of bioaerosols including proteins and bacteria (vegetative cells and spores) and distinguish them from several common interferents. We have studied a variety of simulants and interferents grown under varying conditions to characterize the performance of the instrument. Simulant and interferent aerosols were generated using several different techniques.

The UV-LIF instrument was tested during a two-week-long, blind field trial at the Edgewood, MD breeze tunnel. The instrument operated unattended while simulants and interferents were released at various random times during the test period. The results of the field trial will be highlighted in this presentation. We detected and correctly identified over 90 % of the simulant releases and had zero false alarms over the 2 week testing period. In order to gain a better understanding of the characteristics of aerosols in the ambient air, we conducted background measurements for extended periods of time. These measurements proved valuable in steering the algorithm development efforts. Some preliminary results from our bioaerosol classification algorithm will be presented.

6554-27, Session 4

Early detection of chem-bio attacks using biosensors and hyperspectral image processing

A. K. Shaw, Wright State Univ.; J. I. Medford, M. Antunes, Colorado State Univ.; W. S. McCormick, Wright State Univ.; D. Wicker, Air Force Research Lab.

Preparedness against possible Chemical and Biological (chem-bio) attacks necessitates developing precise early-warning systems that can detect presence of harmful chem-bio material in an environment. The detection capability must be automated with widespread applicability and usage. In a recent paper, the researchers at Dr. Medford's lab have developed a new class of biosensors (Plant Sentinels) that can serve as inexpensive and widely used detectors for explosives, chemical attacks, and environmental pollutants [2]. Specifically, they have developed synthetic de-greening gene circuits that can induce rapid chlorophyll loss, thereby change color under the influence of synthetic estrogens. The synthetic de-greening process mimics (or simulates) the effect of possible chem-bio attack. Currently, the de-greening phenomenon via biosensors is remotely detectable by human eyes. However, in order to make the plant sentinel system practically viable, some form of automated monitoring for early detection scheme is needed. This paper develops novel and effective HSI-based algorithms for early detection of de-greening of plants and vegetation ("biosensors" or "plant sentinels") due to biological or chemical agents. The image processing based automated de-greening detector, proposed in this paper will be capable of 24/7 monitoring of the plant sentinels and to detect minutest possible discoloration of the plant-sensors to serve as a early-warning system. We also plan to develop Hyperspectral Anomaly Detection (AD) algorithms that can detect small regions of bio-degradation in a large swath of vegetation.

6554-28, Session 5

Spectrally resolved fluorescence cross sections of BG and BT with a 266-nm pump wavelength

M. E. Thomas, Johns Hopkins Applied Physics Lab.; J. D. Atkins, Johns Hopkins Univ.

The fluorescence signature is a common diagnostic for biological materials. Of particular interest is the identification of biological aerosols. Spectrally resolved fluorescence cross sections are measured on suspensions of BG and BT in water. The Raman line of water is used to calibrate the fluorescence cross section. The results are in good agreement with published band averaged cross section values on BG.

6554-29, Session 5

Field portable label-free, reagent-free pathogen detection system

N. V. Menon, G. Zeltser, P. Sivanesan, V. Esterkin, Physical Optics Corp.

Physical Optics Corporation (POC)is developing a novel diagnostic system that is capable of simultaneously detecting and identifying up to 100 user-specified pathogens/targets from human blood, serum or other fluidic samples in less than 20 minutes. The Dielectrophoretic Ramon Scattering Biosensor (DIRASBI) System is designed to perform label-free and reagent-free detection of pathogens by uniquely combining dielectrophoresis and surface enhanced Ramon spectroscopy in an integrated detection chip. POC has demonstrated the feasibility of DIRASBI by immobilizing multiple surrogate pathogens without the use of any analyte specific reagents and identifying them without the use of any labels. We are currently developing a fully automated sample analysis system that will detect for the presence of multiple targeted pathogens in blood/serum samples in real time. This prototype will be lightweight, compact (<1 lb, <10in3), ruggadized and portable; requiring no sample preparation with low cost of ownership (<$2/sample analyzed. The DIRASBI system will include a self-cleaning system with automatic sample decontamination and a user-friendly GUI enabling non-expert usage. We will discuss the recent developments that are aimed to revolutionize pathogen detection for military, homeland and medical applications.

6554-30, Session 5

Detection and classification of atmospheric aerosols using multi-wavelength CO2 lidar

R. E. Warren, EO-Stat, Inc.; R. G. Vanderbeek, U.S. Army Edgewood Chemical Biological Ctr.

This paper describes the theory and processing algorithms developed to date for parameter estimation, detection and classification of localized aerosols in the atmosphere using information provided by multiple-wavelength range-resolved lidar. The motivation for this work is the need to detect, locate, and identify potentially toxic atmospheric aerosols at safe standoff ranges using time-series data collected at a discrete set of CO2 laser wavelengths. The goals of the processing are to use the digitized transmitted and received backscatter array data to (1) decide if significant aerosol is present, (2) provide estimates of the range and size of the aerosol cloud, (3) produce estimates of the backscatter spectral dependence, and (4) classify the aerosol as a bio-agent or non-threat material. Because of the time-series nature of the data collection, these four functions must be performed sequentially using the current and past data together with background data samples collected at the deployment site from calibration data not containing release-aerosols. These calibration data samples are essential for providing the input to normalize the potentially release-containing data.

The estimation and detection methodology is as follows. Following

preprocessing of the data to remove outlier data, a filter based on the Wiener-Helstrom method is used to deconvolve the CO2 pulse waveform for each pulse. The pulse-deconvolved data is passed on to a sequential filter for estimating the spectral backscatter and range-resolved concentration in parallel. The backscatter is estimated through maximum likelihood given the current estimate of concentration. Likewise, the concentration estimates are updated through a Kalman filter that uses the current backscatter estimates. A possibly novel feature of the concentration filter is the use of an expansion of the concentration range-dependence in an orthonormal set of basis functions. The use of an orthogonal expansion provides a computationally efficient and notationally compact algorithm that effectively "diagonalizes" the problem of range-correlation in the data samples coming from the pulse deconvolution filter. In effect, the harmonic basis function set used to express the range-dependence acts as an approximation to a Karhunen-Loeve (KL) expansion. The eigenvalues of the KL expansion for each wavelength are estimated by maximum likelihood from the output of the deconvolution filter using background (calibration) data.

In parallel to the estimation and detection algorithm work, research is currently underway to develop an aerosol classifier using the spectral backscatter estimates as feature vectors. Support vector machines (SVM) are the most promising technology for this purpose. They directly approximate the optimal Bayes classifier without the need for estimating conditional probability densities as an intermediate step. SVM classifiers offer the potential for computationally efficient, large margin classifiers with excellent generalization performance on unseen data.

An extensive set of data has been collected by ECBC using the FAL (Frequency-Agile Lidar) sensor during JBSDS field-testing at Dugway Proving Ground over the past two years. The spectral backscatter estimates from this data serve as training and testing samples for SVM classifier development. The paper describes examples of the reduced backscatter estimates and the performance of multi-category SVM classifiers trained and tested with this data.

6554-31, Session 5

Bayesian probabilistic approach for inverse source determination from limited and noisy chemical or biological sensor concentration measurements

E. Yee, Defence Research and Development Canada Suffield (Canada)

Although a great deal of research effort has been focused on the forward prediction of the dispersion of contaminants (e.g., chemical and biological warfare agents) released into the turbulent atmosphere, much less work has been directed on the "inverse prediction" of agent source location and strength from the measured concentration, even though the importance of this problem for a number of practical applications is obvious. In general, the inverse problem of source reconstruction is ill-posed and unsolvable without additional information. It is demonstrated that a Bayesian probabilistic inferential framework provides a natural and logically consistent method for source reconstruction from a limited number of noisy concentration data. In particular, the Bayesian approach permits one to incorporate prior knowledge about the source as well as additional information regarding both model and data errors. The latter enables a rigorous determination of the uncertainty in the inference of the source parameters (e.g., spatial locations, emission rate, release time, etc.), hence extending the potential of the methodology as a tool for quantitative source reconstruction.

A model (or, source-receptor relationship) that relates the source distribution to the concentration data measured by a number of sensors is formulated, and Bayesian probability theory is used to derive the posterior probability density function of the source parameters. A computational efficient methodology for determination of the likelihood function for the problem, based on an adjoint representation of the source-receptor relationship, is described. The Bayesian inferential methodology for source reconstruction is validated against real dispersion data for two cases involving contaminant dispersion in highly disturbed flows over urban and complex environments where idealization of horizontal homogeneity and/or temporal stationarity in the flow cannot be applied to simplify the problem.

6554-32, Session 5

Binary shaped femtosecond pulses as a multidimensional tool for controlled molecular fragmentation and chemical recognition

I. Pastirk, Biophotonic Solutions, Inc.; V. V. Lozovoy, T. C. Gunaratne, J. C. Shane, M. Dantus, Michigan State Univ.

The highest importance for any method used in detection and recognition of chemicals is its reliability of measurement. Ultimate goals are minimal false positive and false negative alarms. The experimental results presented here on a set of chemical war agent simulants (para-nitrotoluene and dimethylphosphite) and mixtures, approach the problem of designing a dependable chemical detection tool by using a set of binary, spectral-phase shaped femtosecond laser pulses to control the outcome of molecular fragmentation in a mass-spectroscopy setup. Control of the fragmentation pathways initiated by phase-shaped laser pulses is achieved by utilizing the nonlinear optical response of the sample through the multiphoton intrapulse interference. In presented experiment a set of 2^n (where n is 8-10) binary-shaped pulses are used in a sequence for fragmentation of the sample and time-of-flight mass spectra are recorded. Different fragmentation pathways are result of a highly sensitive quantum-mechanical interaction of shaped ultrashort pulse and a sample molecule. A smaller subset of results is then selected to form a database and serve as a 'fingerprint' of a sample molecule where each different pathway represents additional dimension of analysis.

Binary phase-shaped pulses have advantage over other phase-shaping approaches (i.e. genetic-algorithm based closed loops) as they are fast (measuring a response of a sample while building a database for a thousand different binary shapes takes minutes, while actual detection once database is acquired is only several seconds), easily reproduced and cause either constructive or destructive interference between competing outcomes therefore enabling a scientific analysis of underlying fragmentation mechanisms.

6554-33, Session 5

Biomolecule sensors using high-Q microring resonators

E. T. Knobbe, J. Clarke, L. Flood, D. Goad, Nomadics, Inc.; A. Ramachandran, Oklahoma State Univ.; L. Wald, S. Wang, Nomadics, Inc.

High Q-factor optical ring resonators are being adapted as a powerful new tool for advanced microsensor applications. Primarily developed for use in the telecommunications sector, microring resonator technologies are now being extended for a variety of biochemical and biomedical applications. Of particular interest to many researchers is the potential for in-vitro sensing of biomolecules using a transducer having a scale length on the order of tens of microns. Discussion will include a summary of recent investigations in which optically-interrogated microring resonators have been demonstrated to provide direct in-situ, label-free detection of biomolecules with a mass detection limit of less than 1 pg. Extension of the technology for clinical diagnostics and/or as a quantitative health indicator will be discussed.

6554-34, Session 5

Investigation of synthetic molecular recognition for biosensing applications

D. N. Stratis-Cullum, S. McMasters, L. J. Sooter, P. M. Pellegrino, Army Research Lab.

Understanding any technology or methodology relying on molecular recognition of a specific target species requires a fundamental understanding of the factors which influence binding performance. For the Army, there is a growing need for a basic understanding of these interactions with traditional recognition elements (e.g., antibodies) in non-traditional environmental conditions, such as with new and emerging threats. There is a similar need for building a knowledge base on non-traditional affinity ligands that are biomimetic or biosynthetic in nature (e.g., peptides, nucleic acid aptamers, etc.)

In this talk, specific research at the Army Research Laboratory towards the development, evaluation and use of synthetic affinity ligands for sensing applications will be discussed. This will include the results of our investigations of three aptamer-based affinity ligands targeting Campylobacter jejuni. Using a combination of capillary electrophoresis and fluorescence microscopy techniques, the relative binding affinities of the aptamer ligands towards the target pathogen as well as the degree of cross-reactivity with other food food-pathogens (i.e., Escherichia coli O157:H7 and Salmonella typhimurium) were evaluated. Current progress towards the development of synthetic affinity ligands and application to sensing will also be discussed.

6554-35, Session 5

Recent testing and performance improvements of a fluorescence-based biological aerosol sensor

G. A. Wilson, B. Dable, J. Brady, M. Carrabba, Hach Homeland Security Technologies

In this paper we describe BioLert, an ultraviolet laser induced fluorescence (LIF) biological agent monitor for detecting low concentrations of pathogens amid the ambient aerosol. BioLert measures the fluorescence intensity and size of individual particles, and computes the Degree of Threat (DoT), an indicator of the likelihood that a particular threat material has appeared amid the recently sampled aerosol background. Performance is quantified using Receiver Operating Characteristic (ROC) curves, which plot the relationship among threat concentration, probability of detection, and false alert rate. We present BioLert ROC curves for several environments of interest.

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6555-01, Session 1

Remote sensing phase fluorimetry using mercury vapor lamp

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Phase Fluorimetry, or Frequency Domain (FD) Fluorimetry, is a technique which capitalizes on the phase delay from excitation modulation of fluorescent

media and offers independence from light scatter and excitation/emission intensity variations in order to extract the lifetime of the sample. Samples which fluoresce in the UV are commonly excited with UV laser sources, which are not necessarily high power, portable devices. Mercury vapor lamps, a common source of industrial facility lighting, emit wavelengths (365 nm, 405 nm, and 436 nm) that overlap the UV/blue spectrum and may be used as an efficient and portable excita-tion source. The absorption spectrum of UO+2

2 (390-450 nm), its high quantum yields, and long lifetime enable FD fluorimetry to be utilized. The phase angle given by tan(f) = wt and excitation demodulation m = (1+w2t2)-1=2 are easily detected by this method. Using t = 85µs and t = 600µs, the phase difference would range between 0:032 0:189 rad s-1 and 0:222??0:935 rad s-1 respectively. Mercury vapor lamps show strong peak intensities at 120 Hz and higher harmonics, however, intensities at these harmonics vary with frequency. For this research effort, single exponential decay will be assumed and lifetime

calculation will be performed by least squares analysis with corrections made for lamp intensity variations at harmonics. This research effort will demonstrate FD fluorimetry as an effective detection technique to utilize an excitation source mod-

ulated at multiple frequencies at once, which to our knowledge is a new method.

Data for this method will include the use of a mercury vapor lamp, modulated by facility power, as the excitation source for both willemite, a naturally occurring crystal with similar characteristics, and a sample containing uranium.

6555-02, Session 1

Design and development of ultra-narrow bandpass tunable photonic-crystal interferometers for visible and infrared spectral domains

V. B. Markov, A. Khizhnyak, MetroLaser, Inc.; W. B. Cook, NASA Langley Research Ctr.

Ultra-narrow bandpass tunable filters are critical for the remote sensing industry, high-resolution spectroscopy, multi-spectral and hyperspectral imaging. This report presents the results on the analysis and engineering of such filters for visible and infrared spectral regions with their design based on the unique features of a photonic crystal interferometer (PCI). An optimal choice of the parameters of the PCI components and its high finesse (\>200) enable to achieve an ultra-narrow bandpass f with a broadband tunability F in visible and IR spectral regions with the ration f/F ~ 100.

The stringent (air or space borne) operational conditions of the PCI requires for system's high thermo-mechanical stability - the subject of special interest that was performed based upon the finite element analysis. In order to optimize system performance and satisfy the requirements for practical exploitation such an analysis for the visible and IR modules, respectively, was made for the room and low temperature operational conditions.

In this report, along with the information on the PCI development, we present the results of tests and validation of its performance at various operational conditions, from the lab to field testing.

6555-03, Session 1

High-efficiency UV laser for space-based wind lidar

F. E. Hovis, Fibertek, Inc.; J. Wang, Raytheon Santa Barbara Remote Sensing

Tropospheric winds data remains a high priority yet unmet Environmental Data Record (EDR) for the US National Polar Orbiting Environmental Satellite System (NPOESS). Direct detection Doppler wind lidar systems have been demonstrated to be capable of providing measurements of wind velocities in clear air regions of the atmosphere, an important component of this unmet need. The relatively small wavelength shift and strong inverse wavelength dependence of the molecular backscattering signal require that a single frequency UV laser transmitter be incorporated into this type of lidar system. For any space-based application, high efficiency is a key system level design goal. We have been actively developing the required UV laser transmitter.

Our approach uses a single-frequency Nd:YAG master oscillator/power amplifier as the primary pump source. The system is diode pumped and conductively cooled for compatibility with space-based operation. We use a variation of the ramp and fire technique to injection seed the master oscillator. The space-qualifiable electronics provide user control of the injection seeding, diode pump power, and operational modes of the laser. The 1064 nm laser transmitter has been demonstrated to achieve a true system level wall plug efficiency of 6.4% for a q-switched output power of 44 W at 50 Hz. We use high efficiency doubling and sum frequency mixing of the 1064 nm pump to generate 24 W of 355 nm output. This result implies a third harmonic optical to optical generation efficiency of 55% and a system level efficiency of 3.5%. Our presentation will provide the details of how these results were achieved.

6555-04, Session 1

Incoherent scattered lidar from near-space

T. H. Zurbuchen, Univ. of Michigan; P. Tchoryk, Jr., Michigan Aerospace Corp.; R. Walker, Univ. of Michigan; J. C. Pavlich, M. T. Dehring, Michigan Aerospace Corp.; R. French, R. Swoish, Univ. of Michigan

There is an important need for accurate measurements of tropospheric wind altitude profiles. These wind-systems have long been recognized as one of the primary unknowns limiting weather forecasting over time-scales of several days. Typical measurement architectures have focused primarily on space-based based approaches, using a high-powered and highly effective LIDAR system.

This paper discusses mission architectures for near-space missions that are both space-born and carried by a high-altitude airship. The architectures are analyzed in the context of a weather forecasting system for the Gulf of Mexico region during hurricane season. The architecture studies were developed by collaboration between a class of engineers who are part of The University of Michigan's new Space Engineering program and Michigan Aerospace Corporation, a University of Michigan spin-off company specializing, in part, in LIDAR systems.

6555-05, Session 1

Optical sensing atmospheric emissions from cubesats and nanosats at Univ. of Illinois with Taylor Univ. collaboration

G. R. Swenson, V. Coverstone, M. Frank, Univ. of Illinois at Urbana-Champaign; H. Voss, Taylor Univ.

Small satellites and satellite payloads in the (1-2 kg) class called Cubesats and (20-30 kg) called Nanosats have been under development at the University of Illinois since fall, 2001. Taylor University has led the development of a nanosat called TEST, which was designed to study ionospheric structure, where the UofI provided a remote sensing optical sensor including a CCD camera and dual photometers. Both Taylor University and U of I are evolving 2 new nanosatellites, TEST2 (Taylor) and Ionospheric Structure Observatory (ISO) at Illinois.

The ISO satellite is conceived to contain insitu plasma sensors and electric field measurements, provided by Taylor, and dual imagers of ionospheric emissions, viewing forward and aft from an attitude stabilized spacecraft. The development activity is largely implemented by Interdisciplinary Design class, ENG491, at the College of Engineering where students participate in the systems engineering experience for 2 semesters, typically. The students (15-25 typically enrolled) are responsible for the design , fabrication, and testing of the systems. The developments of Cubsat and Nanosat systems will be described.

6555-06, Session 2

Optical artifacts in a laser-based spacecraft navigation imaging sensor

R. T. Howard, NASA Marshall Space Flight Ctr.; J. E. LeCroy, D. S. Hallmark, The Boeing Co.

The Advanced Video Guidance Sensor (AVGS) is one of the proximity operations sensors on the Orbital Express ASTRO spacecraft. During testing, several unexpected optical artifacts surfaced in the sensor. These artifacts all required in-depth examination and understanding to determine their causes, final effects, and find mitigation techniques. The artifacts, their causes and effects, mitigation techniques, and test results are described.

6555-07, Session 2

Superresolution structured light illumination

L. G. Hassebrook, C. J. Casey, V. Yalla, Q. Hao, D. L. Lau, Univ. of Kentucky

We present an eight million point structured light illumination scanner design. To our knowledge, it has the highest potential single patch, projection resolution of any scanner at 12,000 lines along the phase direction. The configuration consists of a custom Boulder Nonlinear Systems Spatial Light Modulator for the projection system and dual four mega pixel digital video cameras. The camera field of views are tiled with minimal overlap region and a potential capture rate of 24 frames per second. We will report on various performance characteristics of the system. These characteristics will include the measured spatial system resolution on flat surfaces. Discussion of optical limitations, capture synchronization and system frame rate will also be discussed. System will be evaluated with the multi-pattern, multi-frequency phase measuring profilometry technique already published by our group. We expect a typical 3-D capture rate of 1 point cloud (8 million points) per second but slower rates will produce higher signal-to-noise ratios on the depth measurements.

6555-08, Session 2

Multicamera phase measuring profilometry for accurate distance measurement

D. L. Lau, W. Wang, Univ. of Kentucky

Structured ligh illumination refers to a scanning process of projecting a series of striped patterns such that, when viewed from an angle, a camera is able to extract range information. Ultimately, resolution in depth is controlled by the number of patterns projected which, in turn, increases the total time that the target object must remain still. By adding a second camera sensor, it becomes possible to not only achieve wrap around scanning but also reduce the number of patterns needed to achieve a certain degree of depth resolution. But a second camera also makes it possible to reconstruct 3-D through stereo-vision techniques and triangulation between the cameras instead of between the cameras and the projectors. Specifically in this paper, we will analyze the resulting stereo-vision depth accuracy as a function of the number of structured patterns as well as analyze the resulting depth accuracy when fusing the surfa e recconstructions between all cameras as well as with the projector.

6555-09, Session 2

Composite pattern demodulation and post processing by means of stereo vision

D. L. Lau, K. Liu, Univ. of Kentucky

Structured light illumination generally refers to the scanning process of projecting a series of striped patterns onto a surface such that the range of the object is determined by the distortion in the pattern when viewed at an angle for the projector. Composite patterns are a technique of applying frequency modulation to the individual stripped patterns such that multiple SLI patterns are combined into a single, continuously projected pattern and where depth is determined by first demodulating a single captured image. As such, SLI can now be used for acquiring depth video, but the resulting video shows significant distortion near discontinuities in depth and texture. This bandwidth limitation has successfully been addressed previoulsy be means of stereo-vision processing between the captured image with the projected composite pattern, but real-time processing has never been achieved. In this paper, we will look at processing the captured, composite pattern image using stereo-vision algorithms performed on the graphics processing unit of a commodity 3-D video card, and through this, we hope to achieve real-time performance on the order of 10-15 fps.

6555-10, Session 2

Space-based active optical zoom

D. V. Wick, B. E. Bagwell, Sandia National Labs.; T. Martinez, Air Force Research Lab.; S. R. Restaino, Naval Research Lab; D. M. Payne, Narrascape; R. Romeo, Composite Mirror Applications, Inc.; G. L. Peterson, Breault Research Organization

Space-based systems need the flexibility of a wide FOV for surveillance while simultaneously maintaining high-resolution for threat identification and tracking from a single, nonmechanical imaging system. In order to meet these stringent requirements, the military needs revolutionary alternatives to conventional imaging systems.

We will present recent progress in active optical (aka nonmechanical) zoom for space applications. Active optical zoom uses multiple active optics elements to change the magnification of the imaging system. In order to optically vary the magnification of an imaging system, continuous mechanical zoom systems require multiple optical elements and use fine mechanical motion to precisely adjust the separations between individual or groups of elements. By incorporating active elements into the optical design, we have designed, demonstrated, and patented imaging systems that are capable of variable optical magnification with no macroscopic moving parts.

6555-11, Session 3

Advancements in pose determination for space operations

J. M. Trenkle, E. Erlandson, J. C. Pavlich, P. Tchoryk, Jr., Michigan Aerospace Corp.

Many space operations require knowledge of a spacecraft's position and orientation (pose), including autonomous docking and on-orbit inspection. Algorithms have been developed based on ensembles of decision trees and have been demonstrated to perform highly accurate pose determination of spacecraft models in a laboratory setting. In addition, a simulation environment that allows generation of realistic 3D images has been developed to enable rapid training of the pose determination algorithms. Results of the laboratory testing are provided.

6555-12, Session 3

Processing 3D flash ladar point clouds in real-time for flight applications

R. Craig, I. Gravseth, R. P. Earhart, J. Bladt, S. Barnhill, L. Ruppert, Ball Aerospace and Technologies Corp.

No abstract available

6555-13, Session 3

Stereo-vision-based 3D modeling of space structures

S. Se, P. Jasiobedzki, MacDonald, Dettwiler and Associates Ltd. (Canada); R. P. Wildes, York Univ. (Canada)

Servicing satellites in space requires accurate and reliable 3D information. Such information can be used to create virtual models of space structures for inspection (geometry, surface flaws, deployment of appendages), estimation of relative position and orientation of a target spacecraft during autonomous docking or satellite capture, replacement of serviceable modules, detection of unexpected objects and collisions. Existing space vision systems rely on assumptions to achieve the necessary performance and reliability. Future missions will require vision systems that can operate without visual targets, under less restricted operational conditions towards full autonomy.

Our vision system uses stereo cameras with pattern projection and software to obtain reliable and accurate 3D information. It can process images from cameras mounted on a robotic arm end-effector on a space structure or a spacecraft. Image sequences can be acquired during relative camera motion, during fly-around of a spacecraft or motion of the arm. The system recovers the relative camera motion from the image sequence automatically without using spacecraft or arm telemetry. The 3D data computed can then be integrated to generate a calibrated photo-realistic 3D model of the space structure.

Feature-based and shape-based approaches for camera motion estimation have been developed and compared. Imaging effects on specular surfaces are introduced by space materials and illumination. With a pattern projector and redundant stereo cameras, the robustness and accuracy of stereo matching are improved as inconsistent 3D points are discarded. Experiments in our space vision facility show promising results and photo-realistic 3D models of scaled satellite replicas are created.

6555-14, Session 3

Developing a pose estimation system development for Hubble space telescope servicing mission

J. S. Hannah, M. Balch, J. Berry, Advanced Optical Systems, Inc.

As NASA develops the new space explorations systems required for systems such as the Crew Exploration Vehicle (CEV), there is a growing need for hardware and algorithms to support Automated Rendezvous and Docking (AR&D) technology for both manned and unmanned flights. A new definition of space hardware is also emerging based on re-configurable computing.

Goddard Space Flight Center (GSFC) has developed a high processing bandwidth hardware platform based on the latest Xilinx Field Programmable Gate Array (FPGA) technology. This platform, called Space Cube, incorporates the processing power of immersed PowerPC core technology with an extremely flexible I/O capability. The result is an adaptable, reconfigurable computing platform well suited for hosting computationally intensive AR&D algorithms.

Advanced Optical Systems, Inc. (AOS) has developed several electro-optical sensor systems for both NASA and the Department Of Defense. One such sensor technology, developed for Automatic Target Recognition (ATR) in missile guidance systems is called ULTOR(r). AOS has applied ULTOR(r) to target position and attitude measurements in space, commonly referred to as pose estimation. Under GSFC funding, AOS has successfully integrated ULTOR(r) into the Space Cube platform. GSFC plans to demonstrate on-station pose estimation using the integrated ULTOR(r) Space Cube system on the next shuttle mission to the service the Hubble Space Telescope.

6555-15, Session 3

Ladar-assisted spacecraft rendezvous and docking laboratory tests

R. C. Fenton, R. R. Fullmer, R. T. Pack, Utah State Univ.

The autonomous close-in maneuvering necessary for the rendezvous and docking of two spacecraft requires a relative navigation sensor system that can determine the relative position and orientation of the controlled spacecraft with respect to the target spacecraft. Ladar imaging systems offer the potential for accurately measuring the relative six degree-of-freedom positions and orientations and the associated rates.

In this paper, we present experimental laboratory results. A commercial ladar system is used to capture close-proximity experimental range images of a model target spacecraft, producing 3-D point cloud data. The relative time-varying motion of the model is accurately measured and controlled using a precision motion control system. The sequentially gathered point-clouds are compared with the previous point-cloud using a real-time point-plane correspondence-less variant of the Iterative Closest Points (ICP) algorithm. The resulting relative displacement data is used as the input to a Kalman filter predicting the motion state of the target spacecraft to improve the relative position estimates. These estimates are used in turn to prime the next time-step iteration of the ICP algorithm. Results from detailed point-plane simulations and the laboratory experiments will be presented. The implications for real-time implementation are discussed.

6555-16, Session 4

Hydra AR&D sensor suite

F. D. Roe, S. R. Granade, Advanced Optical Systems, Inc.

AOS is designing a Modular AR&D System named Hydra and building an initial prototype with selected (near-field and docking) capabilities and expansion capabilities to accommodate a time-of-flight and far-field sensor. Lessons learned from DART and Orbital Express have been applied to the proposed Hydra design. The initial Hydra system design will include an AVGS sensor head and an ULTOR(r) sensor head. Although the initial Hydra system will be constructed as a ground demonstration unit, design methods and component selection will enable a straightforward path for building a space qualified Hydra system. The basic architectural component for Hydra is based on a common processing platform that can be configured to process inputs from a variety of sensors. The design consists of three elements: The sensor head or camera, which can be mounted external to the spacecraft; the processing electronics, which can be mounted internal to the spacecraft; and the Hydra target, which is mounted on the target spacecraft at or near the docking interface. We will discuss the individual Hydra sensors, the overall Hydra architecture, and the current progress in building the prototype.

6555-17, Session 4

The lunar orbiter laser altimeter (LOLA)

H. Riris, X. Sun, J. Cavanaugh, G. Jackson, L. Ramos-Izquierdo, D. E. Smith, NASA Goddard Space Flight Ctr.; M. Zuber, Massachusetts Institute of Technology

The Lunar Orbiter Laser Altimeter (LOLA) instrument on NASA's Lunar Reconnaissance Orbiter (LRO) mission, scheduled to launch in October 2008, will provide a precise global lunar topographic map using precise laser altimetry. LOLA uses short pulses from a single laser through a Diffractive Optical Element (DOE) to produce a five-beam pattern that illuminates the lunar surface. For each beam, LOLA measures the time of flight (range), pulse spreading (surface roughness), and transmit/return energy (surface reflectance). The LOLA will produce a high-resolution global topographic model and global geodetic framework that enables precise targeting, safe landing, and surface mobility to carry out exploratory activities. In addition, it will characterize the polar illumination environment, and image permanently shadowed polar regions of the lunar surface to identify possible locations of surface ice crystals in shadowed polar craters.

6555-18, Session 4

Commissioning of the CALIPSO payload

C. S. Weimer, L. Ruppert, J. Spelman, Ball Aerospace & Technologies Corp.

The CALIPSO satellite launched on April 28, 2006. It successfully entered into the Aqua (A) -train of Earth observing satellites along with its co-manifested Cloudsat satellite. CALIPSO includes a Payload built for NASA by prime contractor Ball Aerospace & Technologies Corp. The Payload includes three instruments for earth remote sensing: A two-wavelength polarization-sensitive lidar, a visible wide-field camera (WFC), and an infrared imaging radiometer (IIR). The commissioning and performance assessment of the satellite were successfully completed in the first ninety days after launch. This paper highlights some of the key instrument performance measured during commissioning, focusing on the lidar and wide-field camera.

6555-19, Session 4

Utilizing UV and visible sensors on micro-satellites to demonstrate target acquisition and tracking

S. B. Brown, D. Wada, A. Ghafourian, M. Greenman, C. Howlett, T. Humpherys, Space Dynamics Lab.; V. Nguyen, Missile Defense Agency

The Distributed Sensing Experiment (DSE) program is a technology demonstration of target acquisition, tracking, and three-dimensional track development using a constellation of three micro satellites. DSE is a concept demonstration to show how micro satellites, working singly and as a group, can observe test-missile boost and ballistic-flight events. The overarching program objective of DSE is to demonstrate a means of fusing measurements from multiple sensors into a composite track. To perform this demonstration, each DSE micro satellite will acquire and track a target, determine a two-dimensional direction and movement rate for each, communicate observations to other DSE satellites, determine a three-dimensional target position and velocity, and relay this information to ground systems. A key design parameter of the program is incorporating commercial off-the-shelf (COTS) hardware and software to reduce risk and control costs, while maintaining performance. Having completed a successful Critical Design Review, the program is currently in fabrication, integration, and test phase. The constellation of satellites is scheduled for launch in CY2009. This paper describes the status and capabilities of the UV and visible sensor payloads, as well as the algorithms and software being developed to achieve the DSE mission.

6555-20, Session 5

DART advanced video guidance sensor flight results

R. T. Howard, T. Bryan, NASA Marshall Space Flight Ctr.

The Demonstration of Autonomous Rendezvous Technologies (DART) flew with the Advanced Video Guidance Sensor (AVGS) as its primary proximity operations sensor. The sensor was never allowed to track the target, but it did gather data on the reflectors on the target. Those results will be presented.

6555-21, Session 5

Miniature, light weight, coherent optical receiver system for space platforms

A. M. Joshi, Discovery Semiconductors, Inc.

We have manufactured a miniaturized, light weight, high data rate, optical coherent receiver system with weight less than 25 Kg and power consumption less than 100 W. By using a coherent heterodyne method, the bench-top receiver has achieved a link rate of 2.5 Gb/s with a Bit Error Rate of 1e-9 with a sensitivity of -43 dBm. This receiver could be used as a critical component of a free-space optical link, where the large distances and power limitations necessitate a high sensitivity. Optical communications links provide tremendous bandwidth and can achieve data rates two orders of magnitude higher that an RF communications link. Potential mass and power savings that go with using an optical system over an RF, along with the significantly higher bandwidth and reduced susceptibility to interference make them very attractive in the further development of the space environment.

6555-22, Session 5

Real-world educational experience through project-oriented graduate classes in collaboration with industry

T. H. Zurbuchen, Univ. of Michigan; P. Tchoryk, Jr., Michigan Aerospace Corp.

There is an important need for a motivated and innovative work force for the US aerospace industry. The education of such engineers and scientists typically revolves around fundamental knowledge of basic important technologies, such as the mechanics relevant to orbit-design, structures, avionics, and many others. A few years ago, the University of Michigan has developed a Masters of Engineering program that provides students with skills that are not taught as part of a typical engineering curriculum. This program is focused on open problem solving, space systems, and space policy, as well as other classes that further their understanding of the connections between technologies and the non-technical aspects of managing a space mission. The value of such an education is tremendously increased through a direct connection to industry. An innovative problem-oriented approach has been developed, which enables direct connections between industry and classroom teaching. The class works as a system study-group and addresses problems of interest to and defined by a company with a specific application. We discuss such an application, a near-space wind measurement system for weather prediction, as well as the approach taken to link educational rationales.

6555-23, Session 5

High-resolution imaging with small satellites: what are the possibilities and limitations

R. Sandau, U. Dombrowski, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

High resolution mapping systems follow the trend to smaller ground sample distances (GSD) making use of the best technology available at the given time. From the 80 m GSD of ERTS in 1972, the GSD now approached 1 m and even less for civil applications. Mass and power consumption of spacecrafts and imaging instruments follow similar trends in conjunction with the immense improvements in very divers fields of technology. SAR systems are an alternative to passive optical systems; they also benefit from the technology improvements. But the most promising prospects for high resolution mapping with small satellites are connected with passive optical systems. The paper gives a MTF based metrics and analytical method to assess how far we can go with decreasing instrument size and decreasing the GSD at the same time and what features the spacecraft needs to provide. In this context the paper deals with such important parameters for topographic mapping with small satellites like spatial resolution, radiometry, data volume and data transmission rate, pointing accuracy and stability. It is shown that the imagers as well as the spacecraft bus need to follow certain rules to allow high resolution imaging aboard of small satellites.

6555-24, Session 5

Autonomous docking experiments using the SPHERES testbed inside the ISS

S. Nolet, A. Saenz-Otero, D. W. Miller, Massachusetts Institute of Technology

The MIT Space Systems Laboratory (SSL) is currently performing research on autonomous docking with free tumbling targets. The objective of this research is to develop a control architecture that will enable safe and fuel efficient docking of a thruster based spacecraft with a free tumbling target in presence of obstacles and contingencies. Over the summer 2006, experiments were performed inside the

International Space Station (ISS) to demonstrate a subset of the control architecture on hardware in a relevant environment. The SPHERES testbed, a series of micro-satellites (Spheres) developed by the MIT SSL and designed to operate autonomously inside the ISS, was used for the experiments. A first set of experiments involving one satellite were performed in May, after a first Sphere was launched in April on Progress 21P. An autonomous docking maneuver with a fixed target was attempted to validate the glideslope algorithm used to generate the approach velocity profile. A station-keeping maneuver in close proximity to the same target was also performed to demonstrate the capability of the Sphere to precisely control its position. The second set of experiments occurred in August, after a second Sphere was launched in July on STS-121. Multiple docking maneuvers between two satellites were then performed, including one with a free drifting satellite to study the effect of plume impingements. Good contact between both satellites was obtained in most cases, although some refinements on the navigation algorithm are necessary when they are a few centimeters from each other. Results collected during both sets of experiments will be presented in this paper.

6555-25, Session 6

TBD

R. T. Howard, NASA Marshall Space Flight Ctr.

No abstract available

6555-26, Session 7

Health monitoring: propellant ullage pressurization subsystem

J. L. Edwards, D. B. Buchanan, Boeing North American

Human space travel is inherently dangerous. Hazardous conditions will exist. Real time health monitoring of critical subsystems is essential for providing a safe abort timeline in the event of a catastrophic subsystem failure. This paper will discuss a practical and cost effective process for developing critical subsystem failure detection, diagnosis and response (FDDR). This paper will be combined with a real time health monitoring simulation of a propellant ullage pressurization subsystem failure. The health monitoring development process identifies hazards, isolates hazard causes, defines software partitioning requirements and quantifies software algorithm development. This paper will discuss how health monitoring software tracks subsystem control commands, interprets off-nominal operational sensor data, predicts failure propagation timelines, corroborate failures predictions and formats failure protocol.

6555-27, Session 7

Evaluation of holographic subsurface radar for NDE of space shuttle thermal protection tiles

T. T. Lu, T. Chao, A. P. Thakoor, Jet Propulsion Lab.; C. Snapp, NASA Johnson Space Ctr.; T. Bechtel, Enviroscan, Inc.; S. I. Ivashov, I. A. Vasilyev, Bauman Moscow State Technical Univ. (Russia)

The disastrous loss of the Space Shuttle Columbia, as well as even more recent dangerous incidents that were thankfully resolved, have aroused interest in interferometric microwave radar devices for non-destructive testing and evaluation of the Space Shuttle Thermal Protection System, the external fuel tank insulating foam, materials and structures on the shuttle, and other air and space vehicles. Experiments have been carried out to evaluate holographic subsurface radar (RASCAN) for non-destructive evaluation (NDE) of subnominal bond conditions between the Space Shuttle Thermal Protection System tiles and the aluminum substrate. The characteristic feature of this device is the ability to obtain one-sided radar soundings/images with high sensitivity and high resolution in the frequency band of 3.6-4.0 GHz. Initial results have shown detection of small voids and spots of disbonding between Space Shuttle thermal protection tiles and underlying aluminum substrate. The holographic return signal forms a high-resolution image that shows the effect of improper bonding due to contamination, water moisture, and air separation under 1 - 2 inches thick tiles. Image processing methods to extract defects will be discussed. Potential applications of this technology for in-flight non-destructive inspection of structure health of spacecrafts will be presented.

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

6555-29, Session 8

An efficient systematic method for system sensors optimization and analysis

A. Fijany, F. Vatan, E. Barroth, Jet Propulsion Lab.

We present a new efficient algorithmic method for system sensors optimization and analysis. At the design stage, where the number and position of sensors need to be determined, this methodology provides an optimal system of sensors which satisfies the design requirements while minimizing the sensor resources. For a given system with a set of sensors, it would provide an extensive analysis of sensors capability for system monitoring, diagnosis, and prognosis. This analysis would provide following capabilities: a) Determination of system's diagnosability, i.e., the set of faults that can be covered and isolated; b) Determination of sensors' sensitivity, i.e., the impact of any sensor loss on the system diagnosability; c) Improving system's monitoring, diagnosis, and prognosis by providing a direct relation between a given fault and a subset of sensors' reading.

The quality and efficiency of any Fault Detection and Diagnosis (FDD) tool depends on the availability and relevance of the information that it can retrieve from the sensors system. In fact, current approaches to system's sensors design and selection are rather ad hoc and do not fully consider the impact of the sensors on the ability to detect faults and diagnose/prognose the system. Obviously, if the relevant information is not provided by the sensors then the system cannot be fully diagnosed/prognosed, no matter the efficiency and accuracy of the deployed tools. Our proposed approach enables filling this technology gap by providing the capability to directly relate sensors optimization and analysis to system's monitoring and diagnosis/prognosis. Our approach combines our two developed technologies on sensors optimization and analysis and on efficient model-based diagnosis. As a result, not only it provides a capability for a better design optimization but it also provides unique and significant new capabilities for system monitoring, and diagnosis/prognosis.

6555-30, Session 8

Stable 600 oC silicon carbide MEMS pressure transducers

R. S. Okojie, NASA Glenn Research Ctr.

We report thermally stable silicon carbide (SiC) piezoresistive pressure transducers that have been reproducibly operated over time at 600 C (1112 F) without significant parametric degradation. These transducers now extend pressure measurement further into the higher temperature environment beyond previously possible and provides three immediate significant technological benefits: i) wider frequency bandwidth (overcomes acoustic attenuation associated with pitot tube), ii) accuracy (stable output), and iii) reduced packaging complexity (no cooling tubes). Operation at 600 C provides immediate applications in military and commercial super- and hypersonic engines in which critical static and dynamic pressure measurements are performed to improve engine performance (i.e., reduced emission, reduced noise, improved CFD code validation).

The SiC pressure sensor is based on multi-user SiC MEMS bulk micro fabrication technology while the packaging is based on the NASA-patented MEMS Direct Chip Attach (MEMS-DCA) technique. The packaging technique eliminates the need for wirebonding and allows the sensor chip to be flip-mounted and attached directly to external wires. The flexibility associated with the packaging allows the sub-package to be inserted into pre-existing standard stainless steel housing, thereby eliminating the need for fixtures. Pressure transducer failures at high temperature are largely due to the degradation of the wirebond interface with the sensor, particularly with the additional

presence of vibration. The MEMS-DCA technique significantly reduces bond failure since the entire component parts have closely matched coefficient of thermal expansion and are rigidly connected.

6555-52, Session 8

Fiber optic sensor technologies for detection of hydrogen in space application

A. A. Kazemi, The Boeing Co.; K. Goswami, InnoSense LLC

Optical hydrogen sensors are intrinsically safe since they produce no arc or spark in an explosive environment caused by the leakage of hydrogen. Safety remains a top priority since leakage of hydrogen in air during production, storage, transfer and distribution creates an explosive atmosphere for concentrations between 4% (v/v) - the lower explosive limit (LEL) and 74.5% (v/v) - the upper explosive limit (UEL) at room temperature and pressure. Being a very small molecule, hydrogen is prone to leakage through seals and micro-cracks. Hydrogen detection in space application is very challenging; public acceptance of hydrogen fuel would require the integration of a reliable hydrogen safety sensor. For detecting leakage of cryogenic fluids in spaceport facilities, Launch vehicle industry and NASA are currently relying heavily on the bulky mass spectrometers, which fill one or more equipment racks, and weigh several hundred kilograms. An optical sensor system can decrease pay load while monitoring multiple leak locations in situ and in real time. Presentation will be made to discuss various designs of optical hydrogen sensors and their relative merits being used at Evolved Expandable Lunch Vehicle (EELV)/Delta IV Program and NASA field applications.

6555-32, Session 9

Algorithm development for autonomous assembly demonstrations

N. R. Hoff III, S. Mohan, S. Nolet, D. W. Miller, Massachusetts Institute of Technology

On-orbit servicing and assembly is a critical enabling technology for the advancement of large scale structures in space. The goal of the SWARM project is to develop and mature algorithms for autonomous docking and reconfigurations, to be used as the building blocks for autonomous servicing and assembly. Algorithms for approach, docking, and reconfiguration have been implemented and tested through a demonstration of the assembly of two telescope sub-apertures at Marshall Space Flight Center in July 2006. The algorithms developed for reconfiguration sets the mass properties based on the configuration. Updatable parameters include the location of sensors and receivers with respect to the geometric center, thruster locations with respect to the center of gravity, and control gains specific to each configuration. In order to test these algorithms in a 2-D environment, a ground testbed was developed that enables multiple docking ports and modular payload attachments. Hardware components include Nodes, UDPs, Posts, sub-aperture mirrors, and corresponding electronics. A SPHERES satellite was used as the assembler tug that moves these pieces into the desired configuration. Testing results from MSFC show good rendezvous and docking performance. Reconfiguration was demonstrated as well, but full functionality is dependent on good control after docking. Maneuvering after docking has slightly lesser performance due to limited control authority when the CG is outside the thruster envelope. Further algorithm development includes updating the controller to account for if the CG is outside the thruster envelope.

6555-33, Session 9

Autonomous precision formation flying: a proposed fault tolerant attitude control strategy

K. Khorasani, T. Jiang, Concordia Univ. (Canada)

Future space missions, such as those involving formation flying of multiple satellites require high operation autonomy mainly with the aim of reducing the operation costs and improving reactivity to sensed data. In particular, the stringent performance requirements envisaged in the precision formation flying cannot be achieved by currently available technologies. One of the main challenges in achieving autonomy is the capability of fault management without extensive involvement of ground station operators.

Within the fault diagnosis research community, fault detection and isolation have been researched extensively, although few efforts have been made in the domain of “autonomous fault tolerant systems” for formation flight of satellites. In this paper, a fault tolerant attitude control strategy is proposed, where nonlinear sliding mode observers are utilized to reconstruct the actuator faults present in the attitude control system as opposed to merely detecting the presence of faults. Furthermore, the proposed system will incorporate the fault estimates and take them into account to autonomously reconfigure the control algorithms for maintaining the attitude control objectives and requirements.

In the simulation results presented, a formation flight with four satellites flying along a sun-synchronous orbit is considered. The leader-follower formation control approach is utilized to maintain the relative attitudes among the satellites. Concurrently, a specific relative attitude of the leader with respect to the earth has also to be maintained. Major attitude perturbations and disturbances such as gravity-gradient effects, the Earth’s magnetic field, aerodynamic torques and solar radiation torques are also included in the simulations. The simulation results show that the attitude objectives for the precision formation flying may be achieved autonomously by our proposed fault tolerant control strategy even in the presence of actuator faults.

6555-35, Session 9

SUMO/FREND vision for unaided spacecraft grappling

J. L. Obermark, Jr., Naval Research Lab. and DCS Corp.; W. J. Wagner, Naval Research Lab. and Honeywell Corp.; C. G. Henshaw, Naval Research Lab.

The SUMO/FREND mission calls for a utility tug spacecraft to grapple a customer spacecraft to execute an orbit modification. This grappling task presents a number of technical challenges. The customer spacecraft may be one of several broad types of GEO satellite and is not expected to cooperate with the grapple operation. In this paper we will describe the machine vision aspects of this grappling task and our preliminary designs to provide a solution.

The customer satellite does not have any artificial visual targets or beacons to guide the SUMO/FREND craft in grappling. Our task is identify features common to a broad class of potential customer satellites that are amenable to tracking. The GEO space environment presents a number of challenges to the task, from lighting conditions to sensor and processor limitations.

We will identify and test an image processing system that locates and tracks visual features in real time conditions to accomplish the satellite grapple and capture. Rapid feedback from the tracking is critical to maintaining the relative position of the spacecraft. The system must be accurate enough to ensure a solid grapple on the satellite to bind the two spacecraft together as needed for a successful mission.

6555-36, Session 10

Quantifying an imagery system’s performance with transformational mission data analysis

A. W. Mauck, Booz Allen Hamilton Inc.

Traditionally, the performance of an intelligence imagery collection system is quantified by a satisfaction percentage. The mission satisfaction is the number of images collected divided by the number of images requested. This paradigm assumes the information needed is generated from the collected imagery data if the data is delivered on time. As persistent surveillance requirements become more prominent, the time sequence of data collection is increasingly important. The satisfaction percentage is not wholly descriptive of a collection system’s ability to complete persistent surveillance missions. A metric of imagery data utility that is dependent on the time sequence of data collected and the timeliness of data delivered is necessary.

Booz Allen Hamilton’s transformational mission analysis focuses on additional metrics to characterize satisfaction of persistent surveillance requirements. Surveillance missions are based on a need to monitor an activity or event. The observables are animate, and may require a time sequence of images. For surveillance imagery data to be useful, the system must collect the data in required sequence and deliver the information in a timely fashion. Booz Allen defines a utility score to quantify system performance against persistent surveillance missions. The utility score includes the satisfaction percentage, but is sensitive to the time dependences of data.

This paper outlines a transformational approach to mission analysis. The paper introduces examples of persistent surveillance missions, and the limited value of satisfaction percentage. It defines data relationships between imagery system capabilities and surveillance missions. Finally, it computes the utility score, and quantifies the performance of an example collection system.

6555-38, Session 10

Modeling of electro-statically actuated two-axis tip-tilt MEMS micro-mirrors for laser beamsteering

C. L. Edwards, B. G. Boone, Johns Hopkins Applied Physics Lab.; C. C. Davis, Univ. of Maryland/College Park

The availability of recently developed MEMS micro-mirror technology provides an opportunity to replace macro-scale actuators for free-space laser beamsteering in lidar and communication systems. Such an approach is under investigation at the Johns Hopkins University Applied Physics Laboratory for use on space-based platforms. Precision modeling of mirror pointing and its dynamics are critical to optimal design and control of MEMS beamsteerers. Beginning with Hornbeck's torque approach, this paper presents a first principle, analytically closed-form torque model for an electro-statically actuated two-axis (tip-tilt) MEMS structure. An Euler dynamic equation formulation describes the gimbaled motion as a coupled pair of damped harmonic oscillators with a common forcing function. Static physical parameters such as MEMS mirror dimensions, facet mass, and height are input to the model as well as dynamic harmonic oscillator parameters such as damping and restoring constants fitted from measurements. A Taylor series expansion of the torque function provides valuable insights into basic one dimensional as well as two dimensional MEMS behavior, including operational sensitivities near "pull-in." The model also permits the natural inclusion and analysis of pointing noise sources such as electrical drive noise, platform vibration, and Brownian molecular motion. Commercial-off-the-shelf micro-mirror measurements confirm the model's validity. SimuLink simulations illustrate performance sensitivities, controllability, and physical limitations which are important considerations in the design of optimal pointing systems.

6555-39, Session 10

A low-cost test-bed for real-time landmark tracking

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A low cost vehicle testbed system was developed to iteratively test, refine and demonstrate algorithms before attempting to transfer the algorithms to more advanced rover prototypes. The platform used here was a modified radio controlled (RC) car. A microcontroller board was inserted between the RC receiver and the motor controllers. It allows the passing of RC commands that are received from the remote operator or computer, or to modify or substitute motor commands generated by the computer. The sensors in these vehicles represent the types currently used on NASA-JPL rover prototypes. For dead-reckoning sensing, optical wheel encoders, a single axis gyroscope, and 2-axis accelerometer were used. An ultrasound ranger is available to calculate distance as a substitute for the advanced stereo vision systems presently used on rovers. The prototype (Figure 1) also carries a small laptop computer with a USB camera and wireless transmitter to send real time video to an offboard computer. A real-time user interface was implemented that combines an automatic feature selector, tracking parameter controls, streaming video viewer, and user generated or autonomous driving commands. Using the test-bed real-time landmark tracking was demonstrated by autonomously driving the vehicle through the JPL Mars yard. The algorithms stably tracked rocks and generate coordinate data from which to calculate relative motion and visually servo to waypoints or science targets. The limiting stage for the current system is serial computing-each additional landmark is tracked in order-but, since each landmark is tracked independently, if transferred to appropriate parallel hardware, adding targets would not significantly diminish system speed.

6555-40, Session 10

Flight robotics laboratory testing of optical sensors for automated rendezvous and docking

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Many of the missions in NASA's Exploration Systems Architecture require the use of Automated Rendezvous and Docking (AR&D) of spacecraft with either the International Space Station or with other spacecraft. An important part of an AR&D system is the sensor suite that provides the chase vehicle's GN&C system with the information it needs to successfully approach and dock with its target. The AR&D Sensor Technology project was created to reduce the risk of sensor development by increasing the maturation of various relative navigation sensor technologies and by improving NASA insight into the strengths and weaknesses of different technologies. Much of this work involved testing different optical sensors in a realistic environment to assess their capabilities. The testing was performed in the Flight Robotics Laboratory at the Marshall Space Flight Center using an APAS mockup and docking target designed and built at Johnson Space Center. The test program, different sensors, and results are presented.

6555-41, Session 10

New approach to analysis and new principle for optimization of remote sensing systems

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The proposed new approach to the analysis of remote sensing systems is that such systems should be considered as transitional and fuzzy ones and these two features are inseparable. This determination may be grounded by such well-known fact that each of such systems is under effect of many internal and external factors having random and systematic character. Effects of random character lead to fuzziness of RS systems, and effects of systematic character leads to transitional regimes of RS systems. Taking into consideration of abovementioned we have developed the new multi-stage principle for optimization of RS systems which consists of 3 steps: (i) Application of Gauss - Zeidel method; (ii) Application of variation principle of optimization; (iii) Application of classical mathematical analysis principle for finding of extremums functions. The proposed principle makes it possible to evaluate the potential informativeness of RS systems taking into consideration above features of them.

6555-42, Session 11

Optimization of the design of systems that evolve over time using neural networks

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Computational design optimization is challenging when the number of variables becomes large. One method of addressing this problem is to use pattern recognition to decrease the solution space in which the optimizer searches. Human "common sense" is used by designers to narrow the scope of search to a confined area defined by patterns conforming to likely solution candidates. However, computer-based optimization generally does not apply similar heuristics. In this paper, a system is presented that recognizes patterns and adjusts its search for optimal solutions based on performance associations with these patterns. A design problem was selected that requires the optimization algorithm to assess designs that evolve over time. A small sensor network design is evolved into a larger sensor network design. Optimal design solutions for the small network do not necessarily lead to optimal design solutions for the larger network. Systems that are well-positioned to evolve have characteristics that distinguish themselves from systems that are not well-positioned to evolve. In this study, a neural network was able to recognize a pattern whereby flexible sensor networks evolved more successfully than less flexible networks. The optimizing algorithm used this pattern to select candidate systems that showed promise for successful evolution. In this limited exploratory study, a genetic algorithm assisted by a neural network achieved better performance than an unassisted genetic algorithm did. In a Pareto front analysis, the assisted genetic algorithm yielded three times the number of optimal "non-dominated" solutions as the unassisted genetic algorithm did. It realized these results in one quarter the CPU time. This paper uses a sensor network example to establish the merit of neural network use in multi-objective system design optimization and to lay a basis for future study.

6555-43, Session 11

Modeling and control of active gravity off-loading for deployable space structures

T. J. Bihl, Ohio Univ. and Air Force Research Lab.; K. D. Pham, T. W. Murphey, Air Force Research Lab.

Kinematics behavior of deployable space structures must be examined through ground based testing to predict deployment in a microgravity environment. In order to simulate the microgravity conditions a test article would experience in space, a method of counteracting the force due to gravity is required. This is accomplished through gravity off-loading, which introduces a force opposite and equal to the force of gravity acting upon a test article throughout its deployment. Current gravity off-loading methods are passive and suspend a test article through counterweights or balloons with their movement forced due to their physical coupling with a test article, introducing unwanted boundary conditions, such as inertia and side-loading from a test article's transverse deployment. Therefore, an active gravity off-loading method is being developed that will deploy simultaneously with a test article. This method employs motorized carts with active load control and active position control based upon the lead angle of the off-loading tether. The maximum allowable lead angle is designed to be $\pm 2.5°$, with the intention of minimizing the forcing of the carts' longitudinal deployment. Additionally, a test article will be permitted to deploy naturally along its transverse due to the active load controller's ability to apply constant, uniform support.

6555-44, Session 11

Nonlinear modeling and precise position control of flexible space manipulator joint

X. Zhang, H. Sun, Q. Jia, Beijing Univ. of Posts and Telecommunications (China)

This paper addresses problem on position control of a flexible space manipulator joint. For a joint equipped with flexible harmonic drive, its performance of motion control is considerably restricted by the inherent nonlinearity caused by friction and nonlinear stiffness, which is identified as the main obstacles in obtaining high precision positioning. In this paper, a nonlinear model of flexible space manipulator joint is set up firstly, according to Harmonic-derive stiffness model compliance is compensated; Secondly, LuGre friction model is used and an improved observer-based adaptive method is proposed for friction compensation. Computer simulations demonstrate that this approach is effective and can obtain satisfactory tracking performance, steady-state accuracy, and improve low-speed performance significantly compared with conventional PID control.

6555-45, Session 11

Differential game barrier model for orbiter under target maneuvering based on relative coordinates

Q. Zhang, Z. Zhou, S. Sun, Y. Sun, Harbin Institute of Technology (China)

The pursuit-evasion game problem was analyzed by the qualitative differential game for space vehicle while the target is maneuvering, based on a system of orbit coordinates. The purpose is to obtain the pursuit-evasion barrier under the maneuvering manner which control is provided by varying the direction of thrust vector and the magnitude of thrust vector is considered as constant value for both spacecrafts. In constructing the barrier, terminal conditions are one of key problems to be solved under given capture criterion. This problem is solved by two-time parameterized equation, and the terminal critical position is obtained by the restricted formulation which is relative to thrust vector magnitude, terminal relative velocity and capture radius. A set of solution of barrier are find by theorizing. From mathematical simulation it is verified that there are the barriers.

6555-46, Session 11

Differential game barrier model for spacecraft under target maneuvering based on minimum error

Q. Zhang, S. Sun, Y. Sun, Harbin Institute of Technology (China)

This paper explores the pursuit-evasion game of two spacecraft in low coplanar orbit under minute continuous thrust. Using differential game theory, this study verifies terminal conditions confined by controlling, target set and velocity and gives the linear game model of minimum error which is compared with nonlinear game model on sight coordinate. The terminal conditions are fixed by constructing parameter equations set which are obtained after coordinate transformation and by the optimal controlling strategy for both spacecraft. Within the equations set linearized, there are variable parameters which are associated with the linearization process. Using differential game of kind theory, this paper obtains the expression of the barrier with the variable parameters to be established. According to extremum theory of the minimum error, the parameters to be established are achieved. This paper gives the results of theoretical derivation and numerical simulation.

6555-47, Session 12

Simulation study of a robotics-based method for on-orbit identification of spacecraft inertia properties

O. Ma, New Mexico State Univ.; K. D. Pham, Air Force Research Lab.; H. Dan, New Mexico State Univ.

The inertia properties (i.e., mass, location of mass center, inertia tensor) of a spacecraft can change in orbit for many reasons such as fuel consumption, fuel transfer, hardware reconfiguration, payload deployment, capturing a flying object (satellite), docking with another spacecraft, or some mechanical malfunctions like an unexpected deployment problem. In many missions the inertia properties of the involved spacecraft need to be known. For example, state-estimate and control systems need to know correct inertia parameters; space vehicles need to know how much fuel remains; a servicing spacecraft needs to know the inertia of the target satellite that it captured or docked to in order to stabilize the compound system; spacecraft needs to update its inertia parameters after deployment of appendages, etc. Therefore, it is desirable to identify the inertia properties of a flying spacecraft whenever needed. To be acceptable by industry, such technology has to not only solve the problem but also be reliable, efficient and economical.

This paper describes a simulation-based study of a new method of identifying inertia properties of spacecraft in orbit. The method makes use of an onboard robotic arm to change the inertia distribution of the entire spacecraft system. As the result of the redistribution of the inertia, the velocity of the spacecraft system will change correspondingly because of the conservation of momentum, as shown in Fig.1. The

velocity change is measurable and the inertia change of the robotic arm is predictable. This leaves the inertia properties of the spacecraft body as the only unknowns in the momentum equations. Therefore, the unknown inertia properties can be determined from a series of momentum equations corresponding to a series of changes/ measurements using standard system identification techniques. The largest advantages of this method are: (1) it does not consume fuel because a robotic arm is energized by solar power; (2) it requires to measure steady-state velocities only because the method is based on the momentum conservation law; (3) it will not be affected by internal energy dissipation because of the momentum based approach. In addition, structural flexibility of the robot or satellite will not add much difficulty to the method because each measurement can always be done after the structural oscillation dies down.

For the simulation study, the dynamics model of a rigid satellite and a 6-DOF robotic arm were implemented. All the kinematics and dynamics of the robotic arm are assumed to be known and the inertial properties of the satellite body are assumed unknown. By commanding the robotic arm to move to several different configurations and measuring the resulting linear and angular velocities changes, we can successfully identify the unknown inertia parameters of the satellite using the method. It is interesting to see that the arm does not need to move significantly in order to identify all the unknown parameters. This gives us an hint that we may not have to use a 6-DOF arm for the purpose. Some simple mechanisms such as a solar area may also be able to do the job. We also investigated how the ratio of the arm mass over the satellite mass affects the identification results. It turns out that the identification result is not sensitive to the mass ratio unless a low mass ratio causes a larger measurement error. This means that a relative small arm may do a good job. An important investigation is to see how measurement errors affect the identification results. This was done by introducing random errors into the “measured” velocity data. The simulation tests did show that errors in measurement may lead to large identification errors. This indicated that we need to introduce measures to minimize identification errors caused by inevitable measurement errors in practice. In general, the simulation results demonstrated that the proposed identification technology works very well in theory. Due to time limitations, no experiment test and verification have been conducted so far. We have had good ideas about how to test this technology in lab environment, which will be our future work.

The last interesting thing that we found from the simulation study is that the method may also work with a solar array instead of a 6-DOF robot although a solar array has very limited manoeuvrability. This finding supports our hypothesis that a solar array and perhaps another simple mechanism can also be used as a “robot” for identifying satellite inertia. Of course, this finding was only from a very preliminary simulation test. More in-depth investigation is still needed in order to prove this hypothesis. If it is proven, the impact will be significant because most of the satellites have solar arrays but only very few are equipped with a robotic arm.

6555-48, Session 12

Online tribology ball bearing fault detection and identification

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Successful operation of many precision machinery used in space instruments require very stringent position accuracy - in the range of microns. Theses systems must be designed to operate reliably with little or no maintenance and long service-life duration. This presents a formidable challenge to the designer since there is a severe paucity of available information on enabling methods that would ensure proper functioning of these systems. Under NASA funding, we have developed a system for the ball bearing fault detection and identification. Our system can effectively identify various fault modes related to the evolution of friction within the contact in the coated ball bearings. Data are collected from lab experiments involving forces, torque and acceleration sensors. To detect the ball bearing faulty modes, we have developed a new bispectrum and entropy analysis method to capture the faulty transient signals embedded in the measurements. Test results have shown that this method can detect the small abnormal signals associated with the friction evolution. To identify the fault modes, we have further developed a set of stochastic models using hidden Markov model (HMM). Instead of using the discrete sequences, our HMM models can incorporate the feature vectors modeled as Gaussian mixtures. To facilitate online fault identification, we build an HMM model for each fault mode. At each evaluation time, all HMM models are evaluated and the final detection is refined based on Bayesian inference. Test results using lab experiment data have shown that our system can identify coated ball bearing fault modes in real-time.

6555-49, Session 12

Integration and test of a robotics-based testbed for verifying contact-dynamics parameter identification technology

O. Ma, J. H. Kim, New Mexico State Univ.

This paper describes the integration and preliminary test of a robotics-based testbed designed for experimentally investigation and verification of a systematic method for identifying key parameters of multiple-point, frictional contact-dynamics models.

Some of the current and future flight systems will be required to make physical contact in orbit such as the assembly of the International Space Station, repair and refueling of a satellite, spacecraft docking and capturing, etc. Because of the high risk associated with contact operations, the design and operation of such a flight system must be thoroughly analyzed and verified in advance by computer simulations using high-fidelity multibody dynamics and contact dynamics models. The accuracy of such a dynamic simulation depends not only on the mathematical model (i.e., formulation, algorithms, and computer code) but also on the values of model parameters. Existing techniques of identifying contact parameters focus on measuring individual parameters from single-contact scenarios and using highly specialized equipment and specimens. Such an approach is non-systematic, specialized-equipment and human-skill dependent, and very inefficient. The leading author of this paper and his Canadian collaborators proposed a systematic method which can identify key stiffness, damping, and friction parameters of a multi-point contact dynamics model all together directly from hardware test of a mechanical component or assembly having complicated geometries [1]. The method can be used to extract contact-dynamics model parameters of a dynamic system from its routine test of complex contact hardware. It can also be used to tune the dynamics simulation model of a space system directly from its flight data. A simulation study of this method showed promising results [2]. However, the method has not been experimentally verified. To be acceptable to the industry to make real impact, the method has to be experimentally verified. A robotics-based testbed has been designed at NMSU to experimentally test and verify the above-mentioned new identification method [3]. This paper will introduce the integration and some preliminary test results of this testbed.

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6555-50, Session 12

Ground experiment verification of space robotic system

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Space robotic technology is very important for on-orbit servicing. In order to assure the task is accomplished successfully, ground experimentations are required for the verification of the planning and control algorithms of space robotic system before it is launched. In this paper, a new experiment concept is proposed, which is a hybrid approach, i.e. it combines the mathematical model with the physical model. The key issues of the concept are dynamic emulation and kinematic equivalence. Dynamic emulation means that the behaviors of the whole space system, including space manipulator, its base and the target, are emulated by the precise dynamic equations. Kinematic equivalence means that the end-effector motion of the space manipulator is realized by the lab robot. Based on the concept, a ground experiment system is set up, which is composed of two industrial robots, two hand-eye cameras, a set of global visual system and a real-time 3D simulation system. Using the system, some key technologies are verified. Firstly, the motion prediction technology of unknown target is studied. The target may move in various modes, such as free-floating, tumbling, and so on. With the measurement of the han-eye cameras, extended Kalman filter is used to estimate the motion of the target. Then, different visual servo control technologies are researched, which include position-based, image-based and 2.5D visual servoing technology. Many experiments are used to compare and evaluate their own advantages and disadvantages. Futhermore, tele-operate technology under large time-delay is also tested by adding the tele-operating devices. After a lot of experiments, the corresponding algorithm are evaluated and then improved.

6555-51, Session 12

A novel method for testing kinematic accuracy of a space manipulator based on electronic theodolite and simulation testing

H. Sun, Y. Tan, Q. Jia, Beijing Univ. of Posts and Telecommunications (China)

Based on an electronic theodolite, a novel method for testing the kinematic accuracy of a space manipulator is developed. The method is used to identify the pose accuracy of a 6-DOF space manipulator depending upon the electronic thedolite, the result of which is compared with the result tested by a laser tracking apparatus, the maximum difference between them are less than 1mm, which shows that this method is feasible.

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6556-01, Session 1

Complex MEMS device: microshutter array system

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A complex MEMS device, microshutter array system, is being developed at NASA Goddard Space Flight Center for use as an aperture array for a Near-Infrared Spectrometer (NirSpec). The instrument will be carried on the James Webb Space Telescope (JWST), the next generation of space telescope after Hubble Space Telescope retires. The microshutter arrays are designed for the selective transmission of light with high efficiency and high contrast. Arrays are close-packed silicon nitride membranes with a pixel size close to 100x200 * m. Individual shutters are patterned with a torsion flexure permitting shutters to open 90 degrees with a minimized mechanical stress concentration. Light shields are made on to each shutter for light leak prevention so to enhance optical contrast. Shutters are actuated magnetically, latched and addressed electrostatically. The shutter arrays are fabricated using MEMS bulk-micromachining technologies and packaged using single-sided indium flip-chip bonding technology. The MSA flight concept consists of a mosaic of 2 x 2 format of four fully addressable 365 x 171 arrays placed in the JWST optical path at the focal plane.

6556-02, Session 1

MEMS and microsystems: future tools for nanodevices

R. Ghodssi, Univ. of Maryland/College Park

Materials technology and process integration are the key enabling tools for novel advances in MEMS and Microsystems for future nano-scale devices and applications. In this talk, I present an overview of the various building block materials and process technologies developed in our group, MEMS Sensors and Actuators Lab (MSAL), at the University of Maryland to address this exciting and diverse goal. First, the use of InP as an attractive monolithic integrative material for all-optical switching applications is described through micro-actuators for sensing nano-scale particles. Next, the challenges involved in developing a precision and batch fabricated 3-D micromachining technology in silicon by way of gray-scale lithography and deep reactive ion etching (DRIE) are presented. This powerful microfabrication technique is now enabling the development of next generation 3-D micro-scale devices for gas delivery and sensing. Finally, selective deposition of the biopolymer chitosan as an interface between organic and inorganic materials is proved to be versatile and robust for biofabrication of optical and micro-mechanical sensors in a micro-fluidic environment for biomolecular reactions and cell-based sensing.

6556-03, Session 1

Micropolarizer arrays in the MWIR for snapshot-polarimetric imaging

S. A. Kemme, A. Cruz-Cabrera, P. Nandy, R. R. Boye, J. Wendt, Sandia National Labs.; T. Carter, S. Samora, L&M Technologies, Inc.

We report on the design, fabrication, and simulation of a four-state pixelated subwavelength optical device that enables mid-wave infrared (MWIR) or long-wave infrared (LWIR) snapshot polarimetric imaging. The polarization information can help to classify imaged materials and identify objects of interest for remote sensing and military applications. Traditionally, sequential polarimetric imaging sensors produce scenes with polarization information through a series of assembled images. Snapshot polarimetric imaging collects the spatial distribution of all four Stokes' parameters simultaneously. In this way any noise due to scene movement from one frame to the next is eliminated.

In this presentation, we will quantify near-field and diffractive effects of the finite pixel apertures upon detection. We have designed and built an experimental setup that models a pixel within a focal plane array (FPA) to measure crosstalk from adjacent gold wiregrid micropolarizers. This configuration simulates a snapshot polarization imaging device where the two substrates are stacked; micropolarizer array substrate on top of an FPA. Modeling and measured data indicate crosstalk between the adjacent pixels even after a few microns behind the polarizer plane. Crosstalk between adjacent pixels increases uncertainty in the measured polarization states in a scene of interest. Measured and simulated data confirm that the extinction ratio of a micropolarizer pixel in a super-cell will be reduced by 17% when moving the FPA from only 0.5 microns to 1.0 microns away from the polarizer. These changes in extinction ratio are quite significant since typical glue separation is on the order of 10 microns.

6556-04, Session 1

Distributed intelligence and cooperative monitoring for sensor networks in space applications

Y. Wen, A. Agogino, Univ. of California/Berkeley

Massive deployment of miniature sensors with integrated microcontrollers and communicational capabilities is being facilitated by the progress of MEMS (Micro-Electromechanical Systems) technologies. The small sizes of the sensors enable localizing detection that is suitable for application such as health monitoring of space shuttles or carriers to provide early warnings and prevent catastrophes in space missions. The integrated microcontrollers make in situ processing possible, and the communicating capacities further allow cooperation among distributed sensor nodes.

A cooperative monitoring mechanism for sensor networks incorporating distributed intelligence and comparative analysis of sensors is described in this paper. Three hierarchical layers are processed and analyzed for locating abnormalities: single sensor nodes, local cluster of sensors and the entire (global) sensor network. Each sensor node is made intelligent by monitoring its own reliability, adjusting the sensing resolution dynamically upon irregular events, and determining its computational and communicating responsibilities under a probability framework. The readings from each sensor are fused locally and globally using a fuzzy rule-based algorithm. The local fusion is carried out by optimally elected sensor nodes in each local cluster, while the global fusion is executed on a central data aggregation unit with higher computational power. As the irregular minority will be either rejected or lightly weighted in global fused value, the comparison between local and global fused values reveals the location of any potential problematic spots. The mechanism is verified on a small scaled sensor network composed of “smart dust motes” that simulates the detection of the local raise of temperature (referred to as a hot spot) on the space shuttle surface insulating materials.

6556-05, Session 1

Piezoelectric micropower generation devices for autonomous remote sensor systems

D. Kim, D. Shen, J. Park, S. H. Yoon, J. Ajitsaria, S. Choe, Auburn Univ.

Current development of sensor technology continues to push past boundaries of integration and functional density toward completely autonomous, self-powered remote sensor systems. To be truly autonomous, sensor will need on-board, renewable power supplies.

One way of supply such power is through power scavenging from ambient mechanical vibrations to electricity by straining a piezoelectric material. We studied piezoelectric devices to achieve maximum efficiency of power conversion under various environments. Two factors are focused; 1) developing optimal structures and materials and 2) highly efficient electrical circuits to store and deliver the generated charge. Three types of bulk scale piezoelectric materials such as ceramic PZT, polymer PVDF, and micro-fiber composite were utilized for demonstration and modeling. Resonating characteristics, power generation, and mechanical failure of devices were simulated using numerical analysis and finite element analysis (ANSYS) and tested experimentally. A high-efficiency electronic converter interface was developed to achieve maximum power transfer from various vibration patterns including irregular and random bursts. The circuit consisting of an ac-dc rectifier, a storage unit, and dc-dc converter components is designed and simulated by using MATLAB Simulink. With the developed modeling and circuit simulation, MEMS scale devices have been fabricated by using PZT films. Prototypes of miniaturized generators integrated with optimized electronic circuit are demonstrated.

6556-06, Session 1

A high-performance MEMS time-of-flight mass spectrometer for investigations in planetary astrobiology

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NASA's scientific interest in the characterization of the solar system and biomarker detection is driving the development of a high performance MEMS time-of-flight (TOF) mass spectrometer. Space flight exploration may be enhanced through miniaturization by means of reduced mass, volume, power requirements, and instrument redundancy enabled using MEMS and nano scale technologies. Until recently TOF mass spectrometry has been limited to large detection distances, thus making miniaturization impractical. However, TOF system miniaturization may be realized through the increased detection capabilities available from modern computing speeds, coupled with MEMS and nanotechnology components. A systems level approach to the development of a miniaturized TOF mass spectrometer will be presented based on the recent efforts at NASA Goddard Space Flight Center. System design and protoype, MEMS silicon ion sources, a carbon nanotube electron gun, and sample delivery systems will be discussed, as well as relevant applications.

6556-07, Session 2

Micro-actuators for wavefront correction

E. Yang, Stevens Institute of Technology

Active wavefront control is required subsequent to reflection from the primary mirror, particularly to overcome the potentially large spatial frequency errors anticipated with Gossamer type structures. Development of new, low-mass technologies is essential for wavefront correction for next generation optical instruments in Space. Linear actuators are required to provide the fine shape correction of primary apertures for future space telescopes. There is considerable incentive to develop miniaturized actuators. Linear microactuator technology with large linear motion has been demonstrated, and a continuous membrane deformable mirror (DM) with a large-stroke piezoelectric unimorph actuator array has been developed for this purpose. A PZT unimorph actuator showed a deflection of 5.7 microns * at 20 V. An assembled DM showed an operating frequency bandwidth of 30 kHz and influence function of approximately 30 %.

6556-08, Session 2

MEMS deformable mirror optical limiter for dynamic range compression deconvolution

J. Khoury, C. L. Woods, Air Force Research Lab.; B. Haji-Saeed, S. K. Sengupta, W. D. Goodhue, Univ. of Massachusetts/Lowell; J. Kierstead, Solid State Scientific Corp.

In this paper, for the first time Dynamic Range Compression Deconvolution using our new designed nonlinear optical limiter Micro-Electro-Mechanical-System (NOLMEMS) device is proposed. The NOLMEMS utilizes aperturized reflected coherent light from optically addressed deformable mirrors, deformed in a parabolic shape, which is collimated by an array of micro-lenses. The reflected light saturate as a function of optical drive intensity. In this scheme, a joint image of the blurred input information and the blur impulse response is captured and sent to a spatial light modulator (SLM). The joint information on the SML is read through a laser beam and is Fourier transformed via a lens to the back of the NOLMEMS device. The output from the NOLMEMS is Fourier transformed to produce the restored image. We derived the input-output nonlinear transfer function of our NOLMEMS device that relates the transmitted light from the pinhole as a function of the light intensity incident on the back side of the device, which shows a saturation dependency. We also analyzed the deconvolution orders for this device using a nonlinear transform method. The computer simulation of image deconvolution by the NOLMEMS device is also provided and demonstrated.

6556-09, Session 2

Optically addressed, spring-patterned, membrane mirror MEMS with MegaHertz response

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In this paper the fabrication, modeling and characterization of an all optically addressed spring patterned silicon-nitride deformable mirror Micro-Electro-Mechanical-Systems (MEMS) device is reported. This device is biased through combinations of high frequency AC and DC voltages. The experimentally verified theoretical modeling for this device shows mirror deflection saturation as a function of light intensity appropriate for dynamic range compression deconvolution. The spring MEMS device has an advantage over conventional deformable mirror devices such as segmented independently actuated rigid mirrors and membrane mirrors with multiple actuators. The conventional deformable mirrors are generally bulky, and their response time is in the millisecond range. This limits their performance to applications in correcting slow aberrations such as atmospheric turbulence. In contrast to these devices, the spring MEMS deformable mirror device has response up to 10 MHz, which opens the possibility of correcting atmospheric turbulence as well as supersonic turbulence.

6556-10, Session 2

Active imaging systems using MEMS mirrors

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MEMS mirrors are becoming increasing capable as design and electronics development continues to improve device performance and reduce fabrication costs. The recent fabrication of larger stroke devices (i.e. greater than 25 * m) has significantly increased the number of potential applications. These devices are currently being integrated in imaging applications in order to improve the performance and flexibility of the system while simultaneously reducing the size and weight compared to a conventional system. We will present recent progress at Sandia National Laboratories in developing foveated imaging and active optical (aka nonmechanical) zoom using large stroke MEMS mirrors.

6556-11, Session 3

Lab-on-a-chip biochemical sensing system based on the liquid core optical ring resonator

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The liquid core optical ring resonator (LCORR) sensor is a newly developed capillary-based ring resonator that integrates microfluidics with photonic sensing technology. The circular cross-section of the capillary forms a ring resonator that supports whispering gallery modes (WGM), which interact with the sample as it passes through the capillary. As in previous ring resonator sensor implementations, the interaction between the WGM evanescent field and the sample enables label-free detection.

With a prototype of an LCORR sensor, we have achieved a refractive index detection limit of 10-6 RIU and a detection limit for protein of 10 pg/mm2. Several engineering developments have been accomplished as well, including a thermal noise characterization, a thermal stabilization implementation, integration of the LCORR with an anti-resonant reflecting optical waveguide array, and electro-kinetic sample delivery. In the near future, the LCORR will be integrated into a dense 2-dimensional sensing array by integrating multiple capillaries with a chip-based waveguide array. This lab-on-a-chip sensing system will have a number of applications, including environmental sensing for defense purposes, disease diagnostics for medical purposes, and as a lab tool for analytical chemistry and molecular analysis.

6556-12, Session 3

A novel chemical and biological fiber optic sensor

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Effective response to potentially dangerous environmental situations that can arise requires accurate and real time data on the environment that is being monitored. The ability to respond in an appropriate time frame is determined by the sensitivity and response time of the method used for monitoring. Fiber optic sensors have been used and are capable of detecting chemical compounds within an environment, however the sensitivity and response time of this detection method needs to be improved for many sensing applications. Improving these characteristics can be accomplished by developing an optical fiber sensor with different structures. Through the introduction of new structures and control of these structures, the sensitivity and response time can be designed for a specific application. We have developed a novel porous fiber optic that has potential applications in chemical and biological agent sensing systems. Sensing capabilities of the optical fiber are a result of the structure that is designed into the fiber. The structure of the fiber is described as are the characterization of the fiber and the characterization methods used. Methods used to describe this new fiber optic sensor include nitrogen absorption porosity data, scanning electron microscopy and optical microscopy, and optical characterizations. The structure of the optical fiber is produced by utilizing specific manufacturing and processing methods. Fabrication methods and the processing steps that are used during the fiber optic production are also presented. Effect of altering processing conditions on the sensor structure is detailed and how this affects the performance of the fiber.

6556-13, Session 3

Evanescent optical fluorescence excitation: the role of photonic mode density

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There is a growing nano technological demand for thin film preparations especially in the polymeric materials area, e.g. as thin lubricating, isolation or protective coatings, for integrated or nonlinear optic devices, or to increase the biocompatibility of inorganic materials. This has stimulated the development of novel optical techniques with increased sensitivity, specificity and spatial resolution. For interfacial properties and thin film samples, the use of evanescent optics has proved in recent years to be particularly helpful. This is because of their high surface specificity, which allows sensitive monitoring of the properties of the interfaces and thin layers without the interference of information from the bulk. In this paper we discuss a few basic concepts concerning to the use of the evanescent optical fields for the excitation of fluorescent chromophores placed near the interface. The observation of enhanced fluorescence from chromophores excited by surface and waveguide modes will be presented and discussed. We attribute the enhancement to the near-field interaction between the chromophores and the photonic mode density of surface and waveguide modes. The importance of sensor configurations in providing large changes in photonic mode density is highlighted. Furthermore we report on the development of a Micro Opto Electro Mechanical System (MOEMS) for the detection of surface plasmon resonance with a high potential for integration in system-on-a-chip technology.

6556-14, Session 3

High-speed nano-optical photodetector for free space communication

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An inexpensive, easily integrated, sensitive photoreceiver operating in the communications band with a 50-GHz bandwidth would revolutionize the free-space communication industry. While generation of 50-GHz carrier AM or FM signals is not difficult, its reception and heterodyning require specific, known technologies, generally based on silicon semiconductors. We present a 50 GHz photoreceiver that exceeds the capabilities of current devices. The proposed photoreceiver is based on a technology we call Nanodust. This new technology enables nano-optical photodetectors to be directly embedded in silicon matrices, or into CMOS reception/heterodyning circuit. Photoreceivers based on Nanodust technology can be designed to operate in any spectral region, the most important to date being the telecommunications band near 1.55 micrometers. Unlike current photodetectors that operate in this spectral region, Nanodust photodetectors can be directly integrated with standard CMOS and silicon-based circuitry. Nanodust technology lends itself well to normal-incidence signal reception, significantly increasing the reception area without compromising the bandwidth. Preliminary experiments have demonstrated a free-space responsivity of 50 µA/(W/cm2), nearly an order of magnitude greater than that offered by current 50-GHz detectors. We expect to increase the Nanodust responsivity by at least another order of magnitude in upcoming experiments.

6556-15, Session 3

Integrated optical microring for high-resolution refractive index and pressure sensing applications

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Whispering-gallery mode (WGM) resonators such as microspheres, microcylinders, and microrings have been proposed for telecommunication and sensing applications for decades. However, several challenges, such as the robustness of the optical coupling and sample delivery means, were often found in the path of developing them for the real world sensing applications. In this paper, a robust microring platform based on integrated lightwave circuit technology and a tunable diode interrogation system has been demonstrated as high-resolution refractive index and pressure measurement system. By using a ring with Q factor of about 14,000, a refractive index sensitivity of about 190 nm/RIU and 350 nm/RIU for two different polarization modes and detection limit on the order of 10-7 RIU have been demonstrated. For the high-pressure measurement applications, a pressure resolution of 2 ppm at 10,000 psia has been achieved. The tested microring remained functioning at a hydraulic pressure up to 30,000 psia.

6556-16, Session 3

Optical micro- and nanofibers for sensing applications

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An optical microfiber (MF) is usually fabricated by drawing a conventional optical fiber down to the diameter of ~ 1 micron. A MF with the diameter significantly less than one micron is often called a nanofiber. This paper considers optical MF/nanofiber sensors, which detect changes in the ambient medium by monitoring changes in transmission power of light propagating along the MF. The MF represents a waist of a biconical fiber taper connected to a light source at one end and to an optical spectrum analyzer or a power meter at the other one. An electromagnetic field mode supported by a MF has an evanescent part, which is distributed outside the MF. The evanescent part may be very sensitive to changes at or near the surface of the MF. The performance of the MF sensor can be either (a) not based or (b) based on the interaction of the ambient medium with the evanescent field. First, the sensors of group (a) are briefly discussed. These sensors are MF devices, which transmission characteristics vary due to changes in optical and/or geometrical properties of the MF itself and/or of the propagating mode inside the MF. The changes of this kind can be caused by the outside radiation heating the MF, ambient temperature, mechanical vibration, etc. An example of the first group of sensors is a MF loop resonator, which can be used as a fast direct contact temperature sensor [1] and also as an infrared radiation sensor. Next, sensors of group (b) are considered. The simplest of them is a MF, which detects changes at a cylindrical surface of an optical fiber [2]. Generally, performance of these sensors depends on the structure of evanescent field of micro- and nanotapers. This structure is investigated herein using the recently developed theory [3] and numerical simulations. The calculated dependencies of the transmission power of a nanotaper are in a good agreement with the experimental data. Also, the MF sensor of group (b), which supports more than one mode, is considered theoretically and experimentally. This sensor detects ambient changes with the evanescent field of a higher order mode, which couples to the fundamental mode.

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6556-17, Session 4

Optimal self-referenced sensing with long- and short-range surface plasmons

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Surface plasmon resonance (SPR) sensors are widely used to study biological and chemical interactions. As a result, they have defense and security applications in the detection of agents ranging from small molecules to bacterial pathogens. Because SPR sensors rely on refractive index transduction, standard sensors cannot differentiate between bulk index changes in the analyte and surface binding reactions of interest. As a result, several techniques have been proposed to provide reference measurements that compensate for interfering effects. However, these approaches rely on the interrogation of a separate reference region, often require duplicate readout systems, and can be difficult to calibrate.

Recently, our group and others have investigated the simultaneous excitation of two surface plasmon waves, the so called long-range and short-range surface plasmons, to differentiate surface and bulk effects. The fields of the two waves penetrate to different depths in the analyte and thus exhibit different sensitivities to bulk and surface refractive index changes. This approach is advantageous because the two surface-plasmons propagate over the same sensor region and can be interrogated at different wavelengths using a single readout system. Here we describe the optimization of these sensors for both surface and bulk limits of detection, and we discuss an approach to non-linear calibration and data analysis that allows quantitative measurements over a broader range of bulk refractive indices. The performance of these sensors is demonstrated by monitoring alkane-thiol self-assembled monolayer formation while varying solvent refractive index and by monitoring streptavidin-biotin binding while varying buffer refractive index.

6556-18, Session 4

Photonic transduction for microcantilever sensor arrays

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Microcantilevers show significant promise in sensing minute quantities of chemical and biological analytes in vapor and liquid media. Much of the reported work on microcantilever sensors has made use of single functionalized microcantilevers, usually derived from commercially available atomic force microscope (AFM) cantilevers. However, arrays with hundreds to thousands of microcantilevers on a single chip are required to create sophisticated, broad spectrum chemical and biological sensors in which individual microcantilevers have different bio- or chemoselective coatings. Unfortunately, the most sensitive microcantilever readout mechanisms (such as laser beam reflection as used in atomic force microscopy) are not readily scalable to large arrays. We therefore introduce a new microcantilever transduction mechanism for silicon-on-insulator (SOI) microcantilevers that is designed to scale to large arrays while maintaining a very compact form factor and high sensitivity. This mechanism is based on in-plane photonic transduction of microcantilever deflection in which the microcantilever itself forms a single mode rib waveguide. Light from the end of the microcantilever is directed across a small gap to an asymmetric receiving waveguide with two outputs that enables differential detection of microcantilever deflection. Fiber input and output with compact waveguide bend and splitter arrays are needed to route light to and from the microcantilever array. Initial noise and optical power budget calculations indicate that deflection sensitivities in the 10’s of picometer range should be achievable.

6556-19, Session 4

Microfluidic device detection of waterborne pathogens through static light scattering of latex immunoagglutination using proximity optical fibers

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There have been many cases of accidental outbreaks of waterborne pathogens in drinking water or irrigation system. More recently, concerns have been raised on the use of bacteria/viruses as an act of terrorism. These issues have compelled public health agencies to develop new methods of early surveillance to water-related facilities. Current available methods involve the growth of pathogens in culture media in an analysis laboratory remote from the point of use, which is not real time and not fully automated. Microfluidic device is expected to overcome all of these complications, although it has been used relatively rarely in water studies. The most recent attempts include the methods based on DNA/RNA detection or antibody-based ELISA, which still requires substantial amount of human labor, such as cell lysing, incubation, rinsing, etc. We propose to use latex immunoagglutination as fully-automated, one-step detection method. However simple it appears to be, latex immunoagglutination in a microfluidic device has not been demonstrated properly, because (1) agglutinated particles could not be mixed efficiently in a microchannel (strict laminar flow) and (2) non-specific binding led to many false-positive readings. We have resolved these problems by using highly carboxylated submicron particles without surfactant to enhance diffusion as well as suppress non-specific bindings. Immunoagglutination was quantified on the view cell of a microfluidic device, by either microscope imaging or static light scattering using proximity optical fibers. All detections could be made within 5 min, and the devices were reusable. The level of detection (LOD) was 50 ng/mL for antibodies and 150 cfu/mL for E. coli K-12 (compared with the conventional culturing method). Same LOD was achieved in the realistic water sample, i.e., pond water, without any culturing, filtering, or concentrating. Multiple pathogens will be detected in a single channel using various quantum dots conjugated to the above submicron particles.

6556-20, Session 4

Small form factor microsensor system using optical MEMS for passive optical digital communication (PODC)

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A small form factor microsensor system with optical MEMS devices will be discussed in this paper. The key components in the microsensor system include a temperature and humidity sensor for environmental monitoring, a micro processor for signal processing, and an optical MEMS device (active corner cube retroreflector or CCR) for remote free space optical communication. A flexible circuit design and a folded packaging scheme have been utilized to minimize the overall form factor. A flat, flexible polymer battery is incorporated to minimize the vertical profile to a few millimeters. The entire fully packaged sensor system is about 30Å~30Å~6 mm3. MEMS design of the CCR, fabrication, hermetic packaging of CCR, flexible circuit design and fabrication, flip chip bonding of die form micro processor, and a battery replacement scheme for extended operation life time are crucial elements for the development of a real product for the microsensor system. Optical MEMS CCR is a torsional mirror design and was fabricated using surface micromachining with Si3N4 as structural layer. A finite element analysis (FEA) model was developed to optimize design and performance of the MEMS structures. The sensor system has a micro mechanical switch for local actuation and an optical switch for remote actuation. The applications of such a microsensor system include both tracking, tagging, locating (TTL) and remote sensing.

6556-21, Session 4

Research of spacing stability of tunable F-P filter in ICF facility

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At the fore-end of 9th laser system of ShenGuang II facility, the tunable F-P filter is adopted to dynamically compensate the FM-AM effect in Inertial Confinement Fusion (ICF) facility, the compensation range of spectral bandwidth is determined by the spacing between two parallel glass plates of tunable F-P filter. One glass plate is fixed, and the other mounted on the micro-displacement stage driven by piezoelectric actuators. Owing to inherent hysteresis and creep of piezoelectric ceramic, the spacing between parallel plates undergoes changes slowly with the elapsed time, so that the stability becomes deteriorative, and consequently impacts the dynamic compensation functions of tunable F-P filter.

This paper brings forward a precise monitor system to stabilize the spacing of tunable F-P filter. The monitor system consists of capacitive displacement sensor system and displacement control system, capacitive displacement sensor provides feedback signals for close-loop control, which detects the actual displacement between the parallel plates of F-P filter, displacement deviation can be obtained through the comparison between the actual displacement and the given one with the help of computer. Digital PID control algorithm is applied to calculate the displacement deviation and obtain the driving voltage that piezoelectric actuators need. According to the discrepancy, piezoelectric actuators drive micro-displacement stage to move and accordingly alter the spacing of F-P filter to initial value, consequently realize close-loop displacement control of spacing, and eventually accomplish the functions of dynamic compensation to FM-AM effect.

6556-22, Session 5

Nanolithography of metal catalysts using dip pen nanolithography (DPN(tm))

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DPN(tm) is a versatile technology that leverages microfluidic ink delivery systems with Scanning Probe Microscopy. DPN applications are emerging in biotechnology, brand protection, photo-mask repair, molecular electronics, nano-electronics and mask-less lithography. DPN techniques have been extensively used for deposition of metals and alloys. Metal salts or mixture of metal salts (e.g., PdCl2, PtCl2) can be deposited by DPN process in nano-arrays. Following the deposition step - the metals salts can be reduced to their pure metallic state by various techniques. Metal salts of noble metals (e.g., Pd, Pt) can be reduced to elemental metals by heating the deposited pattern to their decomposition temperatures in an inert atmosphere (e.g., N2 or Ar atmosphere) under ambient pressure. In an alternate method, metal salts can also be heated in a reducing atmosphere (e.g., by passing H2) to obtain metal nano-arrays at ambient pressure.

DPN techniques were used for controlled deposition of catalysts of different compositions (e.g., Ni/Co, Pd/Rh, Pt/Rh, Pt, Pd, Fe, Ni, etc.) on a flat substrate. The DPN process enabled the combinatorial nano-patterning of catalysts with different compositions. The catalysts were characterized using different techniques (e.g., STM, XPS, etc.).

6556-23, Session 5

Dip pen nanolithography(tm): a maturing technology for high-throughput flexible nanopatterning

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Precision nanoscale deposition is a fundamental requirement for much of current nanoscience research. Further, depositing a wide range of materials as nanoscale features onto diverse surfaces is a challenging requirement for nanoscale processing systems. As a high resolution scanning probe-based direct-write technology, Dip Pen Nanolithography(tm) (DPN(r)) satisfies and exceeds these fundamental requirements. Herein we review recent advances in large area patterning with two-dimensional probe arrays, Active Pen(tm) individually actuated cantilevers, and microfluidic ink delivery.

Relative to other nanopatterning techniques, DPN is a direct-write technique maintaining high resolution (14 nm line widths, 20 nm pitches), and among sub-50 nm techniques, DPN is the only one that can directly deposit molecules under ambient conditions. In addition, because NanoInk's nanolithography platform - the NSCRIPTOR(tm) - is based on scanning probe microscopy (SPM) technology, it is inherently capable of both pattern fabrication and immediate verification of the result by imaging.

NanoInk's new 2D nano PrintArrays(tm) enable massively parallel nanoscale deposition with 55,000 pens, and point to breakthrough applications in high-throughput, flexible nanopatterning. DPN is fundamentally a bottom up nanoscale deposition technique (i.e., templated assembly for biological detection or nanotube attachment); however, direct-write with etch resist "inks" leads to a powerful form of top down nanofabrication (i.e., creating nanoscale metallic or solid state structures). These two-dimensional probe arrays are capable of covering a square centimeter with nanoscale features at a rate of 10^7 µm^2 per hour.

Further, researchers have demonstrated nanoscale site-specific placement of single biomolecules (TMV virus, Influenza A, and HIV) on MHA templates, maintaining almost 100% bioactivity. In addition to suggesting novel methods for studying the effectiveness of new drugs and delivery techniques, this technology allows users to routinely pattern libraries of small molecules over very large areas, and realistically practice single cell experimentation.

6556-24, Session 5

Nanopatterning of metals by scanning probe lithography

J. D. Batteas, Texas A&M Univ.

The ability to readily fabricate nanoscale metallic features and contacts would enable numerous applications including molecular electronic and sensing architectures as well as plasmonic devices. Several approaches have been developed in recent years for the patterning of nanoscale metal structures using variations adaptations of scanned probe lithography (SPL). In this paper current approaches for fabricating nanoscale metals structures by SPL are outlined along with the challenges for fabricating such structures by SPL and methods for controlling feature growth and fidelity. Here we will illustrate patterning of metal features using a combination of scanning probe lithography and electroless metal deposition on surfaces for controlled placement of metal nanostructures on surfaces.

6556-25, Session 5

Method of matrix alignment for nanostructure lithography

A. U. Sokolnikov, Visual Solutions and Applications

Nanoimprint is an emerging lithographic technology that promises high throughput patterning of nanostructures. Based on the mechanical embossing principle, nanoprint technology can achieve pattern resolutions beyond the limitations set by the light diffraction or beam scattering in other conventional techniques. The difficulty arises with the exact 90 degree setting of the mould above the wafer. Proposed is the method of achieving this perpendicularity by the means of the crystallographic properties of Si or GaAs and the matrix made of the above materials.

6556-26, Session 6

How diffusion causes problems for nanotechnology (and how to overcome them)

P. E. Sheehan, Naval Research Lab.

Diffusion plays a crucial role in the creation, operation, and decomposition of nanometer scale structures. We will look at two research areas where diffusion dominates device performance—soft nanolithography and nanobiosensors. Soft nanolithographies such a Dip Pen Nanolithography and micro Contact Printing use diffusion to transport material to the substrate and to control feature size. By modeling diffusion in these systems, we can obtain greater control over deposition and gain insights into improving resolution. Out of these insights evolved a new method for controlling deposition, Thermal Dip Pen Nanolithography. By carefully controlling the diffusion of the deposited ink, this technique can rapidly deposit highly-ordered nanostructures with monolayer by monolayer control. This technique is being developed for the rapid prototyping of electronic circuits. Secondly, nanometer scale biosensors have recently been of intense interest. However, the low diffusivity of biomolecules and the new smaller sensors mean that very little analyte arrives at the sensor. We examine the common situation where both the diffusivity and the concentration of an analyte are low (e.g., unamplified DNA in buffer) and show that for a single nanoscale sensor diffusive flux alone will be insufficient to make it useful on a reasonable time scale. Analytic solutions for several sensor configurations will be presented as well as simulations for more complex situations such as laminar flow. Finally, different strategies for increasing the flux will be presented along with their relative advantages and disadvantages.

6556-27, Session 6

Dip pen nanolithography theory and directed-assembly based nanomanufacturing processes

S. Hong, Seoul National Univ. (South Korea)

Dip-pen nanolithography (DPN) utilizes an atomic force microscope tip as a ‘pen’ to directly deposit virtually general soft materials onto solid substrates to create nanoscale patterns. DPN has been utilized for various applications including solid materials patterning, nanoscale biochip fabrication, etc. However, the basic mechanism of DPN was not fully understood yet. This presentation will discuss how we can model the basic and anomalous behaviors of DPN. Furthermore, we will explain how ‘directed-assembly’ strategy combined with ‘direct deposition’ methods such as DPN can be utilized as a ‘quick and cheap’ nanomanufacturing process for nanodevice fabrication.

6556-28, Session 6

Investigating the conducting polymer micropattern sensor arrays enerated using intermediate-layer lithography

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Conducting polymers have received much attention since their discovery in 1977. Applications of conducting polymer microsystems span from electronic devices to sensors. Traditional sensors had one-to-one correspondence between the detector and the target. Multiple conducting polymer micropattern arrays on a common substrate, when used for sensing, can effectively broaden the scope of a sensor. The Intermediate-Layer lithography (ILL) technique was developed to generate multiple conducting polymer micropatterns, of desired dimensions on a common substrate. In this method, the sizes of the micropatterns can be scaled down effectively. Compared to films, micropatterns exhibited higher sensitivity at lower analyte concentrations. Also, the response of film sensors was not accurate when the conducting polymer film was partially covered, indicating that rare concentrations of analytes would be difficult to detect using the conventional conducting polymer film sensors. In the current work, conducting polymer micropatterns of varying dimensions have been fabricated using the ILL method and tested for their responses to organic vapors at low concentrations. The relationship between the surface-to-volume ratios of the micropatterns and their corresponding sensitivities is found for various target concentrations. The research results would provide insights regarding optimization of the micropattern sensors for maximizing their sensitivities.

6556-29, Session 6

Generation of conducting polymer-based diodes and capacitors using intermediate-layer lithography

X. Liu, A. Chakraborty, C. Luo, Louisiana Tech Univ.

Conducting polymer based diodes and capacitors have been generated in this work using an intermediate-layer lithography (ILL) approach which has recently been developed in our group. Compared with Si-based devices, conducting polymer based microelectronic devices have distinctive advantages of low weight and good flexibility, and may potentially replace the corresponding Si-based devices. A challenge is how to fabricate conducting polymer based microsystems. Most conducting polymers are sensitive to the environment, and their electrical properties tend to deteriorate over time due to overoxidation (air), moisture, high temperature and chemical alteration. The current fabrication techniques (i.e., lift-off, dry and wet etching processes) used in lithographic approaches, such as ultra-violet, electron-beam, and x-ray, involve gases (for instance, oxygen and nitrogen), DI water, and/or chemical solution (such as photoresist and acetone), making them improper to pattern conducting polymers.

Since the ILL method does not involve aggressive chemistry in generation of patterns, it has bee employed in this work to fabricate conducting polymer based microdevices, particularly diodes and capacitors. In fabrication of the devices, multiple layers of metals (e.g., Al) and polymers (e.g., PPy and PEDOT) are coated in a PMMA sheet followed by the patterning through the insertion of Si molds. The detailed fabrication procedure and test results will be given in the paper.

6556-30, Session 6

Using dip pen nanolithography and nanografting as tools for directing the assembly of macromolecular scaffolds

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Both dip-pen nanolithography and nanografting can be used to chemically pattern surfaces at length scales commensurate with the dimensions of many viruses. The latter have recently gained attention amongst materials scientists because they can be site-specifically modified to present catalytic, electronic, and optically active moieties or bind to semiconductor and metal nanoparticles. Thus they can serve as building blocks for fabricating hierarchical structures with near-molecular density of functionality, provided their assembly can be directed. Here we report results using scanned probe nanolithography (SPN) to create chemical templates that direct organization of viruses at surfaces.

As model systems, we have chosen near-spherical Cowpea Mosaic Virus (CPMV), wire-like M13 bacteriophage, and disk-shaped capsids of Tobacco Mosaic Virus (TMV). These have been modified to bind specifically to self-assembled monolayers (SAMs) deposited by SPN. For example, CPMV was engineered to present either cysteine (Cys) or histidine (His) tags at the capsid apices in order to bind them to alkyl thiol SAMs terminated by maleimide (MA) or nickel-chelating nitrilotriacetic acid (Ni-NTA) respectively and deposited on atomically flat gold substrates. Template features had sizes ranging from 10-100nm. AFM was used to investigate the degree of ordering, packing geometry, assembly kinetics, and cluster-size distribution.

We show that the assembly morphology depends on all parameters chosen: surface chemistry (mobility), virus concentration (flux), and solution PEG concentration (inter-viral potential). In the case of CPMV, as the virus-virus attraction is increased through introduction of hydrophobic effects, 2D arrays of viruses evolve from poorly-ordered, to well-ordered rhombohedral, and then hexagonally close packed assemblies and 1D patterns increase from single to multiple rows of viruses in width. Taking cues from previous work on both epitaxial and colloidal systems, we present a physical picture of virus assembly at templates which combines the nucleation kinetics of epitaxial systems with the thermodynamics of colloidal condensation.

6556-31, Session 7

Tier-scalable reconnaissance: the challenge of sensor optimization, sensor deployment, sensor fusion, and sensor interoperability

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Robotic reconnaissance operations are called for in extreme environments such as space, including planetary atmospheres, surfaces, and subsurfaces, as well as in potentially hazardous or inaccessible operational areas on Earth such as mine fields, enemy occupied territories, terrorist infiltrated environments, or areas that have been exposed to bio-chemical agents or radiation. Real time reconnaissance enables identification and characterization of transient events. A fundamentally new mission concept for tier-scalable reconnaissance of operational areas recently has been devised (Fink et al., Planetary and Space Science, 53, 1419-1426, 2005; see also http://autonomy.caltech.edu/autonomy/tierscalable.html) that is aimed at replacing engineering and safety constrained mission designs of the past. The tier-scalable paradigm integrates multi-tier (orbit <=\> atmosphere <=\> surface/subsurface) and multi-agent (satellite(s) <=\> UAVs/blimps <=\> ground agents/sensors) hierarchical mission architectures, not only introducing mission redundancy and safety, but enabling and optimizing intelligent, unconstrained, and distributed reconnaissance in real time. To support such mission architectures, a high degree of operation autonomy is required. Essential requirements of such operation autonomy are: (1) automatic mapping of an operational area from different vantage points (including vehicle health monitoring); (2) automatic feature extraction and target/region-of-interest identification within the mapped operational area (e.g., Fink, et al., Geochimica et Cosmochimica Acta, Vol. 69, Number 10S, A535, 2005); and (3) automatic target prioritization for close-up examination (e.g., Fink, Proceedings IEEE WCCI 2006, Vancouver, Canada, 11116-11119). These requirements imply the optimal deployment of sensors (sensor platforms), sensor fusion, and sensor interoperability. Moreover, the design and performance of the individual (MEMS) sensor may/should be subject to an (evolutionary) optimization process both before and during a mission. The Visual and Autonomous Exploration Systems Research Laboratory at Caltech (http://autonomy.caltech.edu) is conducting R&D in all of the above aspects of tier-scalable reconnaissance.

6556-32, Session 7

Fractal analysis of proteins involved in drug design on biosensor surfaces

A. Sadana, The Univ. of Mississippi

A fractal analysis of the binding and dissociation of the natural cyclotide, kalata B1 and its analogue, kalata B6 in solution to DMPE (dimyristoyl-L-alpha-phosphatidylethanolamine) liposome immobilized on a L1 sensor chip (Kamimori et al., 2005) is presented. Cylcotides exhibit a broad range of biological activities that include antimicrobial, cytotoxic, and anti-HIV activities. A better understanding of the binding and dissociation reactions on membrane surfaces would lead to better physical insights into these types of reactions. The fractal analysis is used with this purpose in mind to relate the binding and dissociation rate coefficients with the degree of heterogeneity or fractal dimension present on the DMPE liposome immobilized on the L1 sensor chip surface.

The fractal dimension provides a quantitative indication of the state of disorder (fractal dimension) on the sensor chip surface, and is related to the binding and the dissociaton rate coefficients present on the sensor chip surface. In general, an increase in the fractal dimension or the degree of heterogeneity on the sensor chip surface leads to an increase in the binding and in the dissociation rate coefficeint value.

6556-33, Session 7

Miniaturized self-adaptive tuning of MEMS gyroscope for space

D. Keymeulen, Jet Propulsion Lab.

We propose a tuning method for Micro-Electro-Mechanical Systems (MEMS) gyroscopes based on evolutionary computation that has the capacity to efficiently increase the sensitivity of MEMS gyroscopes through tuning and, furthermore, to find the optimally tuned configuration for this state of increased sensitivity. We present the results of an experiment to determine the speed and efficiency of an evolutionary algorithm applied to electrostatic tuning of MEMS micro gyros. The MEMS gyro used in this experiment is a pyrex post resonator gyro (PRG) in a closed-loop control system. A measure of the quality of tuning is given by the difference in resonant frequencies, or frequency split, for the two orthogonal rocking axes. The current implementation of the closed-loop platform is able to measure and attain a relative stability in the sub-millihertz range, leading to a reduction of the frequency split to less than 100 mHz

6556-34, Session 7

Advanced signal processing for enabling next generation MEMS/NEMS sensors

T. George, ViaLogy Corp.

The application of advanced signal processing algorithms has largely been neglected by the Micro and Nano sensor development community, and yet this is the single most important area for improving the performance of these sensors. In the last two decades, stochastic resonance techniques have emerged as a novel, and counter-intuitive approach toward improving sensor performance. With this approach, named Active Signal Processing, instead of removing system noise, it is possible to improve signal-to-noise ratio (SNR) by injecting noise into the measurement. ViaLogy Corp. has pioneered the development and demonstration of Quantum Resonance Interferometry (QRI), a quantum stochastic resonance (QSR)-based technique for improving SNR. The core of QRI processing involves the QSR-based generation of a Quantum Expressor Function (QEF), which characterizes the system of interest by encoding within it the noise environment, minimum level of detection, and the precision of measurement. Using digital post-processing of sensor information, QRI can determine the presence of a signal by the destruction of the resonance condition responsible for generating the system QEF. For applications aimed at detecting the presence of a signal, the strength of the signal is proportional to the number of iterations of the algorithm required for destruction of the resonance; the fewer the iterations, the stronger the signal. For MEMS/NEMS sensing applications, we envisage exploiting the ability of the QEF to provide high-resolution characterization of the sensor's noise environment (amplitudes and frequencies). The application of QRI processing to detect weakly expressing genes in DNA microarray chips will be presented.

6556-35, Session 7

Reliability shortcomings for micro-/nano- technology based systems

E. J. Garcia, M. A. Polosky, Sandia National Labs.

Micro Nano Technology-Based Systems (MNT-Based Systems) are expected to provide unprecedented capabilities for aerospace applications. However we have not sufficiently addressed the reliability of such systems for a number of reasons. For example, our foundational understanding of such systems is incomplete at the basic physics level and our understanding of how individual subsystems interact is much less than we originally assumed. In addition the manner in which we operate during the product realization cycle has large implications for the ultimate reliability we can expect to achieve. Currently it is quite difficult to determine the reliability of MNT-Based Systems and is in fact borne out by a number of estimates we have seen that are unsatisfactory. We shall discuss a number of issues that at present have slowed our progress in developing NMT-Based Systems and have deterred us from effectively ascertaining the true "reliability" of such systems.

6556-36, Session 8

GaN-based microchemical sensor nodes

K. Son, B. Yang, Jet Propulsion Lab.; N. Prokopuk, Naval Air Warfare Ctr.; J. S. Moon, HRL Labs., LLC; M. Gallegos, Jet Propulsion Lab.; J. Yang, A. M. Khan, Univ. of South Carolina

We are developing GaN-based micro chemical sensor nodes consisting of GaN HEMT (High Electron Mobility Transistor) sensors integrated with RF communication links, which will enable autonomous real-time remote detection and monitoring of chemical agents in large areas under all weather conditions. The GaN HEMT has a two dimensional electron gas (2DEG) conducting channel at the AlGaN/GaN interface near (<30nm) the surface. The 2DEG is highly responsive to surface polarization interactions such as those induced by chemical adsorbates. This high sensitivity provides a detection mechanism for chemical analytes without the need for elaborate surface preparation. For selectivity, we use a novel sensing mechanism based on gate electrode-specific, temperature-dependent desorption spectroscopy, which facilitates fingerprinting of chemical agents. As a solid state chemical sensor, the GaN HEMTs can be mass-produced with a low mass and small volume design. The low dissipation power and short response times of the GaN sensors are ideally suited for chemical detection technologies. In this paper, we present our study on electrical responses of GaN HEMT sensors to chemical agent simulants and other common chemicals and discuss a battery-powered highly efficient data transmission scheme for GaN-based sensor nodes for multi-agent detection. For chemical agent identification based on gate electrode-specific, desorption temperature profile, we present the responses of a GaN sensor array fabricated with Ni, Pt, and Pd gate electrodes measured in a range of 25- 400°C using a microheater integrated with the sensor.

This work has been supported by DTRA through ARO and managed by Dr. Stephen J. Lee.

6556-37, Session 8

Highly sensitive chemical sensors by functional integration of nanoporous zeolites with photonic devices

H. Xiao, J. Montoya, T. Wei, Univ. of Missouri/Rolla; J. Zhang, J. Dong, Univ. of Cincinnati

Recently, we discovered that the nanoporous zeolite materials possess the unique combination of optical and chemical properties suitable for developing highly sensitive chemical sensors. This talk summarizes our recent work in developing such highly sensitive chemical sensors by functionally integrating zeolite thin films with optical fiber devices. One of the sensors will be discussed in this presentation is the zeolite thin film-coated thermal long period fiber gratings which operates by monitoring the adsorption-induced optical refractive index changes in the zeolite thin film. The sensors are tested using various organic chemicals with different molecular sizes and in both vapor and liquid phases. We will also report our exploration on applying such zeolite sensors to point detection of chemical threats using simulants.

6556-38, Session 8

Carbon nanotube-based electronic devices for spaceflight instruments

S. A. Getty, NASA Goddard Space Flight Ctr.; L. Delzeit, NASA Ames Research Ctr.; B. Jamieson, Scientific and Biomedical Microsystems, LLC; T. T. King, P. A. Roman, P. R. Mahaffy, NASA Goddard Space Flight Ctr.; G. Kletetschka, The Catholic Univ. of America; P. J. Wasilewski, NASA Goddard Space Flight Ctr.; D. D. Allred, Brigham Young Univ.

Nanoelectronic components are among the advanced technologies that show promise to benefit NASA's upcoming spaceflight missions where mass and power of sensors and instruments are among the important design considerations. A technology development program is presently in place at Goddard Space Flight Center to develop and integrate nanoscale technologies into scientific instruments. Present activities include development of a next-generation magnetometer, based on the electromechanical properties of carbon nanotubes, and a cold cathode electron gun for integration into a miniaturized time-of-flight mass spectrometer. Growth, fabrication, and electronic properties of carbon nanotubes will be presented, and implications for instrument maturation will be discussed.

6556-39, Session 8

Detection of bacillus anthracis spore in water using magnetostrictive microcantilever

L. Fu, S. Li, K. Zhang, Z. Cheng, Auburn Univ.

Recently, the magnetostrictive microcantilever (MSMC) as a high performance biosensor was introduced. The MSMC is a wireless sensor and exhibits a high Q value. More importantly, the MSMC works well in liquid. In this paper, the pressure dependence of the Q value was reported for the MSMC with different sizes. The reason for MSMC exhibiting high Q value is proposed. Additionally, the detection of Bacillus anthracis spores in water using MSMCs with a phage as bioprobe is reported.

6556-40, Session 8

Micro-initiators as the fundamental building blocks of micro-energetic systems

A. Desai, Tanner Research, Inc.; B. Fuchs, U.S. Army Armament Research, Development and Engineering Ctr.

The need for safe and arm-fire systems for rocket motors, high Isp miniature thrusters for UAVs, composite molded thrusters for hypersonic flow temperatures, and smart munitions, has required a better understanding of energetic initiation and the energetic firing train. Every energetic system needs an initiation mechanism. For the past decade, many groups have worked on reducing the footprint of these systems through batch processing and miniaturization. However, the typical miniaturization and semiconductor-style benefits such as “faster, smaller, cheaper” are only now being investigated for micro-energetics. Advancement of this field requires key breakthroughs in the following areas:

* A SAFE and batch micro-energetics deposition and patterning step.

* The compatibility of subsequent (post or pre) MEMS processing steps.

* Better understanding of the micro-initiation energetic train.

* Special environmental standards for the manufacturer and specialized product qualification/testing.

Initiators under development range from simple patterned gold lines to multiply stacked exothermic metal sandwiches. Typical firing trains range from lead styphnate-lead azide-rdx for munitions and zpp-bkno3-ch6 in missiles. In many cases, exact compositions (grains, crystal structure) are trade secrets in the industry-and the same material packed (loaded) differently may not work at all!

This overview talk will focus on the typical chemical compounds used today in the industry, their associated sensitivities (and dangers), initiating techniques, and typical firing trains that are required for munitions and propellant applications. The industry focus on reliability, the need to characterize, formulation, composition, and performance will also be discussed.

6556-41, Session 8

Computational survey of representative energetic materials as propellants for microthruster applications

B. Fuchs, U.S. Army Armament Research, Development and Engineering Ctr.

The development of microthrusters for satellite control has been an on-going endeavor since the middle 1990’s. Microthrusters are also critical for the development of terrestrial micromissiles and nano air vehicles to be used for reconnaissance, surveillance, and sensor emplacement. With the maturation of MEMS manufacturing methods, the ability to produce the physical components of the thrusters can now be readily fabricated.

The thruster type that is the most straightforward to explore and develop is the combustion of a chemical propellant. The propellant is ignited by a heating element to give a single shot thrust. Utilizing MEMS manufacturing technology, a bank of thrusters can be ganged, with each individual chamber loaded with propellant to give multiple firings. The basic model for such a system is a solid rocket motor. The desired elements for the propellant of a chemical thruster are high specific impulse (Isp), high temperature and pressure, and low molecular weight combustion gases. Since the combustion chamber of a microthruster is extremely small, the propellant material must be able to ignite, sustain and complete its burn inside the chamber. The propellant can be either a solid or a liquid.

There are a large number of energetic materials available as candidates for a propellant for microthrusters. There has been no systematic evaluation of the available energetic materials as propellant candidates for microthrusters. This report summarizes computations done on a series of energetic materials to address their suitabilities as microthruster propellants.

6556-42, Session 9

Micromechanical sensors

T. G. Thundat, Oak Ridge National Lab.

Molecular adsorption on a cantilever surface results in cantilever bending due to an adsorption-induced differential surface stress. The adsorption-induced deflection of a cantilever beam reflects the interplay between strain energy increase of the beam and the free energy reduction of a reaction. Since free energy reduction is common for all reactions, the cantilever array forms a universal platform for label-free detection of various reactions. Microfabrication of inexpensive cantilever arrays offers an unprecedented opportunity in the development of miniature sensors for multiplexed detection chemical and biological analytes. Chemical selectivity is achieved by using receptor based surface modification. Since receptor-based detection does not offer high selectivity, a receptor free technique for molecular recognition can be developed using the extreme high temperature sensitivity of a bi-material cantilever. A bi-material cantilever with adsorbed molecules undergoes bending when exposed to mid infrared (IR) waves when the molecules adsorb the IR light. Differential bending of the cantilever as a function of illuminating IR wavelength resembles an IR absorption spectrum of the adsorbed molecules. We have obtained sensitivity in the sub nanogram level for explosives, and biowarfare agents. The sensitivity could be further improved by optimizing the cantilever properties. This talk will focus on both the scientific understanding as well as the technological progress in the development of cantilever-based analysis of chemical and biomolecular reactions.

6556-43, Session 9

Optical microresonator sensor based on conjugated molecules for trace explosive detection

A. Chen, A. Pyayt, L. Dalton, A. Jen, J. Luo, Univ. of Washington

Conjugated chromophores have electron rich group(s) (donor) and electron deficiency group(s) acceptor(s) connected by a bridge. The charge distribution of conjugated molecular systems is sensitive to the local environment of the molecules. The change in the charge distribution will cause the polarizability (index of refraction), hyperpolarizability (nonlinear optical effects), and band structure (optical absorption) to change. It is know that the optical properties such as absorption spectrum, index of refraction, and fluorescence life time changes dramatically when these molecules are exposed to solvents of different degree of polarity, external electrical field, and intermolecular electrostatic interaction. High explosive chemicals are known to be highly electronegative. It has been demonstrated that conjugated polymers respond to a quantity of vapor as small as about 10-18 mol (100,000 molecules) of TNT and are sensitive enough to detect the odor of TNT and DNT in the air over a buried landmine - an estimated sub-parts-per-quadrillion (10-15) concentration.

Compared with fluorescence detection, for which the excitation and fluorescence lights are typically outside the low loss window of the fiber and the collection of the fluorescence light is hard to be efficient, the change in the index of refraction and absorption are more suited for fiber optic sensors. Several approaches can be used to incorporate these organic sensor molecules in fiber optical sensors. The sensor molecules can be doped in the plastic optical fiber to make a sensor fiber that can serve as a distributed sensor to monitor a large area. The sensor polymers can also be used to make optical resonators that are couple to optical fiber for remote chemical sensing. With a polycarbonate doped with a conjugated electron donor-acceptor molecule, index change in vapor of 100 ppb DNT (a stimulant to TNT) as large as 10^-3 as observed. Taking the advantage of such large index change, the micro ring resonators made with this material have shown large resonance shift on the order of nm.

6556-44, Session 9

Molecular detection in metal nanocavities

S. Blair, The Univ. of Utah

Metallic nanocavities have desirable properties for the detection of molecules using labeled or label-free techniques - strong isolation from background produced by the bulk solution and control over the local electromagnetic environment. I’ll primarily describe our work in the enhancement of fluorescence from metal nanocavities, where the enhancement is a factor of 10 or more. The two contributions to that enhancement arise from the localized plasmonic resonance, namely enhancements in excitation and emission. Both experimental results with DNA detection and computational results will be discussed.

6556-45, Session 9

SERS detection of viruses based on silver nanorod A

Y. Zhao, S. Shanmukh, Y. J. Liu, L. P. Jones, R. A. Dluhy, R. A. Tripp, The Univ. of Georgia

To produce a high enhancement and reproducible SERS substrate is one of the key challenges for practical applications of SERS. We demonstrate that the aligned silver nanorod array substrates prepared by the oblique angle deposition method are capable of providing extremely high enhancement factors (\>108) at near-infrared wavelengths (785 nm) for a standard reporter molecule 1,2 trans-(bis)pyridyl-ethene (BPE). The enhancement factor depends strongly on the length of the Ag nanorods, the substrate coating, the polarization of the excitation light, as well as the incident angle. With the current optimum structure, we demonstrate that the detection limit for BPE can be lower than 10-16 moles. With these Ag nanorod array substrates, we also demonstrated that SERS can distinguish between trace amount of viruses such as respiratory syncytial virus (RSV), rhinovirus, adenovirus, human immunodeficiency virus (HIV), and influenza (flu) virus. The minor spectral differences within strains of single virus type such as RSV virus, can also be detected, suggesting that this technology can be applied to detect genetically modified viruses that may be agents of bioterrorism. The detection of virus presented in infected cells has also been demonstrated. All the results have demonstrated that the aligned Ag nanorod arrays are capable to detect extremely low quantities of viruses.

6556-46, Session 9

Piezoelectric diaphragm as a high-performance sensor platform

L. Odum, K. Zhang, Z. Cheng, Auburn Univ.

The design of a piezoelectric diaphragm as a dual-functional biosensor platform, bending and thickness modes, is reported. The diaphragm using bending mode exhibits higher sensitivity than the state-of-art microcantilevers, while the diaphragm using thickness mode has a much higher sensitivity than the bending mode. It was experimentally found that for the bending mode the diaphragm in liquid exhibits the same Q value as the diaphragm in air, while for the thickness mode the diaphragm in liquid exhibits a much smaller Q value. That is, the bending mode is the better candidate for developing high performance sensor platforms employed in liquid.

6556-47, Session 10

Electrodeposited 1D Nanostructres

N. V. Myung, Univ. of California/Riverside

Nanotechnology and Nano- and Micro-ElectroMechanical Systems (NEMS/MEMS) are rapidly evolving areas of science and engineering that hold the promise of creating new techniques to manufacture devices and develop advanced information technology. It is fundamentally changing the way materials and devices will be produced and it will be central to the next epoch of the information age.

My research group is interested to synthesize multi-functional nanostructures and fabricate nanodevices. It is our group objective to control nanoscale sized features to enhance material properties and device functions beyond those that we currently know. The ability to develop and to engineer materials at the nanoscale level and to apply their unique properties into nanotechnology and NEMS/MEMS will have great impact on technology, industry and commerce. During the presentation, applications of electrochemically fabricated advanced materials including thermoelectric nanowires for micro generators and coolers, ferromagnetic nanowires for spintronics, nanowire sensor arrays for environmental monitoring

6556-48, Session 10

Growth and characterization of ZNO nanowires for various sensor applications

A. K. Sood, Y. R. Puri, Magnolia Optical Technologies, Inc.; D. L. Polla, Defense Advanced Research Projects Agency; Z. L. Wang, Georgia Institute of Technology; M. B. Soprano, U.S. Army

ZnO is a unique material that exhibits both Semi conducting and piezoelectric properties. ZnO devices have been demonstrated for applications in piezoelectric pressure sensors and Pyroelectric infrared detectors (1) and Spintronic devices (2). More recently, there has been significant effort underway for design and development of ZnO nanostructures such as ZnO nanowires for a variety of applications (3, 4).

The ZnO nanostructures can be implemented in Optoelectronic, Sensors, Transducers and Biomedical applications (3-7). Use of these nanostructures, will allow building of Nanoscale nanosensors, nanocantilevers, field-effect transistors and nanoresonators for a variety of Military, Homeland Security and Commercial Applications.

In this Paper we will present growth technique for ZnO nanowires on a variety of substrates, such as alumina, GaN and polymer. Theoretical analysis and experimental results on the ZnO nanowires will be presented about their growth morphology, structure analysis, and dimensionality control.

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6556-49, Session 10

Gas nanosensors: fabrication, performance, and future perspectives for defense and security applications

M. A. Deshusses, S. Mubeen, T. Zhang, N. V. Myung, Univ. of California/Riverside

One-dimensional nanostructures based chemical sensors have recently attracted a great deal of attention because of their superior sensing performance due to their high surface area to volume ratio and unique physical and electrical properties. We have developed several simple fabrication techniques to synthesize micro-gas sensors using electrochemically functionalized single-walled carbon nanotubes (SWNTs) with either metal nanoparticles, metal oxide nanoparticles, or conducting polymer nanodeposits. The method allows creation of high-density individually addressable nanosensor arrays. For examples, Pd nanoparticles were electrodeposited on SWNT networks to create a hydrogen gas sensor and conducting polymers were deposited for ammonia, NOx and volatile organic compound sensing. By varying nanofabrication conditions, the sensing performance could be tuned. In many cases, early prototypes of our sensors exhibited superior sensitivity over existing sensors. Systematic investigations of the effects of selected parameters on the sensor characteristics allowed to develop a better fundamental understanding of the sensors. Recent results including fabrication methods, sensing mechanisms, and sensing performance will be presented at the conference, and future applications in defense and homeland security will be discussed.

6556-50, Session 10

Review of an intermediate-layer lithography approach

C. Luo, Louisiana Tech Univ.

Conducting polymers, because of their promising potential to replace silicon and metals in building devices, have attracted great attention since the discovery of high conductivity in doped polyacetylene in 1977. Lithographic techniques present significant technical challenges when working with conducting polymers. Sensitivity of conducting polymers to environmental conditions (e.g., air, oxygen, moisture, high temperature and chemical solutions) makes current photolithographic methods unsuitable for patterning the conducting polymers due to the involvement of wet and/or dry etching processes in those methods. Existing non-photolithographic approaches have limitations in throughput, resolution or electrical insulation. Therefore, an intermediate-layer lithography (ILL) approach has been recently developed in my group to produce conducting polymer micro/nanostructures. In the ILL approach, an intermediate layer of an electrically insulating polymer is coated between the substrate and a layer of the conducting polymer to be printed. Subsequently, the conducting polymer is printed through a mold insertion using a hot-embossing process. The current hot-embossing based methods face the obstacles of residual layer and depth of field (i.e., the height variation in the mold structures). In contrast, the ILL approach does not have a residual layer in the material of interest, making conducting polymer patterns isolated from one another and avoiding the short-cutting problem in the electrical applications of these patterns. Furthermore, in the ILL, the height variation potentially existing among the mold structures has been transferred to the intermediate layer, ensuring that all patterns in the mold have been properly transferred to the conducting polymer layer. In addition to conducting polymers, the ILL approach can also be applied to pattern metals as well as other types of polymers. In this talk, I will give a review of this ILL method and the corresponding results that we have achieved to date

6556-51, Session 10

Nucleic acid engineering: using DNA as a generic instead of genetic materal

D. Luo, Cornell Univ.

Our research focuses on molecular engineering DNA as a generic instead of a genetic material. By taking advantages of the amazing chemical, physical, and biological properties of DNA and by utilizing a myriad of DNA manipulating enzymes, we have employed DNA as a true polymer. However, unlike chemical polymers which have linear, branched, networked, and dendritic structures, almost all DNA has only linear (or circular) architectures. To realistically use DNA as a polymeric material, we have created branched, networked, and dendritic DNA as additional material building blocks; some of them were inspired by pioneering work of Seeman and his group. These DNA materials are water soluble, biocompatible, biodegradable and most importantly monodisperse and anisotropic and have provided us with an enlarged tool box of designer hybrid materials for complex nano-architectures as well as novel functionalities. In essence we have created DNA-based “tinker-toys” for construction of new materials. A few examples of nucleic acid engineered materials will be discussed in this talk; they include DNA-dendrimers, DNA nano-buckyballs, DNA-based nanobarcode systems, DNA hydrogels, DNA liposomes, DNA-Au nanoparticles, and in particular, a cell-free, protein producing DNA hydrogel. These examples not only illustrate the concept that DNA can be utilized as a generic, designer material but also demonstrate the power of nucleic acid engineered materials as a link between biology and polymer chemistry, as well as between DNA and materials sciences and engineering. New properties and applications are expected from nucleic acid engineered materials.

6556-52, Poster Session

High-performance sensing platform based on surface plasmon-coupled fluorescence

S. Ja, Nomadics, Inc.; J. A. Krouse, Consultant

Fluorescence-based detection is a highly sensitive technique that has been used widely in areas such as chemical and biological sensing. ICx Nomadics has been developing and exploiting innovative fluorescent materials to detect chemical signatures of interest in defense, homeland security, environmental, and industrial applications. Efforts to continue improving the sensing performance of these reporter materials have concentrated on enhancements in the effective collection of analyte response emissions while rejecting ambient and excitation light and background emissions. Recent advances in surface plasmon-coupled emission (SPCE) techniques have shown that this technique can significantly improve the performance of a fluorescence-based sensor system because of their ability to focus reporter emissions into specific distributions. By taking advantage of such designed distributions, the signal-to-noise ratio of the fluorescence signal can be drastically improved. We have successfully combined these unique characteristics of SPCE with our sampling mechanism and fluorescent reporters to demonstrate the potential of this new fluorescence platform for the detection of various chemicals, including toxic analytes.

6556-53, Poster Session

Magnetostrictive nanoparticle as a novel biosensor platform

S. Li, L. Fu, K. Zhang, Z. Cheng, Auburn Univ.

Magnetostrictive particles (MSPs) as a high performance biosensor platform were induced recently. The MSP technology exhibits a much better performance over the current state-of-the-art microcantilevers and provides many unique features for biological detection. The magnetostrictive particles in nano/micro-scale were fabricated using electrochemical deposition. The microstructure and morphology of the nanoparticles were characterized using XRD, SEM, and TEM. The composition and magnetostrictive behavior of the nanobars in diameter from 20 to 200 nm and length from 1 um to 6 um were determined using and XPS and AFM. To protect the surface of nanoparticles and to promote the immobilization of the bioprobe, such as antibody and phage, the surface of the nanoparticles was coated with a SAM (self-assembling monolayer) layer. The results of these experiments are reported here.

6556-54, Poster Session

Ferroelectric tunable photonic crystals based on Ba0.7Sr0.3TiO3/MgO multilayered thin films

D. Wang, The Hong Kong Polytechnic Univ. (Hong Kong China)

It is of interest to the optoelectronic community if index-tunable photonic crystals can be realized by using ferroelectric materials since the refractive index of the ferroelectric materials can be electrically tuned through the electro-optic effect. In this work, we present our study on developing a tunable one-dimensional (1D) photonic crystal (PC) based on Ba0.7Sr0.3TiO3 and MgO multilayer structure. Photonic band-gaps of the photonic crystals with different ratio of Ba0.7Sr0.3TiO3/MgO were numerically demonstrated using the Planewave Expansion (PWE) method. It is found that 1 %-change in refractive index of Ba0.7Sr0.3TiO3 results in a 0.87 % frequency shift in band gap of the photonic crystal, which corresponds to a wavelength-shift of 5 nm and 12 nm at wavelength of 632.8nm and 1550nm, respectively. Ferroelectric 1-D photonic crystals consisted of a Ba0.7Sr0.3TiO3/MgO multilayered thin films were fabricated on MgO (001) single-crystal substrates by pulsed laser deposition technique. The transmission spectra and index-tunable characteristics of a Ba0.7Sr0.3TiO3/MgO 1D photonic crystal with Ba0.7Sr0.3TiO3/MgO ratio of 9:1 were characterized. The transmission characteristics of the photonic crystals are further verified by the Finite Difference Time Domain (FDTD) simulation.

6556-55, Poster Session

Theoretical study of ferroelectric barium strontium titanate-based one-dimensional tunable photonic crystals

K. L. Jim, D. Wang, C. W. Leung, C. L. Choy, L. W. H. Chan Wong, The Hong Kong Polytechnic Univ. (Hong Kong China)

Tunable photonic crystals (PCs) have attracted much attention in the past decade, for their various applications such as ultra-fast optical filters and optical waveguides with add-drop functionalities. A common means of tuning PC is by changing the refractive indices of the constituent materials via the linear or quadratic electro-optic effect, which leads to a shift of the bandgap positions of the PC. The lead-free ceramic barium strontium titanate (BST) has a high quadratic electro-optic coefficient comparable to lanthanum-modified lead zirconate titanate (PLZT), and is a promising candidate for lead-free tunable PCs.

Here we present a study on the feasibility of developing one-dimensional tunable PC, using BST and magnesium oxide (MgO) multilayer structures. The bandgap diagram of the PC structure is calculated using the Planewave Expansion (PWE) method. For a 1% change in the refractive index of BST, a 0.87% frequency shift in the bandgap can be achieved. It corresponds to a wavelength-shift of 5 nm and 12 nm for wavelength of 632.8nm and 1550nm, respectively. The transmission property of the PC is further verified by the Finite Difference Time Domain (FDTD) simulation.

6556-56, Poster Session

Generation of silicon nanowires using a new thinning and trimming method

H. Wang, H. Li, A. Chakraborty, X. Liu, C. Luo, Louisiana Tech Univ.

A new thinning and trimming approach has been explored to produce silicon nanowires (SiNW) from silicon microwires. One-dimensional nanostructures have attracted great attention recently because of their potential applications as excellent components in micro/nanodevices. SiNWs in particular have received much attention since silicon is the most widely used material in integrated-circuit and microfabrication processes and has unique mechanical and electrical properties. However, due to the shortcomings of the existing fabrication approaches, new methods are needed to produce SiNWs that can not only be massively fabricated but also batch integrated to functional devices. The developed thinning and trimming approach is believed to be such a method, and would permit precise control of the structure, size and positions of SiNWs. Furthermore, this method may be used to break through the limitation of lithography in the sense that silicon features fabricated by any lithographic methods can be further miniaturized using the approach. Our progress on developing this new thinning and trimming approach will be detailed in the paper.

6556-57, Poster Session

Fabrication of silicon nanobridge-based sensor

H. Li, A. Chakraborty, X. Liu, C. Luo, Louisiana Tech Univ.

Microsensors have been widely used in various applications, including seismic, temperature, light, sound, magnetic, chemical, etc.; the current trend is towards reducing the dimension further to nano scale, thus increasing their sensitivity and adaptability. The mechanisms for these sensors are different but one common obstacle exists- how to reduce the dimension of the components to nano scale without compromising their mechanical stability. To overcome this challenge, we develop a new method to fabricate silicon nanostructures, and employ them as sensors. We also establish theoretical models for the sensing purpose and compare them with experimental results. The details of these results will be presented in detail in the paper.

6556-58, Poster Session

Piezoelectric-based microcantilevers for MEMS power scavenging device

J. Park, D. Shen, S. H. Yoon, S. Choe, D. Kim, Auburn Univ.

There has been a growing interest in the area of energy harvesting technologies for low-power electronic devices. Among possible energy sources, environmental vibrations have been considered as a potential due to easy accessibility. This paper presents the development of a piezoelectric based energy harvesting device using MEMS process. Lead zirconate titanate (PZT) was used as a piezoelectric material and coated on silicon wafers with several inter-layers for adhesion improvement and stress compensation. The current design of piezoelectric energy harvesting device comprises a cantilever beam structure with integrating the silicon proof mass at the end of a cantilever. Integrated silicon mass patterned by reactive ion etching process is designed to provide enough strain during mechanical vibration. This paper describes the integration process and test with an emphasis on scaling of power generation for developing MEMS scale power scavenging devices.

6556-59, Poster Session

Flexural plate wave devices for biosensor platform

S. H. Yoon, J. Park, D. Shen, D. Kim, Auburn Univ.

Piezoelectric films such as ZnO and PZT have been considered as a potential material for sensor and actuator applications, due to high piezoelectric and electromechanical coefficients. For acoustic wave device applications, the ability to control film structure is required for achieving high piezoelectric activity which determines device performance. Fabrication of ZnO films has been performed by RF magnetron sputtering, and PZT films by chemical solution process. The film structure has been controlled by modifying process parameters. Various characterizations such as XRD, SEM, AFM, and Raman spectroscopy have been performed to examine the structural properties of films. With the ability to modulate film structure which eventually determines the device performance, the arrays of flexural plate wave device have been successfully fabricated onto 4-inch Si wafer, and the relationship between the film microstructure and the electro-acoustic property of the device will be discussed in terms of device performance for the biosensor applications.

6556-60, Poster Session

Piezoelectric micromachined ultrasonic transducers with rectangular diaphragms for binary frequency ultrasonic applications

C. Chao, The Hong Kong Polytechnic Univ. (Hong Kong China)

Piezoelectric micromachined ultrasonic transducer (pMUT) consists of a piezoelectric capacitor built on a micromachined silicon membrane, and exploits its flexural vibration mode for ultrasound transmitting and sensing. It is typically operating at the fundamental frequency where maximum sensitivity can be achieved, and is insensitive at higher order of resonances because the harmonic signals generated from different parts of the diaphragm tend to cancel with each other. This leads to a very narrow bandwidth. In this paper, rectangular-shaped pMUTs for dual-frequency reception are proposed and fabricated by using piezoelectric P(VDF-TrFE) copolymer coating and silicon micromachining technologies. The electrode patterns are properly designed to efficiently make use of both (0, 0) and (0, 2) vibration modes of the rectangular membrane. By adjusting the length and width of the diaphragm, the ratio of the two frequencies can be variable on demand within a wide range. The micromachined dual-frequency sensors will be useful for miniaturized ultrasonic systems operating on binary frequency shift-keyed (BFSK) principles, such as precise distance detectors and ultrasonic local-area communication terminals.

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6557-01, Session 1

All solid-state electrochromic device for helmet mounted displays

H. Demiryont, K. C. Shannon III, J. C. Isidorsson, Eclipse Energy Systems, Inc.

Helmet-Mounted Displays (HMDs) do not allow the pilot to raise or lower a tinted visor when moving from a high to low light level condition. A variable transmittance system is a possible solution. The Eclipse Variable Electrochromic Devices (ECD) is well suited for these light modulation applications. The ECDs modulates light intensity by changing transmission level under an applied electric field (approx 1.5V). The optical density of the ECD may be continuously varied over a transmission range by varying the applied voltage. This process is reversed by changing the polarity of the applied electric field.

An all-solid-state ECD, the Eclipse ECD is comprised of a transparent bottom electrode/active element/transparent top electrode structure which incorporates an all solid state electrolyte, a low resistance Eclipse proprietary electrode and is an all in-situ vacuum deposited system. The solid-state electrolyte eliminates possible complications associated with gel-based technologies for lens applications, the needs for lamination and any additional visor modification. The low temperature deposition process enables direct application of the technology onto HMD flight visors. The average modulation of the system is from 48% to 18% modulation in 3 seconds while bleaching (clearing) and 10 seconds when coloring (darkening). In addition the coating is easily manufactured, trimable, has near spectral neutrality and fails in the clear (bleached) condition.

The paper includes an overview of the performance characteristics of the Eclipse ECD technology, performance results from trimability experiments, and technical progress specific to its application in HMD's and curved surfaces.

6557-02, Session 1

Evolution of electrochromic materials for vision-based applications

R. F. Storm, K. C. Shannon III, Eclipse Energy Systems, Inc.

Electrochromic materials have been at the forefront of potential variable transmission materials for vision enhancement and dimming capabilities for over a decade. Electrochromic technologies modulate light intensity through the application of voltage and have a large number of advantages over LCD and photochromic technologies. The advantages include analog control of light transmission adjustable to the specific needs of the user, low power requirements, and in the case of Eclipse Electrochromic Devices (ECD), the devices are 100% solid state. However the transmission, switching speed, and other specifications required for what would be considered acceptable technology for vision-based applications has often been an elusive target.

Currently there appears to be no written specifications for variable transmittance devices for use in commercial or military vision based applications. This paper details research into the perceived and real performance requirements for both civilian and (non-classified) military vision based applications for variable transmission technologies (including HMDs, combat goggles, extreme sports goggles, etc). Also included is a discussion of the evolution of Eclipse ECD technologies and an overview of their performance characteristics tailoring to meet the changing requirements including range, speed, environmental stability, device color, electronic control package design and the trade-offs to achieve high performance in each.

6557-03, Session 1

Life test results of OLED-xl long-life materials for use in active matrix organic light emitting diode (AMOLED) displays for head mounted applications

D. A. Fellowes, M. V. Wood, U.S. Army Night Vision & Electronic Sensors Directorate; O. Prache, eMagin Corp.

eMagin Corporation has recently developed long-life OLED-XL materials for use in their AMOLED microdisplays for head-worn applications. AMOLED displays have been known to exhibit high levels of performance with regards to contrast, time response, uniformity, and viewing angle, but a lifetime improvement has been perceived to be essential for broadening the applications of OLED's in the military and in the commercial market. The new OLED-XL materials gave the promise of improvements in usable lifetime over 6X what the standard full color, white, and green materials could provide. The US Army's RDECOM CERDEC NVESD life tested several standard and OLED-XL panels from eMagin under a Cooperative Research and Development Agreement (CRADA). Displays were tested at room and elevated temperatures, utilizing eMagin's Minikit driver, allowing computer controlled optimization, brightness adjustment, and temperature compensation. The results of the tests have been added to the current OLED Usable Lifetime Model, developed under a previous NVESD/eMagin SPIE paper (DSS 2005). The result is 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 needed.

6557-04, Session 1

Head tracker evaluation utilizing the dynamic tracker test apparatus

J. L. M. Shattuck III, V. M. Parisi, Air Force Research Lab.

In military aviation, head tracker technologies have become increasingly important to track the pilot's head position and orientation, allowing the user to quickly manipulate the operational environment. This technology allows the pilot to quickly acquire items of interest and see Fighter Data Link-Type information. Tracker-Assisted Weapons-Slewing to acquire the target on a helmet-mounted display is far more efficient than pointing at it with the nose of the aircraft as previously required for the heads-up display (HUD) type of target acquisition. The United States Air Force (USAF) has used and evaluated a variety of helmet-mounted trackers for incorporation into their high performance aircraft.

The Dynamic Tracker Test Apparatus (DTTA) was designed by the Helmet Mounted Sensory Technology (HMST) laboratory to accurately measure azimuth rotation in both static and dynamic conditions for the purpose of evaluating the accuracy of a variety of head trackers, including magnetic trackers, inertial trackers, and optical trackers. This paper describes the design, construction, capabilities, limitations, characterization and performance of the DTTA.

6557-05, Session 1

Non-contact method for characterization of a rotational table

J. L. M. Shattuck III, V. M. Parisi, Air Force Research Lab.

The United States Air Force (USAF) has uses and evaluates a variety of helmet-mounted trackers for incorporation into their high performance aircraft. The primary head tracker technologies commercially available are magnetic trackers, inertial trackers, and optical trackers. And each head tracker has its own method of determining the pilot's head position within the cockpit of the aircraft.

Magnetic trackers generally have a small head mounted size and minimal head weight. Since they sense a generated Magnetic field, their accuracy can be affected by other magnetic fields or ferrous components within the cockpit. Inertial trackers cover the entire head motion box but require constant motion in order to accommodate drifting of the inertial sensors or a secondary system that updates the inertial system, often referred to as a hybrid system. Finally, optical head trackers (OHT) are immune to magnetic fields. Some of their limitations may be daylight/night vision goggle (NVG) compatibility issues and, depending on system configuration, may require numerous emitters and/or receivers to cover a large head motion box and provide a wide field of regard.

The Dynamic Tracker Test Apparatus (DTTA) was designed by the Helmet Mounted Sensory Technology (HMST) laboratory to accurately measure azimuth rotation in both static and dynamic conditions for the purpose of determining the accuracy of a variety of head trackers. Before the DTTA could be used as an evaluation tool, it required characterization to determine the amount and location of any induced pitch or roll as the table rotated in azimuth. Optimally, the characterization method would not affect the DTTA's movement so a non-contact method was devised. This paper describes the characterization process and its results.

6557-07, Session 2

I-PORT(tm); a hands-free near-eye display

J. T. Carollo, M. Hoppe, Creative Display Systems, LLC

The I-PORT(tm) is a highly versatile hands-free, low profile near-eye display system. It was originally deigned with the medical market in mind as an information (monocular) or surgical (binocular) head worn display. The concept takes advantage of a technique used with surgical loupes where the loupes are mounted into eyeglasses. The I-PORT(tm) display module is similarly mounted into the lens of protective eyewear or sunglasses.

The I-PORT(tm) is compatible with Oakley M-Frame(r) sunglasses as well as other protective eye wear. It utilizes a novel adjustment mechanism that is intuitive and maintenance free which ensures optimum placement of image for the viewer. The I-PORT(tm) is a complete system capable of taking inputs from a standard camera system or personal computer. Its light-weight low power design is extremely rugged making it ideal for a variety of applications.

The system is capable of providing fields of view greater than 50 degrees in full color and can incorporate either OLED or AMLCD image sources of various resolutions. Also since the display is inside the sunglasses' lens makes it ideal for outside operation as it does not have to compensate for the low transmission of the lens.

The I-PORT(tm) is a new concept in eyeglass type hands-free near-eye displays that does not require a helmet or other head borne apparatus. It is capable of various fields of view and resolutions with a low profile and minimal obscuration. It is an ideal remote viewer (monocular or binocular) for medical, military and commercial equipment.

6557-08, Session 2

Integrated diver display device (ID3) for diver applications

D. Tremper, Naval Research Lab.; A. Brosky, Cardinal Scientific, Inc.

New dive computer systems have the potential to provide divers in operational scenarios with the processing power of laptop or desktop computers. Existing heads-up displays (HUDs) integrated into dive masks are capable of presenting only limited amounts of situational awareness data to divers during operations. Diver situational awareness can be greatly improved by providing increased access to the full processing capabilities of these next generation dive computers. In an effort to improve operational efficiency in diver scenarios by providing this enhanced access, the Naval Research Lab leveraged technologies developed for the Immersive Input Display Device (I2D2) for the development of the Integrated Diver Display Device (ID3). The ID3 leverages an OLED micro-display combined with a prism optic to provide a full color SVGA solution within the dive mask without obstructing the diver's line of sight (LOS). By not obstructing the diver's LOS, the diver maintains his forward vision and environmental awareness while gaining access to situational awareness data. This paper with examine the development and capabilities of the ID3 for dive applications.

6557-09, Session 2

Analysis of head-mounted displays for advanced night vision goggles

L. West, K. Lyons, W. Robinson, D. W. Roberts, J. C. James, J. M. Cathcart, T. L. Haran, T. Wasilewski, Georgia Institute of Technology

The Georgia Tech Research Institute has designed the next generation digital night vision system. The system is designed to be a man-portable monocular configuration with a head-mounted microdisplay to project digital images to the user. The display unit is based on a 1280x1024 monochrome Active Matrix Liquid Crystal Display (AMLCD) technology. The program began with an overview of possible display technologies that are currently available on the market, followed by the development of a head-mounted system that uses some novel optical techniques for better image viewing. The system was built as a demonstrator, with the intention of taking lessons-learned to modify the system, as necessary, for future field implementation. This paper will report the results of the engineering analysis required to select the display including human factors, processing needs, and sensor inputs. A number of competing displays were considered & the relative performance is discussed, technology trends that are occurring in industry.

6557-10, Session 2

New weather depiction technology for night vision goggle (NVG) training

J. W. Schroeder, S. Theleman, J. Hegarty, R. Vollmerhausen, C. Scott, ONTAR Corp.; F. Colby, Univ. of Massachusetts/Lowell; S. Napier, Naval Air Warfare Ctr.

US Navy and Marine Corps pilots receive Night Vision Goggle (NVG) training as part of their overall training to maintain the superiority of our forces. This training must incorporate realistic targets, backgrounds, and representative atmospheric and weather effects they may encounter under operational conditions. An approach for pilot NVG training is to use a 10' by 10' static terrain model equipped with both natural and cultural lighting that are used to demonstrate various illumination conditions, and visual phenomena which might be experienced when utilizing night vision goggles. With this technology, the military can safely, systematically, and reliably expose pilots to the large number of potentially dangerous environmental conditions that will be experienced in their NVG training flights.

This paper describes work that is being performed for the Navy to add realistic atmospheric and weather effects to the NVG training facility using a new weather depiction technology system. The weather depiction technology consists of a high end multiprocessor server with weather simulation software, and several fixed and goggle mounted displays. Atmospheric and weather effects are simulated using state-of-the-art computer codes such as the Penn State Mesoscale Model; the Advanced Research /Weather Research and Forecasting) modeling systems; and the US Air Force Research Laboratory radiative transport model. Imagery for a variety of natural and man-made obscurations (e.g. rain, clouds, snow, dust, smoke, chemical releases) are being calculated and injected into the scene being observed via fixed and goggle mounted displays.

Previous results were presented at the August 2006 SPIE Optics and Photonics Conference in San Diego, California. This paper will focus on work accomplished since the original presentation.

6557-36, Session 2

Digital sensor technology for advanced night vision goggles

J. C. James, W. Robinson, D. Roberts, J. M. Cathcart, K. Lyons, L. West, T. L. Haran, T. Wasilewski, Georgia Institute of Technology

There is an increasing interest in applying advanced digital imaging techniques such as image fusion and image enhancement to night vision (NV) applications. For NV systems operating in the visible and near-infrared portions of the spectrum, 3rd generation image intensifiers

utilizing Gallium Arsenide photocathodes and micro-channel plates have been the performance leading sensor technology for many years. While NV engineers and users of systems operating in other wavebands are accustomed to working with digital image sensors, the majority of NV systems utilizing intensifiers have only provided the users with a direct-view of the intensifiers phosphor output via an eyepiece. Some systems have made use of an analog or digital video sensor coupled to the intensifier with a fiber-optic bundle to display imagery on televisions and head-mounted displays, but this usually has resulted in a drop in system performance relative to the direct-view systems in terms of resolution, contrast sensitivity, and time response. The Georgia Tech Research Institute (GTRI) is currently executing a NV research and development effort for the US Marine Corps Systems Command to produce an Improved Night Vision Demonstrator (INVD) device which will feature a helmet-mounted digital image sensor. Maintaining or surpassing the performance of a direct-view NV system with a digital replacement while minimizing important system parameters such as power consumption, size and weight has proved to be an exciting challenge. This paper will present the results of GTRI's analyses and trade studies performed during the INVD development effort. An overview of existing and promising new technologies will be provided as well as a discussion of possible improvements that could be implemented in future sensors to take advantage of features unique to the human visual system.

6557-11, Session 3

The legibility of HMD symbology

T. H. Harding, C. E. Rash, J. S. Martin, U.S. Army Aeromedical Research Lab.

As the military increases its reliance upon and continues to develop Helmet Mounted Displays (HMD), it is paramount that HMDs are developed that meet the operational needs of the warfighter. In see-through HMDs, symbology is overlaid or added to the see-through background. For the symbology to be seen and understood, it must have sufficient contrast to stand-out from the background and be clearly recognized. In an earlier paper, Harding et al. (2005) showed that the quality of see-through symbology was greatly influenced by the complexity of natural backgrounds. Complexity was characterized by the standard deviation of small patches (patches subtending about 1.5o). Characterizing the complexity of natural backgrounds by measuring their standard deviation may not be adequate. For example, in the figure below, two grayscale images are shown with each image having about the same standard deviation and about the same average contrast (text/background). Overlaid text can clearly be seen in the image on the left but is difficult to decipher any characters on the image on the right. The two images differ in their spatial frequency content. The gradient background is characterized by low spatial frequencies, whereas the random background is characterized by high spatial frequencies. Predicting the legibility of symbology in a see-through HMD requires additional terms that characterize the local contrast within a background.

Figure. Transparent text overlaid over backgrounds of about the same stardard deviation

Harding, T.H., Martin, J.S., and Rash, C.E., 2005, Using a helmet-mounted display computer simulation model to evaluate the luminance requirements for symbology. Helmet- and Head-Mounted Displays X: Technologies and Applications, Proceedings of the SPIE. 5800, 159-168

6557-12, Session 3

Target acquisition using combined visual and audio cueing

R. Westergren, U.S. Air Force; P. R. Havig, Air Force Research Lab.

Previous studies have shown that helmet-mounted displays (HMDs) are advantageous in maintaining situation awareness and increasing the amount of time pilots spend looking off-boresight (Geiselman & Osgood, 1994; Geiselman & Osgood, 1995). However, space is also limited on a HMD and any symbology that is presented takes up valuable space and can occlude a pilot's vision. There has been much research area of visual cueing and visual search as they relate to seeking out visual targets in the sky. However, the idea of localized auditory cueing, as it could apply in the realm of air-to-air targeting, is an area less studied. One question is how can we present information such that a pilot's attention will be directed to the object of interest the most quickly? Some different types of target location cueing symbology have been studied to find such aspects of symbology that will aid a pilot most in acquiring a target. The purpose of this study is to determine the best method of cueing a person to visual targets in the shortest amount of time possible using auditory and visual cues in combination. Specifically, participants were presented with different combinations of reflected line cues, standard line cues, and localized auditory cues for primary and secondary targets. The cues were presented using an HMD and 3-D auditory headphones, with a magnetic head tracker used to determine when the participant had visually acquired the targets. The possible benefits of these cues based on the times to acquire are discussed.

6557-13, Session 3

Effects of simple HMD operations on primary visual tasks

J. McIntire, P. R. Havig, G. A. Reis, Air Force Research Lab.

Previously Havig, McIntire and Swinney (2006) reported a study in which not only the placement but also the task to be performed on a head-mounted display (HMD) had an effect on the user's ability to perform an "outside task" (i.e., on a large screen placed in front of them). They concluded that certain tasks on an HMD may not lead to optimal performance on outside tasks. However, there may be times when an HMD can be used for a task that does interfere. The purpose of the present set of experiments was to determine what types of tasks may be conducted on an HMD that may either 1) not hinder performance on an outside tasks and/or 2) actually improve performance on an outside task. We conducted two studies to investigate both of these situations using a similar visual search task to the one we used previously as our outside task. In one study the HMD task was similar to a monitoring task in which the observer only needed to respond to the HMD task when a certain event occurred. In the other study, the HMD task was designed to help with the visual search task. We also replicated these tasks using a desktop monitor in place of the HMD to simulate the situation found in modern air operation centers. We discuss these results in terms of tasks that may be at least innocuous if not beneficial to use on a secondary display.

6557-14, Session 3

Helmet-mounted sensor-offset evaluation using manual and locomotion tasks

J. E. Melzer, Rockwell Collins Optronics; K. Moffitt, Consultant

The advent of small, electronic sensors, displays and fusion processors, provides the opportunity to mount these assemblies on an infantry helmet, thus providing the soldier the ability to see, navigate and fight in a variety of lighting conditions. The nature of the sensors allows the designer to position them in one of several positions on the helmet to improve head and neck loading. The question is what impact this has on the perception of the real world by the soldier.

A monocular helmet-mounted display with three different camera positions was developed for a preliminary evaluation of sensor-offset effects. This system was used to measure performance and workload for a manual card-sorting task and for a walking obstacle-course task. This paper will summarize the results of these experiments.

6557-15, Session 3

Optimizing multispectral sensors through enhanced imagery for the warfighter

S. Dixon, P. L. Marasco, Air Force Research Lab.

Today's fighter pilot has a multitude of sophisticated displays providing diverse information and imagery. These displays provide critical targeting information enabling anytime/anywhere strike capability. A drawback however is the potential for task saturation from having to process visual information while navigating the aircraft through dangerous aerial combat environments. Numerous computer algorithms already exist to process these images to improve display information resolution. Image enhancement helps reduce the workload by processing and refining images thereby providing faster, more precise information for the pilot. In order for image enhancement to be effective, the relevant environmental features need to be determined. This paper addresses a study examining the salient battlespace image features in need of enhancement for delivery of operationally relevant visual information. Through literature searches and pilot interviews, imagery requirements for land and air features were determined. This information was utilized to create a series of degraded battlespace images . This imagery was then enhanced using computer-based algorithms. A Human Factors evaluation was performed to determine if there was a significant improvement in target detection for the enhanced imagery when compared to the baseline information. The results from this study provide guidelines for programming efficient image processing algorithms useful for current and future multi-spectral imaging systems.

6557-16, Session 4

A limited flight study for investigating hyperstereo vision

C. E. Rash, M. E. Kalich, W. E. McLean, U.S. Army Aeromedical Research Lab.

A novel helmet-mounted display (HMD) design that attempts to reduce head-supported weight and center-of-mass (CM) offset while offering the expanded capability of integrating image intensification (I2) and forward-looking infrared (FLIR) thermal imagery relocates the I2 tubes on the sides of the helmet. This approach introduces a visual phenomenon referred to as hyperstereo vision. This phenomenon manifests itself primarily as exaggerated depth perception, causing objects in the near field of vision to appear closer than they actually are.

A limited flight study was conducted to identify areas of concern for U.S. Army rotary-wing aviators having to perform standard flight maneuvers using an HMD design that introduces the hyperstereo condition. Five Army aviators flew a hyperstereo HMD with a safety pilot on the controls in a UH-60 helicopter; two pilots accumulated a total of eight flights each and three pilots flew only one-hour orientation flights. Pilots completed both in- and post-flight questionnaires requested pilot comparison on operational and performance capabilities as compared to previous flight experience with I2-based night vision goggles (NVGs).

It was concluded that above approximately 100 ft (~30 m), the hyperstereo HMD design can be successfully utilized in the flight tasks required at such altitudes. However, for flight operations involving a high percentage of low-level navigation flight, landings, and takeoffs in demanding environments, the visual impact of hyperstereo on depth perception and distance estimation introduces moderate to potentially high levels of perceptual problems. The foremost perceptual problem is that the ground and near objects appear closer than they really are.

Pilots reported difficulties with hovering, takeoffs, and landings, especially roll-on landings and landings on sloping terrain. Cross-cockpit scanning was reported as uncomfortable since many objects and the co-pilot were doubled and semitransparent.

Data seem to support claims that a moderate level of flight training (5-8 hours) permit pilots to develop compensation techniques that allow adequate and safe performance on the majority of flight tasks performed in this study, but with the trepidation and caution associated with a new learning experience. The one exception was landing on terrain slopes, which was considered by the subject pilots to not having been mastered in the 8-hour flight exposure. Study subjects estimate approximately 10 hours of flight experience would be needed to reach proficiency with the maneuvers performed.

6557-17, Session 4

Hyperstereopsis in helmet mounted NVDs: Slope perception

G. W. Stuart, Defence Science and Technology Organisation (Australia); P. R. Flanagan, Deakin Univ. (Australia); P. Gibbs, Defence Science and Technology Organisation (Australia)

Some night vision systems have sensors mounted on the sides of the helmet with visual output projected onto a display in front of the operator's eyes. This arrangement produces a situation of hyperstereopsis in which binocular disparities are magnified. This has the potential to distort the perception of slope in depth (an important cue to landing), because the slope cue provided by binocular disparity conflicts with veridical cues to slope, such as texture gradients and motion parallax. In the experiments, eight observers viewed sparse and dense textured surfaces tilted in depth under three viewing conditions: normal stereo (equal to IPD) hyper-stereo (4 times IPD), and hypostereo (1/4 IPD). The surfaces were either stationary, or rotated slowly around a central vertical axis. Stimuli were projected at 6m to minimise conflict between accommodation and convergence, and stereo viewing was provided by a Z-screen and passive polarised glasses. Observers matched perceived visual slope using a small tilt table set by hand. We found that slope estimates were distorted by hyperstereopsis, but to a lesser degree than predicted by disparity magnification. This distortion was almost completely eliminated when motion parallax was present.

6557-18, Session 4

Hyperstereopsis in helmet-mounted NVDs: Time to contact estimation

P. R. Flanagan, Deakin Univ. (Australia); G. W. Stuart, P. Gibbs, Defence Science and Technology Organisation (Australia)

Some night vision systems have sensors mounted on the sides of the helmet with visual output projected onto a display in front of the operator's eyes. This arrangement produces a situation of hyper-stereopsis in which binocular cues available to the operator are exaggerated so that distances around fixation are magnified. As an object moves towards an observer, the increased apparent distance travelled per unit time, increases its apparent velocity and reduces its apparent time to contact (TTC). To see if hyper-stereoscopic cues influenced TTC judgements, over and above those produced by normal optic-flow cues (texture size change, texture flow rate and texture edge rate), we measured estimates of TTC with 12 observers under three viewing conditions: no stereo (bi-ocular), normal stereo (equal to IPD) and hyper-stereo (4 times IPD). Motion towards a surface was simulated using computer-generated graphics and stereo viewing was provided by a Z-screen and passive polarised glasses. A large, random-field textured vertical plane 9 metres from the observer moved towards them under computer control, to provide TTCs of 3, 4, 5 or 6 s, and disappeared at 3 metres. The observer had to estimate when the plane would have reached the Z-screen (which was 0.84 m in front of their eyes). We found that TTC estimates were 200 ms shorter under the hyperstereoscopic condition than those under non-stereo and normal stereo, indicating that hyperstereopsis may cause observers to underestimate TTC and this may lead operators to undershoot the ground plane when landing.

6557-19, Session 4

Hyperstereo algorithms for the perception of terrain drop-offs

A. Mohananchettiar, V. Cevher, Univ. of Maryland/College Park; V. G. CuQlock-Knopp, Army Research Lab.; R. Chellappa, Univ. of Maryland/College Park; J. Merritt, The Merritt Group

The timely detection of terrain drop-offs is critical for autonomous off-road navigation. In this paper, we propose a joint tracking and detection approach for accurate and efficient terrain drop-off detection and localization. We formulate the problem with a hyperstereo camera system using a regularized combination of optical flow and disparity maps to obtain a dense depth map of the scene, and a regularization incorporating physical smoothness constraints in the scene for estimation robustness. Terrain drop-offs are detected using a gradient analysis of the dense depth map with temporal tracking to increase accuracy of detections. The resulting field data and estimates are then compared with baseline data of drop-off detections obtained with human observers. Also reported are experiments done to establish the performance advantage of using hyperstereo as opposed to normal stereo.

6557-20, Session 4

Wide-angle optical systems with combiner on the basis of the synthesized volume holograms for HMD

M. A. Gan, S. Scheglov, I. Gan, A. Tchertkov, S.I. Vavilov State Optical Institute (Russia)

Designing and manufacturing wide-angle optical systems for application in helmet mount displays are considered. Specific requirements which are showed to such systems are analyzed, including: minimization of weight and size, achievement of the big field of vision, convenience of allocation on a helmet and others. Key element HMD is combiner. Questions of designing spectral and polarizing combiners are considered. As spectral combiner we proposed to use the synthesized volume holograms. The analysis and comparison of optical and operational properties of holographic optical elements on the basis of the volume holograms which have been written down by registration interference picture by a method of U. Denisjuk and synthesized volume holograms is executed. Research of color distortions external space at vision through combiner is carried out.

Problems of optimum designing of lighting system for LCOS matrixes on the basis of high power LED and also questions of synthesis and optimization relay lens are considered. Results of designing, the analysis and testing of optical systems for HMD are present.

6557-21, Session 4

Advanced helmet-mounted display (AHMD)

A. Sisodia, L-3 Communications Corp.; M. Bayer, Zygo Optical Systems

Due to significantly increased U.S. military involvement in deterrent, observer, security, peacekeeping and combat roles around the world, the military expects significant future growth in the demand for deployable virtual reality trainers with networked simulation capability of the battlespace visualization process.

The use of HMD technology in simulated virtual environments has been initiated by the demand for more effective training tools. The HMD overlays computer-generated data (symbology, synthetic imagery, enhanced imagery) with the actual and simulated visible environment.

In previous papers we had presented the innovative design concepts, manufacture and performance of the resulting prototype AHMD. Subsequently we had evaluated the AHMD to a) validate the system performance and its ergonomic design features and b) highlight areas that require improvement.

This paper will present the results of the evaluation, conclusion reached and changes made to the basic AHMD design. In the remainder of this paper we provide a concise description of AHMD operations, and current development status. Then, the prototype AHMD is described in more detail, followed by the test results of an initial evaluation of the new generation, ready for deployment system.

The AHMD with its superior visual performance will enhance pilots' situational awareness, which greatly improves piloting and navigation tasks, enabling training in a synthetic, yet realistic environment.

We conclude by mentioning several opportunities for the use of the AHMD in simulation applications, as well as implications for further work.

6557-39, Session 4

Effects of hyperstereopsis on visual perception I: absolute distance perception

P. R. Flanagan, Deakin Univ. (Australia); G. W. Stuart, P. Gibbs, Defence Science and Technology Organisation (Australia)

Some night vision systems have sensors mounted on the sides of the helmet with visual output projected onto a display in front of the operator's eyes. This may affect the judgement of absolute distance by distorting two cues. First, the required amount of vergence required to achieve binocular fusion is increased as the inter-camera distance exceeds the inter-ocular distance. Second, there is an increase in gradients of horizontal and vertical disparity, which represent the only possible binocular geometric cue to absolute distance. Distortions of absolute distance are of interest because they moderate the effects of hyperstereopsis on the perception of relative depth within the limits of binocular fusion. In the experiments, ten observers viewed a virtual fronto-parallel textured surface under three viewing conditions: normal stereo (equal to IPD) hyper-stereo (4 times IPD), and hypostereo (1/4 IPD). Stimuli were projected at 6m, and stereo viewing was provided by a Z-screen and passive polarised glasses. A vertical grid was displayed at varying depths within a virtual "leaf room", which provided rich depth cues. The distance of the textured surface was measured by finding the matching depth of the grid using a temporal forced choice procedure. We found that there was no effect of stereo viewing condition on absolute distance judgement. This suggests that under real-world conditions, absolute distance judgement relies on monocular cues such as familiar object size and linear perspective.

6557-22, Session 5

Applied and theoretical aspects of night vision goggle resolution and visual acuity assessment

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The image quality of night vision goggles is often expressed in terms of visual acuity, resolution or modulation transfer function (MTF). The primary reason for providing a measure of image quality is the underlying assumption that the image quality metric correlates with the level of visual performance that one could expect when using the device (such as target detection or target recognition performance). This paper provides a theoretical analysis of the relationships between these three image quality metrics (visual acuity, resolution and MTF) and presents results and analysis from laboratory and field studies conducted to relate these metrics to visual performance. The results of this analysis can also be applied to non-image intensifier based imaging systems such as a helmet-mounted display coupled to an image sensor.

6557-23, Session 5

Comparison of experimental vision performance testing techniques, including the implementation of an active matrix electrophoretic ink display

M. W. Swinney, Air Force Research Lab.

Standard black and white printed targets have been used for numerous vision related experiments, and are ideal with respect to contrast and spectral uniformity in the visible and near-infrared (NIR) regions of the electromagnetic (EM) spectrum. However, these targets lack the ability to refresh, update, or perform as a real-time, dynamic stimulus. This impacts their ability to be used in various standard vision performance measurement techniques. Emissive displays, such as a LCD's, possess some of the attributes printed targets lack, but come with a disadvantage of their own. LCD's lack the spectral uniformity of printed targets, making them of debatable value for presenting test targets in the near and short wave infrared regions of the spectrum. Yet a new option has recently become viable that may retain favorable attributes of both of the previously mentioned alternatives. The electrophoretic ink display is a dynamic, refreshable, and easily manipulated display that performs much like printed targets with respect to spectral uniformity. This paper will compare and contrast the various techniques that can be used to measure observer visual performance through night vision devices and NIR imagers - with a focus on the visible to infrared region of the EM spectrum. Furthermore, it will quantify the electrophoretic ink display option, determining its advantages and situations that it would be best suited for.

6557-25, Session 5

Changes in distance estimation when using night vision goggles in changing ambient illumination

S. A. Jennings, T. Macuda, National Research Council Canada (Canada); W. A. Simpson, Defence Research and Development Canada (Canada)

The Flight Research Laboratory (FRL) of the National Research Council of Canada (NRC) has been performing a series of studies in collaboration

with Research and Development Canada (DRDC). These studies, called the Collaborative Image Intensifier Research Program (CIIRP), were aimed at determining a pilot's perception and performance with night vision goggles (NVGs). The goal of this phase of the study was to determine the effect of NVGs on the estimation of distance between two objects under varying illumination levels.

Eighteen participants were divided into two groups, with one group using the NVGs in a high NVG illumination environment and the second group using the NVGs in a very low ambient illumination condition. Subjects were asked to make exocentric distance estimates between two points of light in an eye lane.

The distance estimates were fitted to the form Destimate = C1 x DActual^exp(C2). The exponential term C2 was higher in the high light condition (C2high = 0.80) than in the low ambient light condition (C2low= 0.72) and this change was statistically significant (p=0.007). While distance estimate errors increased with the actual distance increased, the increase in estimation errors was larger in the low illumination condition than in the high illumination condition. This is believed to be the first time that this effect has been quantified. Implications of this finding will be discussed with respect to NVG operation in aviation.

6557-26, Session 5

Comparison of an NVG model with experiments to elucidate temporal behaviour

P. J. Thomas, Topaz Technology Inc. (Canada); H. Mehbratu, York Univ. (Canada); S. A. Jennings, National Research Council Canada (Canada); J. Zacher, York Univ. (Canada); T. Macuda, National Research Council Canada (Canada); R. S. Allison, R. I. Hornsey, York Univ. (Canada)

A parametric Matlab model has been created for a night vision goggles (NVG), including the temporal behaviour in response to pulsed illumination. Of particular interest was the variation of NVG gain after a strong burst of illumination.

Gain reduction after a strong pulse was modeled with an exponential time constant for gain recovery. A capability for temporal modulation of the NVG gain was also modeled with a single time constant.

Laboratory measurements were performed to validate the model and tune its parameters. Highlights of the model are described, along with selected experimental data on its validation.

6557-37, Session 5

Hands-free focus technology for night vision applications

D. Roberts, W. Robinson, J. C. James, J. M. Cathcart, K. Lyons, L. West, T. L. Haran, T. Wasilewski, Georgia Institute of Technology

The lack of depth of field is a chronic problem for users of night vision goggles. The extremely low objective lens f-numbers required to collect sufficient light produce sharp images only over very limited ranges of object distances, especially for object distances less than a few meters. Manual focusing is currently the only option, which is difficult to impossible when the user is carrying a weapon or when involved in complex tasks. As a result, NVG users must frequently tolerate low resolution, defocused images that make navigation around obstacles difficult at best. The Georgia Tech Research Institute has developed a "hands-free focus" system for night vision application that greatly reduces the focus problem and enables the NVG user to concentrate on the task at hand rather than on constantly adjusting the NVG focus setting. The system design is presented as well as an analysis of its performance.

6557-27, Session 6

Effects of image intensifier halo on perceived layout

J. Zacher, T. Brandwood, York Univ. (Canada); P. J. Thomas, Topaz Technologies Inc. (Canada); M. Vinnikov, G. Xu, York Univ. (Canada); S. A. Jennings, T. Macuda, National Research Council Canada (Canada); S. Palmisano, Univ. of Wollongong (Australia); G. Craig, National Research Council Canada (Canada); R. S. Allison, York Univ. (Canada)

Night vision devices (NVDs) based on image intensifiers improve nighttime visibility and extend night operations for military and increasingly civil aviation. However, NVD imagery is not equivalent to daytime vision and impaired depth and motion perception has been noted. One potentially contributing factor to impaired perception of space and environmental layout is NVD halo, which is a phenomenon where bright light sources appear to be surrounded by a disc-like halo. In this study we measured the characteristics of NVD halo psychophysically and objectively and then evaluated their influence on perception of environmental layout in a simulation experiment. Halos are generated in the device and are not directly related to the spatial layout of the scene. We found that, when visible, halo size - but not intensity - was only weakly dependent on both source intensity and distance. Thus, the size of halos of sources at various distance are invariant of their distance and do not obey the normal laws of perspective. In simulation experiments we investigated the effect of halo on the judgement of an observer's attitude with respect to the ground during simulated flight. Night scenes containing halos showed systematic errors in perceived slope. We discuss these results in terms of the design of NVD and of human operators to compensate for perceptual distortions.

6557-28, Session 6

Night vision goggles, laser eye protection, and cockpit displays

G. L. Martinsen, P. Havig, Air Force Research Lab.; J. Dykes, T. Kuyk, Northrop Grumman Corp.; L. McLin, Air Force Research Lab.

The increasing use of lasers on the modern battlefield may necessitate the wear of laser eye protection devices (LEPDs) by warfighters. Unfortunately, LEPDs that protect against visible wavelengths often have reduced overall light transmittance. A wearer's vision can be degraded if light transmittance is significantly reduced, a problem that is exacerbated in low light conditions. Wearing night vision goggles (NVGs) can provide some laser eye protection but might leave areas of the peripheral retina exposed. The approach to this research effort was two pronged. First, the extent of a subject's field of regard (FOR) protected from laser exposure by wearing NVGs was measured. In a specialized device, subjects had the extent of their FOR measured. Then, each subject wore NVGs and the area of coverage was determined. The second part of this effort involved determining the effects of wearing LEPDs on vision in low light conditions, with and without the presence of a simulated head-down display (HDD). Subject's visual acuity under moonlight illumination levels was measured while wearing neutral density filters and LEPDs. Similar measurements of subject's visual detection, both on and off-axis, were made. Finally, the effects of LEPD wear on visual acuity on the HDD were determined. The results showed that NVG wear only protects about 25% of the FOR. Also, wearing LEPDs in low-light conditions reduces visual acuity and detection. The presence of the HDD reduced acuity slightly but significantly. The HDD had no effect on on-axis detection and actually improved off-axis detection. The reasons for this final finding are unclear.

6557-29, Session 6

AH-64 monocular HMD visual assessment during urban combat in operation Iraqi freedom

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In Hiatt et al. (2004), it was recommended that a final investigation into Apache Integrated Helmet and Display Sighting System (IHADSS) visual issues would need to look at the new urban combat role of the AH-64 Apache helicopter. The IHADSS imagry is provided by a nose-mounted forward-looking infrared (FLIR) sensor. To perform this investigation, a questionnaire/survey was distributed and completed by AH-64D Apache pilots who participated in Operation Iraqi Freedom (OIF) between March 15, 2006 and April 8, 2006. The survey followed the

general format used in Hiatt et al. (2004).

Both male (35, 92%) and female (3, 8%) Apache pilots responded to the survey. Respondent age ranged from 23 to 43 years with a mean of 33.6 years and a median of 33.5 years, the standard deviation was 5.4 years. Total flight hours across all airframes had a mean of 1483.0 hours with a median of 1150 hours. The range was between 500-4000 hours, with a standard deviation of 911.0 hours. Overall, AH-64 time ranged from 300-3850 hours with a mean of 1139.1 hours and a median of 900 hours.

Respondents had a mean FLIR usage time of 440.2 hours, with a median of 311.5 hours and standard deviation of 360.5 hours. Total flight hours for combat sorties had a mean of 62.9 hours.

Data for reports of physical complaints and static and dynamic illusions were found not to be significantly different from frequencies reported in the previous OIF study. Both OIF studies reported height judgement and slope estimation as the most frequently reported static illusions and undetected drift and Faulty closure judgment as the two most frequently reported dynamic illusions. This general agreement between the two studies also continued for the type and frequency of degraded visual cues encountered during flight.

6557-30, Session 6

Integrated headgear for the future force warrior: results of first field evaluation

W. J. Schuyler, J. E. Melzer, Rockwell Collins Optronics

The ground soldier of the future will benefit from current developments in electronics, lightweight ballistic materials, and importantly, displays and sensors. The Army's Future Force Warrior program is taking advantage of initiatives in both government and industry labs as well as human factors information to demonstrate the advantages they can provide. This paper will present the results of the first field evaluation of the Future Force Warrior Integrated Headgear system.

6557-31, Session 6

Evaluation of head-worn display concepts for commercial aircraft taxi operations

R. E. Bailey, J. J. Arthur III, L. J. Prinzel III, L. J. Kramer, NASA Langley Research Ctr.

Previous research in the development of the Taxiway-Navigation and Situation Awareness (T-NASA) system and the Runway Incursion Prevention System (RIPS) have demonstrated that a Head-Up Display (HUD) enables more efficient and safer surface operations. However, this research also noted that two of major HUD limitations during ground operations are their monochrome form and a limited, fixed field-of-regard. A monochromatic display precludes the use of color for information decluttering and information cuing so the display area of a HUD must be carefully designed to provide the pilot with enough information without saturating the display with clutter. Further, HUD imagery, while allowing head-out operations, is restricted to its forward, fixed field-of-view and the use of conformal imagery is, consequently, limited.

Emerging Head Worn Displays (HWDs) are small, lightweight, full color display devices that may be worn without significant encumbrance to the user. By coupling the HWD with a head tracker, unlimited field-of-regard may be realized for commercial aviation applications. Therefore, head-tracked HWDs may directly address the limitations of the HUD while retaining all of its advantages. A previous study evaluated HWDs for approach and landing operations. The present work complements this previous work and is similar in some respects to other concepts and architectures but with several significant differences.

In the proposed paper, the results of a simulation experiment conducted at the NASA Langley Research Center are summarized. The experiment evaluated the efficacy of head-worn display applications of Synthetic Vision and Enhanced Vision technology to enhance transport aircraft surface operations, complementing the previous T-NASA and RIPS work. The simulation experiment was conducted using a Chicago, O'Hare (FAA Identifier: ORD) airport operational environment. Full details of the experimental results pertaining to the Synthetic and Enhanced Vision technologies are described in a companion paper in the Enhanced and Synthetic Vision Systems session in this year's SPIE Conference. This paper describes the specific design and evaluation results related to the head-worn display.

Following a summary of the results, the implications of HWDs for commercial business and transport aviation applications will be presented. Specific design and evaluation issues for HWDs are detailed related to the appropriateness of simulator evaluations for these technologies (i.e., sickness tendencies), commercial pilot acceptability and usability, user encumbrance due to the HWD, and overall HWD system latency, accuracy, and techniques for boresight and alignment. Finally, a comparison is made of the operational and safety benefits provided by the HWD system relative to current-day and "next-day," non-HWD applications

6557-32, Session 6

Preliminary assessment of the utilization of night vision goggles in airborne forest fire suppression

S. A. Jennings, G. Craig, R. Erdos, T. Macuda, National Research Council Canada (Canada); D. Filiter, B. Crowell, Ontario Ministry of Natural Resources (Canada)

Helicopters are widely used in daytime forest fire suppression, conducting diverse tasks such as spotting, re-supply, medical evacuation and airborne delivery. Potential operational improvements necessitate consideration of airborne fire suppression at night. Helicopter operators are likely to deal with many challenges when operating in the vicinity of forest fires at night, including scene obscuration from smoke and dynamic changes in lighting conditions. Data on the use of Night Vision Goggles (NVGs) for airborne forest fire suppression is lacking. To address this issue, the Flight Research Laboratory (FRL) of the Institute for Aerospace Research of the National Research Council of Canada (NRC), in collaboration with the Ontario Ministry of Natural Resources, performed a preliminary flight test to examine the use of NVGs while operating near forest fires. The study also simulated aspects of night time water bucketing. The preliminary observations from this study suggest that NVGs have potential to improve the safety and efficiency of airborne forest fire suppression, including forest fire perimeter mapping and take-off and landing in the vicinity of open fires. NVG operations at some distance from the fire pose minimal risk to flight, and provide an enhanced capability to identify areas of combustion at greater distances and accuracy. However, as operations move closer to the fire, NVG flight becomes more risk intensive as a consequence of a reduction in visibility attributable to the adverse effects on NVG performance of the radiation and smoke emitted by the fire. It is suggested that risk mitigation strategies be developed to handle these situations. Although forest fire perimeter mapping and landing and departing from unprepared locations at night while using NVGs are feasible, pilot training and operating procedures should recognize that NVG image quality may be degraded, and the capacity to identify terrain and obstacles may be impaired in the vicinity of the fire. The preliminary results of this study suggest that water bucketing at night is a difficult operation with elevated risk, therefore it is recommended that further investigation be pursued to determine safe operational limits for water bucketing utilizing risk mitigation strategies. In summary, the results from the current study suggest NVGs are a useful tool in fire suppression and further research is necessary to clarify the operational limitations and implementation of these devices in forest fire suppression.

6557-33, Session 6

Wireless communication technology as applied to head mounted display for a tactical fighter pilot

G. Saini, Air Force Research Lab.

The use of Helmet-Mounted Display/Tracker (HMD/Ts) is becoming widespread for air-to-air, within visual range target acquisition for a tactical fighter pilot. HMD/Ts provide the aircrew with a significant amount of information on the helmet, which reduces the burden of the aircrew from having to continually look down in the cockpit to receive information. HMD/Ts allow the aircrew to receive flight and targeting information regardless of line-of-sight, which should increase the aircrew's situation awareness and mission effectiveness. Current technology requires that a pilot wearing a Helmet Mounted Display/ Tracker be connected to the aircraft with a cable. The design of this cable is complex, costly, and its use can decrease system reliability. Most of the problems associated with the use of cable can be alleviated by using wireless transmission for all signals. This will significantly reduce or eliminate the requirements of the interconnect cable/ connector reducing system complexity, and cost, and enhancing system safety. A number of wireless communication technologies have been discussed in this paper and the rationale for selecting one particular technology for this application has been shown. The problems with this implementation and the direction of the future effort are outlined.

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6558-02, Session 1

Vehicle and dismounted displays in the operational environment

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Displays in the operational environment, whether vehicle mounted or utilized by the dismounted soldier, can be direct-view or virtual-view, and are analyzed in terms of a broad range of performance parameters. These parameters include image area, field of view, eye-relief, weight and power, luminance and contrast ratio, night vision goggle compatibility (type and class), resolution (pixels per inch or line pairs per milliradian), image intensification, viewing angle, grayscale (shades or levels), dimming range, video capability (frame rate, refresh), operating and storage altitude, depth limit for water immersion, operating and storage temperature range, shock and vibration limits, mean time between failure, color vs. monochrome, and display engine technology.

This study further looks at design class: custom, versus rugged commercial, versus commercial off-the-shelf designs and issues such as whether the design meets requirements for the operational environment and modes of use, ease of handling, failure modes and soldier recommended upgrades.

6558-03, Session 1

Using ARINC 818 avionics digital video bus (ADVB) for military displays

J. A. Alexander, T. Keller, Great River Technology, Inc.

ARINC 818 Avionics Digital Video Bus (ADVB) is a new digital video interface and protocol standard developed especially for high bandwidth uncompressed digital video. The standard, due for release in January of 2007, has been advanced by ARINC and the aerospace community to meet the acute needs of commercial aviation for higher performance digital video. This paper analyzes ARINC 818 for use in military display systems found in avionics, helicopters, and ground vehicles. The flexibility of ARINC 818 for the diverse resolutions, grayscales, pixel formats, and frame rates of military displays is analyzed as well as the suitability of ARINC 818 to support military requirements for bandwidth, latency, reliability, distance, and environment. Implementation issues relevant to military displays are presented.

6558-04, Session 1

Upgraded immersive input display device (I2D2)

D. Tremper, Naval Research Lab.; A. Brosky, Cardinal Scientific, Inc.

In an effort to reduce the effects of ambient light on the read-ability of military displays, the Naval Research Lab began investigating and developing advanced hand-held displays. Analysis and research of display technologies with consideration for vulnerability to environmental conditions resulted in the complete design and fabrication of the hand-held Immersive Input Display Device (I2D2) monocular. The I2D2 combines an OLED SVGA micro-display with an optics configuration and a rubber pressure-eyecup which allows view-ability only when the eyecup is depressed. This feature allows the I2D2 to be used during the day, while not allowing ambient light to affect the readability. It simultaneously controls light leakage, effectively eliminating the illumination, and thus preserving the tactical position, of the user in the dark. This paper will focus on the upgraded I2D2 system as it compares to the I2D2 presented at SPIE 2006.

6558-25, Session 1

The off-axis viewing device: a rifle-mounted sighting system for search and engagement from covered positions

T. W. Chapman, C. G. Brady, Defence Science and Technology Organisation (Australia)

Soldiers involved in urban operations are at a higher risk of receiving a bullet or fragment wound to the head or face compared to other parts of their body. One reason for this vulnerability is the need for the soldier to expose their head when looking and shooting from behind cover. Research conducted by DSTO Australia, using weapon-mounted cameras has validated the concept of off-axis shooting, but has emphasised the requirement for a system that closely integrates with both the soldier and his weapon. A system was required that would not adversely affect either the usability, utility or accuracy of the weapon. Several Concept Demonstrators were developed over a two-year period and the result of this development is the Off Axis Viewing Device (OAVD). The OAVD is an unpowered sighting attachment that integrates with a red dot reflex sight and enables the soldier to scan for and engage targets from a position of cover. The image from the weapon's scope is transmitted through the OAVD's periscopic mirror system to the soldier. Mounted directly behind the sight, the OAVD can also be swivelled to a redundant position on the side of the weapon to allow normal on-axis use of the sight. The OAVD can be rotated back into place behind the sight with one hand, or removed and stored in the soldier's webbing. In May 2004, a rapid acquisition program was initiated to develop the concept to an In Service capability and the OAVD is currently in-service with the Australian Defence Force.

6558-05, Session 2

Validation of resized commercial AMLCD technology for cockpit avionics

P. Bendale, Interface Displays & Controls, Inc.

Despite a 15-year availability of re-sized AMLCD components, the defence industry and military users have been reluctant to field this technology in operational avionics equipment. However, the urgent need to develop and replace certain avionics displays for which no commercial AMLCD is available and for which custom designed devices are too expensive, indicated a need to verify the viability of a resized AMLCD option. This paper will describe development and testing of a resized AMLCD that was conceived and designed specifically to validate resized AMLCD technology to avionics applications. The application and test environment selected is a cockpit Control Display Unit (CDU). We describe the CDU operational environment and how the resized COTS display matched these requirements. Results from performance and environmental tests that were used to validate this technology in the cockpit avionics environment are provided and discussed.

6558-06, Session 2

COTS displays applied to avionics applications

J. T. Thomas, C. Waitman, General Dynamics Canada Ltd. (Canada)

Avionics displays, particularly for cockpit applications are associated with high performance in difficult operational environments and thus with high cost solutions. COTS displays have well acknowledged limitations but provide a potential high value-for-money solution if this performance can be stretched to a level compatible with "fit for use". This paper will describe the initial design tradeoffs and decisions that formed the basis for development of low-cost cockpit and mission-systems displays for a military helicopter.

6558-07, Session 2

A COTS derived NVG compatible avionics display

J. T. Thomas, A. Cavalcanti, General Dynamics Canada Ltd. (Canada)

Many avionics displays, particularly for cockpit applications require NVG compatibility. Unusually, the mission definition for the new Maritime Helicopter Programme (MHP) for the Canadian Forces has identified a need for NVG compatibility for all of the mission-system displays. This paper will describe how this new display was implemented.

6558-08, Session 2

E-2D advanced Hawkeye: control display unit

R. Saxena, Northrop Grumman Corp.; P. W. Paolillo, Naval Air Systems Command; J. Garruba, Northrop Grumman Corp.; D. Saelens, Barco N.V. (Belgium)

E-2D AHE aircraft will use 5 CDUs, of which the two front center console CDUs will be used by the cockpit crew to control IFF, ACAWS, SAFCS, Navigation Systems, tune VHF/UHF radios, etc. The three aft-CDUs will display status of Vapor Cycle System & Mission Computer Display System, etc. The CDUs utilize state-of-the-art AMLCDs with built-in display heater & built-in EMI shield, high density patterned column spacers, LC fluid with high clearing temperature of 103 * C, 8 bits of gray levels with 16.7 million colors. The smart E-2D AHE CDUs main processor board contain Power PC755 \@ 400MHz, 256MB SDRAM, 1MB L2 cache, and a Graphics mezzanine with P9 Permedia chip. The native software is Barco MOSArt(TM) including Vx Works 5.5.1 Operating System and Northrop Grumman OFP. The E-2D AHE CDU has been fully qualified to meet MIL-STD-810F & MIL-STD-461E requirements.

6558-09, Session 2

Black background NVIS radiance for liquid crystal displays

R. M. Maner, D. Hadlich, Honeywell International

The display requirements for Night Vision Imaging System (NVIS) compatibility have not changed since 1986 and do not reflect lessons learned with newer technology. The current military standard, MIL-STD 3009, maintains the performance requirements for Class A and Class B NVIS compatibility as were required by MIL-L-85762 with the addition of Class C NVIS. These requirements do not provide meaningful guidance for the color of black on LCDs, which are transmissive in the near infrared (IR) region where night vision goggles (NVGs) are most sensitive. As a result, ad hoc requirements placed upon display manufacturers have pushed beyond the measurement capability of state of the art spectroradiometers. This paper provides recommendations to reconcile the performance requirements needed for displays and the associated systems used for NVIS requirements verification. The first recommendation is that the black background NVIS radiance requirement be established as 1.6E-10 NRb for all displays. It is also recommended that all colors, including black, use the white scaling factor to determine the reported value for NVIS radiance. NVIS radiance will then be reported at a single operating point. The final recommendation is to lower the spectroradiometer sensitivity requirement of Appendix A of MIL-STD-3009 to a level which is equivalent to the recommended 1.6E-10 NRb NVIS radiance value. This will help meet the intent of the military specifications which strive for repeatable, high-quality measurements of NVIS radiance.

6558-10, Session 3

Real time image enhancement for vehicle mounted and man portable display systems

T. L. P. Olson, H. C. Lee, D. Manville, J. Puritz, DRS Technologies, Inc.

It is critical in surveillance applications to be able to extract features in imagery that may be of interest to the viewer at any time of the day or night. Infrared (IR) imagery is ideally suited for producing these types of images. However, even this imagery is not always optimal. Processing the imagery with a local area image operator can enhance additional features and characteristics in the image that provide the viewer with an improved understanding of the scene being observed. This paper discusses the development of an algorithm for image enhancement for infrared imagery using local area processing. The enhancement algorithm extends theory previously developed for medical applications. Algorithm differences addressed include application to IR imagery and to a panning camera rather than still imagery. It also discusses the obstacles encountered and overcome for insertion of this algorithm into a 10" gimbaled midwave infrared imaging system for a variety of real-time processing applications. This technology is directly applicable to drivers vision enhancement systems as well as other night visions systems such as night vision goggles.

6558-11, Session 3

Design flow for implementing image processing in FPGAs

M. Trakalo, G. Giles, General Dynamics Canada Ltd. (Canada)

A design flow for implementing a dynamic gamma algorithm in an FPGA is described. Real-time video processing makes enormous demands on processing resources. An FPGA solution offers advantages over commercial video chip and DSP. The traditional approach to FPGA development involves a system engineer designing, modelling and verifying an algorithm and writing a specification. A hardware engineer uses the specification as a basis for coding in VHDL and testing the algorithm in the FPGA. This process is work intensive and the verification of the image processing algorithm executing on the FPGA does not occur until late in the program.

The described design process allows the system engineer to design and verify a true VHDL version of the algorithm, executing in the target FPGA. This process yields reduced risk and development time. The process is achieved by using Xilinx System Generator in conjunction with Simulink from The MathWorks. System Generator is a tool that bridges the gap between the high level modeling environment and the digital world of the FPGA. System Generator is used in developing the dynamic gamma algorithm for a candidate display product. The results of this effort are to increase the dynamic range of the displayed video, resulting in a more useful image for the user.

6558-12, Session 3

Image analysis and understanding using super resolution

H. C. Lee, T. L. P. Olson, D. Manville, G. Cloud, DRS Technologies, Inc.

Super-resolution (SR) provides a capability to improve the resolution of undersampled systems. This allows for warfighter display systems to have higher apparent resolution than possible with the detector elements alone. Through the trade-off of temporal information, a significant increase in spatial resolution is obtainable. This improvement is quantifiable by using Airy's disc analysis along with camera sensor pitch. Integrate the use of Airy's disc to quantify the image improvement in resolvability and ultimately image range. It is this comparison that sets the ground work for realistic expectations. Our SR system is also a natural tracker of moving vehicles with the addition of improved target resolvability. Super Resolution can capitalize on camera platforms instability. A by product of SR is digitally stabilized imagery to a fraction of a sub-pixel. Investigation into sub-pixel remapping has lead to the developed of improved super resolved images. Another, approach investigated has lead to the development of a window management scheme for further improvement. The cleaner an image is from a noise and structural point-of-view, the more amenable it is to sharpening in the composite SR image. Mapping into a transform space greatly reduces the correlation complexity which makes it easier to realize the complete algorithm into hardware. We have implemented this system into a real-time architecture. The hardware configuration is composed of an FPGA and supporting DSP processor.

6558-13, Session 3

Advances in temporally multiplexed multiscopic displays

V. B. Markov, S. A. Kupiec, MetroLaser, Inc.; A. R. L. Travis, Univ. of Cambridge; D. G. Hopper, G. Saini, Air Force Research Lab.

Progress in the performance of Spatial Light Modulators (SLM), Graphical Processing Units (GPU) and off the shelf high speed data busses have led to advances in the design of multiscopic 3D displays based on temporal multiplexing. Having developed a proof of concept prototype capable of displaying four independent viewing zones, we report on progress in the development of an improved system incorporating 8-12 viewing zones and a large format display. The designs under development employ a high speed LCD shutter operating synchronously with a high speed Deformable Mirror Device (DMD) based projector that forms multiple viewing zones via persistence of vision. Progress in the development of the optical design and corresponding hardware and software will be reported on.

6558-14, Session 3

Short-wave infrared imager cockpit lighting interface issues

P. L. Marasco, Air Force Research Lab.

With the introduction of the night-vision goggle (NVG) into vehicle cockpits, the transfer of visual information to the observer became more complex. This problem stems primarily from the fact that the image intensifier tube photocathode was sensitive to much of the visible spectrum. NVGs were capable of sensing and amplifying visible cockpit light, making the observation of the scene outside of the cockpit, the primary use for NVGs, difficult if not impossible. One solution was to establish mutually exclusive spectral bands; a band of shorter wavelengths reserved for transmission of visible information from the cockpit instrumentation to the observer and a longer wavelength region left to the night vision goggle for imaging the night environment. Several documents have been published outlining the night vision imaging system (NVIS) compatible lighting performance enabling this approach, seen as necessary for military and civilian aviation. Recent advances in short wave infrared (SWIR) sensor technology make it a possible alternative to the image intensifiers for night imaging application. However, application-specific integration issues surrounding the new sensor type must still be thoroughly investigated. This paper examines the impact of the SWIR spectral sensitivity on several categories of cockpit lighting and explores the possibility of expanding current NVIS compatible lighting requirements to address issues that arise from the SWIR spectral sensitivity.

6558-15, Session 4

Stainless steel display evaluation

D. G. Hopper, F. M. Meyer, S. Longo, Air Force Research Lab.; T. L. Trissell, General Dynamics Corp.

Active matrix organic light emitting diode (AMOLED) technology is one candidate to become a low power alternative in some applications to the currently dominant, active matrix liquid crystal display (AMLCD), technology. Furthermore, fabrication of the AMOLED on stainless steel (SS) foil rather than the traditional glass substrate, while presenting a set of severe technical challenges, opens up the potential for displays that are both lighter and less breakable. Also, transition to an SS foil substrate may enable rollable displays-large when used but small for stowage within gear already worn or carried or installed. Research has been initiated on AMOLED/SS technology and the first 320 x 240 color pixel 4-in. demonstration device has been evaluated in the AFRL Display Test and Evaluation Laboratory. Results of this evaluation will be presented along with a research roadmap.

6558-16, Session 4

Characterization of a monochromatic, 128x64 resolution PLED for military instrumentation applications

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Polymeric Light Emitting Diode (PLED) displays offer several advantages such as low voltage operation, high contrast, backlight elimination, thin form factor and wide viewing angles. PLED technology is currently being used in consumer devices and offers promising attributes for low information content military display applications. Optical and environmental characterization test data is provided to assess the feasibility of adapting an affordable, COTS PLED display for use in demanding military environments.

6558-17, Session 4

Color and shape perception on the Perspecta 3D volumetric display

G. A. Reis, P. Havig, E. Heft, J. McIntire, W. Bell, Air Force Research Lab.

Volumetric displays allow users to freely view 3D imagery without special eye wear. However, due to low display resolution, many colors appear distorted compared to their representation on a flat-panel display. In addition, due to the unique nature of the display, some shapes, objects, and orientations can also appear distorted. This study examines the perceptual range of virtual objects in a Perspecta three-dimensional (3D) volumetric display to determine which combination of color, position, object, and orientation produces the best 3D image. In the first experiment participants viewed three stimuli: a vertical square, an empty cube or a filled cube. They then named the color of the object, rated how solid the object seemed, and finally rated amount and annoyance of visual flicker. In a second experiment, participants viewed sets of three virtual objects for each trial: squares that were oriented vertically, squares oriented at a 45-degree angle, squares oriented near horizontal, or cubes. Participants were required to identify the color being displayed, identify which shape looked best (side or middle), and rate both the amount and annoyance of visual flicker. A third experiment investigated the perceived “solidity” of virtual cubes drawn with various methods. Results are discussed in terms of the optimal color, shape, position, and orientation requirements for subjective viewing quality and comfort.

6558-18, Session 4

Metrics for 3D displays

P. R. Havig, D. Aleva, J. Moore, G. Saini, E. Heft, J. McIntire, Air Force Research Lab.; T. L. Trissell, General Dynamics Corp.

There has been much research on many different aspects of image quality for 2D displays. These range from objective type metrics (e.g, luminance contrast, saturation contrast, resolution, etc.) to more subjective metrics (e.g,. “Rate the quality of the display from 1 - 5”), to metrics in between (subjective-objective) in which observers are asked to perform a task and their performance determines the “goodness” of the display. We would like to start identifying these similar types of metrics for 3D displays. In this case many of the traditional metrics do not work. We first attempted to get traditional objective type metrics for two 3D displays, the Sharp RD3D (autostereoscopic) and the Perspecta (volumentric) from Acuality. We discuss what worked and what did not as well as new objective measures we propose for 3D displays. Secondly we will discuss both subjective and subjective-objective metrics that have been used in the past, how well they may work for our situation as well as developing new metrics of these types. We finally will put forward our lessons learned in the hopes of generating discussion for future research to help display developers in their endeavors for new and innovative 3D displays.

6558-20, Session 5

Linear perspective limitations on VR and realistic displays

L. A. Temme, U.S. Army Aeromedical Research Lab.

There is a tendency to consider the rich images from natural world as the gold standard against which displays should be judged. The realism of photorealistic displays has an intuitive appeal; after all, what could be better? They look like the real world. Part of the shortcoming of this intuitive appeal is its naiveté. Realism itself is full of potential illusions; we just don't notice them since most of the time realism is good enough for our everyday tasks. But when confronted with tasks that go beyond those for which our visual system has evolved, we may be blindsided. If we survive, blind to our erroneous perceptions, we will not be any wiser next time.

Realist displays depend on linear perspective (LP), the mathematical mapping of three dimensions onto two. Despite the fact that LP is a seductively elegant system that predicts results with defined mathematical procedures, the people with the most experience with LP, artists, do not stick to the procedures because, if followed explicitly, they produce ugly, limited, and distorted images. If artists bother with formal LP procedures at all, they invariably temper their LP renderings by eye.

The present paper discusses LP assumptions, limitations, and distortions. It provides examples of kluges that have been used to cover some of these LP shortcomings. This is important so that we let neither naive assumptions nor the seductive power of LP to unrealistically guide our thinking or expectations as we develop modern HUDs, HMDs and VR displays.

6558-21, Session 5

Brightness limitations in integrated lighting systems

T. P. Jannson, M. J. Bennahmias, K. Chua, R. D. Pradhan, T. R. Forrester, Physical Optics Corp.; E. Arik, N. Nathan, K. Yu, Luminit LLC

In this paper, the foundations of radiometry and photometry, based on Second Principles of Thermodynamics are discussed, in terms of brightness (luminance) and ettendee (language invariant) limitations of integrated lighting systems. In such a case, the brightness is defined as phase-space-density, and other radiometric/photometric quantities such as emittance, existance, or irradiance/illuminance, power/flux, and radiant/luminent intensity, are also discussed. Several examples of integrated lighting systems are discussed, for illumination. Also, technologic progress in Luminit is reviewed, including 3D-micro-replication of new non-diffuser microscopic structures, by roll-to-roll web technology.

6558-22, Session 5

Agent-based display adaptation tool for automated visualization

J. J. Gallimore, Wright State Univ.; R. S. Woodley, 21st Century Systems, Inc.; A. Barnes, Wright State Univ.

To facilitate decision making tasks, it is necessary to be able "see" the situation. An enormous array of intelligence gathering, database, and sensor sources of information are available. Methods for visualizing the information must be established and information presented in such a way that human attention is captured and maintained on the most critical aspects of the information. Visualizations need to adapt to the changing circumstances to show the most relevant information at that time. We propose a cutting edge system that allows the user to adjust the visualization to user goals and needs, monitor the effectiveness of the visualization, propose changes, and adapt display information for the user. We are developing a system called Holistic Analysis, Visualization, & Characterization Assessment Tool (HAVCAT) that uses intelligent agents that interact with the user to provide the correct information at the right time. We examine visualization methods such as 2D/3D real pictures, 2D/3D virtual spaces, colors of uncertainty, fly through of terrain or virtual spaces, and animation. HAVCAT agents use data-mining techniques to locate and extract relevant information. The HAVCAT evidence reasoning agent distills the data and extracts the most pertinent actions or consequences. The user will be able to dynamically adjust the input streams and adjust the visualizations, receiving feedback from the agents to provide options for the display. The result is the user will be more in tune with the task by having a visualization that is custom made to the user's abilities and to the dynamic nature of the task goals.

6558-23, Session 5

Optical security and anti-counterfeiting using 3D screen printing

W. H. Wu, W. Yang, M. Kuo, H. Lee, National Defense Univ. (Taiwan); C. Chang, MingDao Univ. (Taiwan)

A novel method for optical decrypted key production using screen-printing technology is proposed. The key is mainly for decrypting the encoded information hided inside of document containing moiré patterns and integral photographic 3-D autostereoscopic images as a second-line security file. It also may apply to anti-counterfeiting of artistic screening. Decryption is performed by matching the correct angle between the decoding key and anti-counterfeiting document for example a text or a simple geometry pattern. Theoretical analysis and experimental results of the decoded key production by the best parameter combination of the moiré pattern size and the screen-printing elements are presented. The experimental results also proved that the proposed method can be widely applied in anti-counterfeiting document design manufacture for fast and comparatively low cost decryption key production.

6558-24, Poster Session

Computational integral imaging reconstruction of 3D objects using simultaneous pickup in real and virtual image fields

H. J. Lee, D. Shin, E. S. Kim, Kwangwoon Univ. (South Korea)

In this paper, a novel pickup method which can express simultaneously 3-D images in both of real and virtual fields and overcome limitation of effective pickup range using imaging lens in three dimensional integral imaging is proposed. When a 3-D object is located far from the lenslet array pickuped elemental image array (EIA) can not be reconstructed well because depth of focus of the lenslet array is limited. This optical pickup limitation can be overcome in the proposed method. In addition, optical limitation in display process can be solved by use of the computer integral imaging reconstruction (CIIR). Some experiments are carried out and its results are discussed as well.

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6559-01, Session 1

Synthetic vision systems: operational considerations simulation experiment

L. J. Kramer, S. P. Williams, R. E. Bailey, L. J. Glaab, NASA Langley Research Ctr.

Synthetic vision is a computer-generated image of the external scene topography that is generated from aircraft attitude, high-precision navigation information, and data of the terrain, obstacles, cultural features, and other required flight information. A synthetic vision system (SVS) enhances this basic capability with real-time integrity to ensure the validity of the databases, perform obstacle detection and independent navigation accuracy verification, and provide traffic surveillance. Over the last 5 years, NASA and its industry partners have developed and deployed SVS technologies for commercial, business, and general aviation aircraft which have been shown to provide significant improvements in terrain awareness and reductions in the potential for Controlled-Flight-Into-Terrain incidents / accidents compared to current generation cockpit technologies.

It has been hypothesized that SVS displays can greatly improve the safety and operational flexibility of flight in Instrument Meteorological Conditions (IMC) to a level comparable to clear-day Visual Meteorological Conditions (VMC), regardless of actual weather conditions or time of day. An experiment was conducted to evaluate SVS and SVS-related technologies as well as the influence of where the information is provided to the pilot (e.g., on a Head-Up or Head-Down Display) for consideration in potential lower landing minima credit for landing based upon aircraft and airport equipage. The “operational considerations” evaluated under this effort included reduced ceiling, visibility, and airport equipage requirements, such as approach lighting systems, for SVS-equipped aircraft. Another objective of this experiment was to define test and evaluation methods to help future government and industry certification activities for synthetic and enhanced vision technologies. Conclusions and future research directions are discussed.

6559-02, Session 1

EGPWS on synthetic vision primary flight display

G. He, T. Feyereisen, Honeywell International, Inc.; K. Conner, Honeywell Defense & Space Electronics Systems; S. Wyatt, J. Engels, Honeywell International, Inc.; A. Gannon, Honeywell Technology; B. Wilson, Honeywell International, Inc.

This paper described flight trials of integrating Honeywell Enhanced Ground Proximity Warning System (EGPWS) output into the Honeywell synthetic vision Integrated Primary Flight Display (iPFD) environment. During flight tests, the prototype IPfd display system is connected to the on-board EGPWS system and the EGPWS output is continuously monitored. When caution or warning events are present, the terrain and obstacle areas on the synthetic vision display, corresponding the EGPWS event, are dynamically displayed in corresponding EGPWS caution and warning colors blended with terrain relief information. The test results are presented and discussed.

6559-03, Session 1

Human factors evaluation of a dynamic channel depiction of navigation procedures in SVS displays

C. Pschierer, J. Schiefele, Jeppesen GmbH (Germany); D. Howland, Jeppesen; N. Barraci, A. Sindlinger, U. Klingauf, Technische Univ. Darmstadt (Germany)

During the last years Jeppesen has developed terrain, obstacle and airport databases as well as different electronic displays as part of the NASA Aviation Safety Program. This paper describes the continuation of this work, which is now focused on a completely dynamic channel depiction of navigation procedures inside a SVS display.

A human factors workshop has been conducted with pilots from the GA, BA and CA segment to identify the pilot’s expectations and requirements for channel guidance. The workshop covered three main topics of the program. A general information and task analysis revealed what information the pilots need while flying a procedure. The two other sessions dealt with the generation of the channel trajectory and the depiction of the channel trajectory.

The channel trajectories are generated dynamically using the flight dynamics of the aircraft in order to make the trajectory easily flyable even in turns and within the performance parameters of the aircraft. Trajectories can be generated for ARINC424 coded STARs and approaches. Additional trajectories and guidance cues for intercepting or reentering a procedure are generated, as well as ATC commands like radar vectors and missed approach procedures. The generated trajectories are verified to ensure they do not conflict with special use airspaces, obstacles and terrain.

Different concepts for the trajectory depiction have been implemented in order to study the repelling nature of the tunnel walls while avoiding discontinuities when leaving the tunnel completely as observable e.g. in the NASAs crow’s feet concept. Another studied idea was, not to use the corner of the tunnel as guidance symbol, but the medians of the four tunnel walls.

Finally, all components of the new SVS display have been compared in a simulator evaluation. Different scenarios have been used to validate different ways to generate guidance and intercept trajectories as well as three different tunnel depictions on STARs, Approaches and Radar Vectors. The situational awareness of the pilots has also been supported by a simple navigation display which shows the channels in front of a synthetic terrain depiction.

This paper described investigated display concepts and focuses on a detailed analysis of the final simulator evaluation.

6559-04, Session 1

Fused enhanced and synthetic vision system (EVS/SVS) for rotorcraft operations

C. L. Tiana, Aireyes, Inc.; R. Hennessy, Monterey Technologies, Inc.; C. W. Jennings, Nav3D Corp.

We describe a system developed for the Army to aid and enhance rotorcraft operations in low-level flight under degraded visibility conditions. The system includes a number of sensors: active, Enhanced Vision (EVS) sensors such as infrared and millimeter wave systems, and stored Synthetic Vision (SVS) sensors such as a terrain database. A real-time 3-dimensional terrain sensing radar corrects any errors in the a-priori database information. All streams (active and synthetic) are fused in real time and presented to the pilot in a cognitively effective display, much improved from current obstacle display and low-level navigation systems.

Particular effort was expended on the human factor aspects of the system, and its functional value is being evaluated by military helicopter pilots. The evaluation has three principal goals: 1) the willingness to use the SVS database for terrain awareness during low level flight (100-200 feet AGL) when FLIR is unavailable or degraded; 2) the value of real-time terrain validation, and 3) the usefulness of being able to switch or combine different sources of terrain information, e.g., IR, SVS, RF, on the fly as conditions warrant. The pilots’ choices of relative brightness for the different sources of terrain information is also being assessed.

6559-05, Session 1

Making a land/go-around decision with runway incursions in near zero-zero weather

D. M. Murphy, General Dynamics Corp.; D. J. Zimmer, U.S. Air Force; G. A. French, Air Force Research Lab.

Preventing runway incursions is considered a top safety priority for the National Transportation Safety Board and is a growing problem among commercial air traffic at controlled airfields. This problem only increases in difficulty when the weather and airfield conditions become severely degraded. Such is the case in this Air Force Research Laboratory work, which focused on the decision making process of aircrew landing under near zero-zero weather at an unimproved airfield. This research is a part of a larger demonstration effort using sensor technology to land in zero-zero weather at airfields that offer no or unreliable approach guidance. Using various head-up (HUD) and head-down (HDD) display combinations that included the sensor technology, pilot participants worked through the decision of whether the airfield was safe to land or go-around. The runway was considered unsafe only if the boundary of the runway was broken by an obstacle causing an incursion. A correct decision is one that allowed the aircrew to land on a safe runway and to go-around when an incursion was present. While going around is usually considered a safe decision, in this case a false positive could have a negative mission impact by preventing subsequent landing attempts. In this study we found a combination of display formats that provided the greatest performance without making significant changes to an existing avionics suite.

6559-06, Session 1

Flight assessment of an integrated DNAW helicopter pilotage display system; flight trials 'Hawk Owl'

J. Sadler, D. Thorndycraft, P. Longman, D. Marsden, QinetiQ (United Kingdom)

Military helicopter operations are often constrained by environmental conditions including low light levels and poor weather. Recent experience has also shown the difficulty presented by certain terrain when operating at low altitude by day and night. For example, poor pilot cues over featureless terrain with low scene contrast, together with obscuration of vision due to wind blown and re-circulated dust at low level (brown out). These sorts of conditions can result in loss of spatial awareness and precise control of the aircraft. Atmospheric obscurants such as fog, cloud, rain and snow can similarly lead to hazardous situations due to reduced situational awareness. Day Night All Weather (DNAW) systems applied research sponsored by UK MOD has developed a systematic, human centred approach to understanding and developing pilotage display systems for challenging environments. A prototype DNAW system has been developed using an incremental flight test programme leading to the flight assessment of a fully integrated pilotage display solution, trial HAWKOWL, installed in a Sea King helicopter. The system comprises several sub-systems including a multi-spectral sensor suite, image processing and fusion, head down and head-tracked Display Night Vision Goggles, onboard mission planning and route generation, precision navigation, dynamic flight path guidance and conformal, task dependent symbology using applied Gestalt theory. A variety of qualitative and quantitative assessment techniques have been developed and applied to determine the performance of the system and capability it provides. The paper describes the approach taken in the design, implementation and assessment of the system and identifies key results from the flight trial.

6559-16, Session 1

Operations concept for the use of synthetic vision system (SVS) display during precision instrument approach

D. A. Domino, The Mitre Corp.

Synthetic Vision Systems (SVS) create images for display in the cockpit from the information contained in databases of terrain, obstacles and cultural features like runways and taxiways, and the known own-ship position in space. Displays are rendered egocentrically, from the point of view of the pilot. The utility of the information provided on SVS displays is subject to the accuracy, reliability and integrity of both the database information used to create the imagery, and the calculated eye point.

Certified synthetic vision systems, however, do not yet qualify for operational credit in any domain, other than to provide enhanced situation awareness. As promising as SVS technology may be, it is not known at this time whether the information provided by the system can be judged sufficiently robust to substitute for natural vision.

In this paper an operations concept is described for the use SVS information during a precision instrument approach in lieu of visual contact with the approach light system. It proposes an operation within the existing framework of regulations, and identifies specific areas that may require additional regulatory guidance to consider certification of the proposed operational credit. The larger purpose of the paper is to provide a concrete example application which will require the elaboration and resolution of issues that will almost certainly be applicable to many application domains. To this end, issues in several categories are identified and a substantial review of prior research is provided.

6559-07, Session 2

Use of X-band weather radar to support the terrain database integrity monitoring and terrain referenced navigation function

A. Singh, M. Uijt de Haag, Ohio Univ.

To enable safe use of Synthetic Vision Systems (SVS) at lower altitudes, real-time sensor measurements are required to ensure the integrity of terrain and obstacle models stored in the system and to detect hazards that may have been omitted from the stored models. This paper discusses various aspects of using X-band weather radar for terrain database integrity monitoring and terrain referenced navigation. Various feature extraction methods will be addressed to support the correlation process between the weather radar measurements and the stored terrain databases. Furthermore, improved weather radar antenna models will be discussed to more reliably perform the shadow detection and extraction (SHADE) functionality. In support of the navigation function, methods will be introduced to estimate aircraft state information, such as velocity, from the geometrical changes in the observed terrain imagery. The outputs of these methods will be compared to the state estimates derived from Global Positioning System (GPS) and Inertial Navigation System (INS) measurements. All methods discussed in this paper will be evaluated using flight test data collected with Ohio University's King Air in Juneau, AK, with NASA's DC-8 in Reno, NV and with a Gulfstream V in Reno, NV (GVSITE).

6559-08, Session 2

Enhanced and synthetic vision system for autonomous all weather approach and landing

B. R. Korn, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Enhanced Vision Systems (EVS) are aiming to alleviate restrictions in airspace and airport capacity in low-visibility conditions. EVS relies on weather-penetrating forward-looking sensors that augment the naturally existing visual cues in the environment and provide a real-time image of prominent topographical objects that may be identified by the pilot. The basic idea behind the technology is to allow VMC operations under IMC. The recently released (in spring 2004) final rule of the FAA for Enhanced Flight Vision Systems (EFVS) for part 92 aircraft (business aircraft, general aviation aircraft) clearly acknowledges the operational benefits of such a technology by stating the following: "Use of an EFVS with a HUD may improve the level of safety by improving position awareness, providing visual cues to maintain a stabilized approach, and minimizing missed approach situations". Moreover, "The pilot would use this enhanced flight visibility ... to continue the approach from DH or MDA down to 100 ft above the touchdown zone elevation of the runway of intended landing". This rule change marks a significant token of confidence towards EVS technology and clearly demonstrates that EVS offers the capability to decrease landing minima and thus, increase accessibility of airports (even of non-equipped airports) under low visibility conditions. Furthermore, they offer the possibility for reduction of radar separation in case the pilot is able to clearly detect the leading aircraft in the sensor image. One mayor advantage of EVS is that it can be easily used in combination with other landing aids like e.g. SBAS. Allowing the pilot to "see" under low visibility conditions, EVS increases safety and offers the possibility to increase accessibility and capacity by reducing landing minima or even by reducing separation distances.

It easily can be seen that the performance of the Enhanced Vision System is strongly depending of the selection of imaging sensors. At DH (or MDA) of the flown approach procedure the pilot has to use EVS as primary input to continue the approach down to 100ft after which visual contact to the runway has to be established. Infra-red (IR) and millimeter-wave (MMW) sensors are currently envisaged as EVS support of pilot vision in low visibility. One important benefit of IR-sensors is that these sensors generate a perspective image, from which the human can derive the perceptual cues of depth to generate a three-dimensional interpretation of the outside world. This is an important feature of the IR-sensor as such a perspective sensor image can be overlaid to the outside scene on a head-up display (HUD). However, the penetration of bad weather in the infrared spectrum is remarkably poorer than the weather penetration that can be achieved by MMW-radar. An active MMW-radar delivers primarily information about the range and the angular direction (azimuth) of a certain object. This range/angle information can be transformed into a view "out-of-the-window", but there is still a lack of information about the objects' height or their vertical position. The presentation of such images needs knowledge about the surrounding elevation, which often is estimated by the so-called "flat-earth-assumption".

An important topic for integrating new visual sensors into existing cockpit environments concerns the question on how to visualize the acquired images and/or visual cues. An obvious method for showing this information is a simple overlay onto the head-up-display (HUD). Due to its simplicity this method has been applied in several projects in the past.

Within its research project ADVISE-PRO (Advanced visual system for situation awareness enhancement - prototype, 2003 - 2006) that will be presented in this contribution DLR has combined elements of Enhanced Vision and Synthetic Vision to one integrated system to allow all low visibility operations independently from the infrastructure on ground. The core element of this system is the adequate fusion of all information that is available on-board. In principle, high precision on-board navigation data in combination with an accurate airport database is sufficient to enable the pilot to land the aircraft (Synthetic Vision System). But under low visibility condition, the pilot cannot verify whether these information are correct, or if there are errors in either the navigation data or in the airport database. Up to now, sufficient integrity neither of available airport databases nor of on-board navigation (combination of DGPS with INS) can be guaranteed. Therefore, without additional means to verify the correctness of such information, approach and landing cannot be performed under such circumstances. In the ADVISE-PRO system, the necessary verification of navigation and airport database (integrity monitoring) is obtained by the additional use of weather penetrating imaging sensors an MMW radar sensor and a long wave infrared camera. Significant structures, e.g. like the runway itself, are extracted from the sensor data (automatically by means of "machine vision") and checked whether they match with the navigation data in combination with database information. Furthermore, the sensor images are analysed to detect obstacles on the runway.

Aircraft that are equipped with such a system can perform board-autonomous all-weather approach and landing, only on those airports of which accurate airport databases are available. Thus, on part of ADVISE-PRO was the development of a subsystem that calculates the position of the aircraft relative to the runway threshold based on the analysis of the senor data only (sensor based navigation).

The key modules of the ADVISE-PRO system are:

1. Integrity monitoring of navigation data and terrain data:

Verification of on-board navigation data ((D)GPS + INS) with sensor data (MMW-Radar, IR-Sensor, Radar altimeter) and airport / terrain databases.

2. Sensor based navigation:

Determination of the aircraft's position relative to the runway by automatically analysing sensor data (MMW, IR, radar altimeter) without using neither (D)GPS nor precise knowledge about the airport geometry.

3. Obstacle detection

Detection of obstacles on the runway.

4. Consistent description of situation:

Coordination, evaluation and fusion of the information processing systems (pos 1- 3) to a consistent and reliable description of the situation to be displayed to the pilot.

Altogether, more than 100 flights (approaches and landings) have been performed within ADVISE-PRO for acquisition of sensor data as well as for successful verification of the system.

6559-09, Session 2

Towards an inexpensive computer vision-based automated landing system for unmanned aerial vehicles

K. Blenkhorn, S. O'Hara, 21st Century Systems, Inc.

Most Unmanned Aerial Vehicles (UAVs) currently require a dedicated pilot for landing, adding significant cost and complexity to UAV deployment. Existing automated landing systems typically require specialized equipment both at the landing site and on the aircraft. Our proposed system for UAV auto-landing requires minimal landing site preparation, no additional electronics, and no additional aircraft equipment of any kind. This is a Joint-UAV solution that will work equally well for land-based aircraft and for shipboard recoveries.

Our proposed system requires only a simple target that can be permanently painted on a runway, temporarily marked in dirt, or laid out with chemlights for night operations. Its appearance is unique when seen from the optimal approach path, and from other angles its perspective distortion indicates the needed correction. By making continual adjustments based on this feedback, the plane can land in a very small area at the desired angle.

We time the pre-touchdown flare using only a 2D visual reference. We use a biomimetically-inspired algorithm to determine the distance to the landing target. Assuming a constant closing speed, we can estimate the time to contact and initiate a controlled flare at a predetermined interval. The aircraft then switches to using distant targets as references to ensure a straight rollout after touchdown.

Using these techniques to determine approach path and flare timing, the proposed system will enable automated landings in difficult conditions including heavy seas, moving ships, and crosswinds, promoting ship or land recovery for most current OTS Small and Micro UAVs.

6559-10, Session 2

Applying SVS technology to improve UAV manual control performance

J. Tadema, Netherlands Defence Academy (Netherlands); E. Theunissen, J. Koeners, Technische Univ. Delft (Netherlands)

For the manual control of the flight path of Unmanned Aerial Vehicles (UAVs), the instruments provided in a UAV Control Station (UCS) are similar to those found in the cockpit of an aircraft. Typically the out-of-the-window view is represented by a nose-mounted camera view and a plan-view display containing an electronic map is used for navigational conformance monitoring. Obviously, the richness of the visual-, motion- and auditory cues that are available to the pilot of a manned aircraft is not available to the UAV operator. In addition, the information that is available to the UAV operator typically suffers from low update-rates, caused by sensor and datalink bandwidth limitations. Furthermore, compared to manned aircraft, the data presented by the instruments in the UCS is subjected to an increased latency due to the (SATCOM) datalink.

With the current generation UAVs one of the most demanding tasks for the operator is the manual control task in the landing phase. Current accident statistics indicate that manual control related loss is significant. A reduction in control related landing accidents might be achieved through the improvement of control performance by benefiting from the unexplored potential in the areas of data filtering and advanced display concepts.

A prototype UAV operator station has been extended with the capability to systematically vary sensor and datalink properties. Furthermore it comprises functionality to mitigate undesired artifacts and includes a perspective guidance overlay. An experiment has been performed in which a baseline representative for the current state-of-the-art UCS instrumentation was compared with a concept that includes conformally integrated trajectory preview and advanced data filters.

6559-11, Session 2

Ecological interface paradigm for remote and mobile manipulation

J. A. Atherton, M. A. Goodrich, Brigham Young Univ.

Mobile robots with manipulation capability are useful tools in dangerous or inaccessible areas. For example, they are used in planetary exploration (Mars rovers), urban search and rescue, and explosive ordinance disposal. In remote situations, the only connection the operator has with the robot is the user interface.

One difficulty in remote and mobile manipulation is to understand the environment around the robot. Typical user interfaces show the video feed from a camera separate from other information, such as robot position. This separation requires performing a mental transformation to correlate robot position with video. When the video and telemetry are displayed in context with each other, the mental transformations are reduced.

Situation awareness is especially important when the operator is directing multiple agents. We can consider as an example four agents on a team: mobile robot, camera mounted on the robot, attached manipulator, and camera mounted on the manipulator. The agents in the team are displayed together in a way that resembles their physical configuration. Such organization encourages acquisition of situation awareness.

The interface we present displays a synthesized view of the mobile robot, manipulator arm, and telemetry. The video feeds are projected onto a plane in front of each camera in virtual space. The virtual view acts as a common frame of reference for all agents in the system. Ecological interfaces provide grounding for team coordination.

Although the above example directly applies to mobile manipulation, the ideas are applicable to other teams. For example, a team composed of multiple UAVs, UGVs, and humans.

The scope of this paper is to explain the requirements of an ecological interface for remote and mobile manipulation.

6559-12, Session 3

Design and testing of an unlimited field-of-regard synthetic vision head-worn display for commercial aircraft surface operations

J. J. Arthur III, L. J. Prinzel III, L. J. Kramer, S. P. Williams, R. E. Bailey, NASA Langley Research Ctr.

Experiments and flight tests have shown that a Head-Up Display (HUD) and a head down, electronic moving map (EMM) can be enhanced with Synthetic Vision for airport surface operations. While great success in ground operations was demonstrated with a HUD, the research noted that two major HUD limitations during ground operations are their monochrome form and a limited, fixed field of regard. A potential solution to these limitations found with HUDs may be emerging Head Worn Displays (HWDs). HWDs are small, lightweight full color display devices that may be worn without significant encumbrance to the user. By coupling the HWD with a head tracker, unlimited field-of-regard may be realized for commercial aviation applications. In the proposed paper, the results of a ground simulation experiment conducted at NASA Langley are summarized. The experiment evaluated the efficacy of head-worn display applications of Synthetic Vision and Enhanced Vision technology to enhance transport aircraft surface operations. The study tested four display concepts: (1) baseline consisting of existing cockpit displays including a Class III electronic flight bag display of the airport surface; (2) a modified version a HUD and EMM display demonstrated in previous research; (3) an unlimited field-of-regard, full color, head-tracked HWD with a conformal 3-D synthetic vision surface view; and (4) a fully integrated HWD concept. The fully integrated HWD concept is a head-tracked, color, unlimited field-of-regard concept that provides a 3-D conformal synthetic view of the airport surface integrated with advanced taxi route clearance, taxi precision guidance, and data-link capability. Following a summarization of the results, the implications of these data for commercial business and transport aviation applications for taxi operations will be presented.

6559-13, Session 3

The challenges with displaying EVS and SVS video on a head-up display

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Displaying video on a Head-up Display from an Enhanced Vision camera presents some unique challenges not seen on conventional head-down flight deck displays. All information displayed on the HUD has to be seen against a background that can vary from bright sunlight to a dark night sky. The video has to include enough gray shade information to support visual identification of runway features and the image shown on the HUD has to be visually aligned to the real world accurately enough to support low visibility operations at airports. The pilot wants to clearly see the image on the HUD but also needs to see the real world through the display when it can be seen with the naked eye. In addition, the video display cannot interfere with the display of existing flight information symbology. This paper identifies the challenges with displaying video on the HUD from enhanced vision and synthetic vision sources and some solutions that make this display media an important part of new flight deck designs.

6559-14, Session 3

A real-time panoramic video display system for local situational awareness

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Distributed aperture sensor (DAS) systems can enhance the situational awareness of operators in both manned and unmanned platforms. In such a system, images from multiple sensors must be registered and fused into a seamless panoramic mosaic in real time, whilst being displayed with very low latency to an operator.

This paper describes an algorithm for solving the multiple-image alignment problem and an architecture that leverages the power of commercial graphics processing units (GPU) to provide real-time display of a live panoramic mosaic.

We also describe other developments aimed at integrating high resolution imagery from an independently steerable fused TV/IR sensor into the mosaic, panorama stabilisation and automatic target detection.

6559-15, Session 3

The use of configural displays to promote pilot situation awareness

J. C. Jenkins, U.S. Air Force; J. J. Gallimore, Wright State Univ.

An unresolved issue in the theory of situation awareness (SA) is how to best portray critical information in visual displays such that the user can quickly detect cues relevant to their current goal amid vast amounts of other data and form the basis for Level 1 SA, the perception of elements in the environment. Previous research has shown that the use of configural displays allows subjects to more easily detect changes in dynamic processes for integration tasks thereby enhancing operator performance, yet the benefit of configural displays on operator SA has yet to be assessed. To test whether or not the use of configural displays impacts the formation of pilot situation awareness, a computer-based study was undertaken using two presentation rates (500ms and 1000ms) and three display formats (Mil-Std-1787 HUD, Dual-articulated (DA) HUD, and the Arc Segment Attitude Reference (ASAR)) to present aircraft flight reference information to pilots. One of five questions were possible following the removal of the display from the screen, a query about aircraft airspeed, altitude, flight path angle (climb or dive) or bank angle. The aim of the study was to demonstrate the ability to provide an increase in operator SA by utilizing emergent features in configural displays to increase cue saliency and thereby increase operator SA. The analysis of pilots' recall of aircraft flight path angle (percent correct) showed that pilots were significantly more aware of aircraft attitude with the ASAR than with either the Mil-Std-1787 or DA displays. There was no difference among displays for recall of actual flight path angle (RMS error). The results are discussed in terms of the use of configural displays utilizing goal-relevant system information mapped onto emergent features to promote operator SA.

6559-17, Session 4

Prevention of runway incursions due to closed runways or unsuitable runway choices by enhanced crew situational awareness and alerting

C. Vernaleken, C. Urvoy, U. Klingauf, Technische Univ. Darmstadt (Germany)

Of all incidents on the aerodrome surface, Runway Incursions, i.e. the incorrect presence of an aircraft on a runway, are the by far most safety-critical, resulting in many fatalities if they lead to an accident. A lack of flight crew situational awareness is almost always a key causal factor in these occurrences, and like any Runway Incursion, the special case of choosing a closed or unsuitable runway - including mistaking a taxiway for a runway - may have catastrophic consequences, as the Singapore Airlines Flight SQ006 accident at Taipei in 2000 and, most recently, Comair Flight 5191, tragically show. In other incidents, such as UPS Flight 896 at Denver in 2001 departing from a closed runway or China Airlines Flight 11 taking off from a taxiway at Anchorage in 2002, a disaster was only avoided by mere luck.

This paper describes how the concept for an onboard Surface Movement Awareness & Alerting System (SMAAS) can be applied to this special case and prevent flight crews from taking off or landing on closed runways, unsuitable runways or taxiways, and presents initial evaluation results. An airport moving map based on an ED-99A/DO-272A compliant aerodrome database is used to visualize runway closures and other applicable airport restrictions, based on NOTAM and D-ATIS data, to provide the crew with enhanced situational awareness in terms of position and operational environment. If this is not sufficient to prevent a hazardous situation, e.g. in case the crew is distracted, a tailored alerting concept consisting of both visual and aural alerts catches the crew's attention.

For runway closures and restrictions, particularly those of temporary nature, the key issue for both extended situational awareness and alerting is how to get the corresponding data to the aircraft's avionics. Therefore, this paper also develops the concept of a machine-readable electronic Pre-flight Information Bulletin (ePIB) to bring relevant NOTAM information to the flight deck prior to the flight, with a possibility to receive updates via data link while the aircraft is airborne.

6559-18, Session 4

Compact self-contained enhanced-vision sensor (EVS) simulator

C. L. Tiana, Aireyes, Inc.

We describe a simulation system developed by Aireyes, Inc. specifically for commercial Enhanced Vision System (EVS) sensor emulation. Current FAA-approved (AFS-205) systems need only reflect very basic, and rather idealized, EVS system characteristics. We believe that, as experience with deployment and certification of these systems matures, the simulation requirements will be raised to reflect more realistic sensor performance. The system we describe can accurately simulate infrared (multiple spectral bands) sensors as well as millimeter-wave systems. It is designed to be easily integrated in standard visual flight simulators, with minimal downtime and configuration.

Unlike other current systems, this simulator can accurately represent many aspects of sensor imagery well beyond just the basic scene phenomenology (e.g. thermal aspects, radar returns): rather, we successfully model system degradation under different weather and other obscurant conditions, noise characteristics, temporal response, failure modes, and image processing pipeline (e.g. for fused systems or specific image processing features). The system is easily configurable or customized for specific sensors and, once installed in the simulation environment, acts as a “black box” with minimal required operator intervention. It is eminently suitable for pilot training, certification test flights, human factor evaluation, system analysis and improvement, airborne flight test support and marketing demonstrations. The system is currently in use at a number of major EVS system development and training sites.

6559-19, Session 4

Flight assessment of a real time multi-resolution image fusion system for use in degraded visual environments

M. I. Smith, Waterfall Solutions Ltd (United Kingdom); J. Sadler, QinetiQ (United Kingdom)

Military helicopter operations are often constrained by environmental conditions, including low light levels and poor weather. Recent experience has also shown the difficulty presented by certain terrain when operating at low altitude by day and night. For example, poor pilot cues over featureless terrain with low scene contrast, together with obscuration of vision due to wind blown and re-circulated dust at low level (brown out). These sorts of conditions can result in loss of spatial awareness and precise control of the aircraft. Atmospheric obscurants such as fog, cloud, rain and snow can similarly lead to hazardous situations due to reduced situational awareness.

Day Night All Weather (DNAW) systems applied research sponsored by UK MOD has developed a multi-resolution real time Image Fusion system that has been flown as part of a wider flight trials programme investigating increasing situational awareness. Dual band multi-resolution adaptive image fusion was undertaken using imagery from a Passive Millimetre Wave Imager Unit, a Thermal Imager and a Low Light TV all co-bore sighted on the rotary wing trials aircraft. A number of sorties were flown in a range of climatic and environmental conditions both during day and night. (Neutral density filters were used on the LLTV during daytime sorties.) This paper reports on the results of the flight trial evaluation and discusses the benefits offered by the use of Image Fusion in Degraded Visual Environments.

6559-20, Session 4

Applying daytime colors to nighttime imagery with an efficient color transfer method

G. Li, K. Wang, Jilin Univ. (China)

We propose a color transfer method to give fused multiband nighttime imagery a natural daytime color appearance in a simple and efficient way. Instead of using traditional $l\alpha\beta$ space, the proposed method transfers the color distribution of the target image (daylight color image) to the source image (fused multiband nighttime imagery) in a linear color space named IUV. The transformation between RGB and IUV spaces is simpler than that between RGB and $l\alpha\beta$ spaces, moreover, the IUV space is more suitable for image fusion. Our experiments on infrared and visual images show that the IUV based color transfer method works surprisingly well for transferring natural color characteristics of daylight color images to false color fused nighttime imagery.

6559-21, Session 4

Semantic bifurcated importance field visualization

E. R. Lindahl, P. G. Petrov, 21st Century Systems Inc.

While there are many good ways to map sensual reality to two dimensional displays, mapping non-physical and possibilistic information can be challenging. The advent of faster-than-real-time systems allow the predictive and possibilistic exploration of important factors that can affect the decision maker. Visualizing a compressed picture of the past and possible factors can assist the decision maker summarizing information in a cognitive-based model thereby reducing clutter and perhaps related decision times. Our proposed Semantic Bifurcated Importance Field Visualization (SBIFV) uses saccadic eye motion models to partition the display vertically with possibilistic and sensed data, and horizontally for spatial and semantic data. Saccadic eye movement precedes and prepares decision makers before nearly every directed action. Cognitive models for saccadic eye movement show that people prefer lateral to vertical saccadic movement. Studies have suggested that saccades may be coupled to momentary problem solving strategies. Also, the central 1.5 degrees of the visual field represents 100 times greater resolution that then peripheral field, so concentrating factors can reduce unnecessary saccades. By packing information according to saccadic models, we can augment potential

Synthetic Vision displays to relate important decision factors, reduce factor dimensionality, and present the dense summary dimensions of semantics and importance. Inter- and intraballistics of the SBIFV provide important clues on how semantic packing assists in decision making. Future directions of SBIFV are to make the visualization reactive and conformal to saccades specializing targets to ballistics, such as dynamically filtering and highlighting verbal targets for left saccades and spatial targets for right saccades.

6559-23, Poster Session

Geospatial video augmentation

M. J. Daily, HRL Labs., LLC

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6560-01, Session 1

A bio-inspired system for spatio-temporal recognition in static and video imagery

D. Khosla, C. Moore, D. J. Huber, S. E. Chelian, HRL Labs., LLC

This paper presents a bio-inspired system for spatio-temporal recognition in static and video imagery. An attention and object recognition system is used to determine the location and identities of objects in a scene at a particular time. A working memory model is continuously updated with object location and label data. It uses this data to construct and maintain ordered spatio-temporal sequences. A bio-inspired classifier ascribes event labels to these sequences. A separate network, executed in parallel with the former, classifies any significant spatial relations it observes among the recognized objects. None of the algorithms in our system require offline training, and our system can acquire its entire knowledgebase via interactive online learning if desired. The system attempts to classify all events that it observes. If it is not confident in its classification, then it will query the user for the event's correct label and immediately acquire the new knowledge. Unknown spatial relationships can also be interactively learned. Our event recognition system is robust to variations in an object's motion profile. We evaluated the performance of our system on real world video footage of vehicles and pedestrians in a busy street. Our system is able to recognize the events in this footage involving vehicles and pedestrians. Our system was also used to learn the spatial relationships that compose a particular scene category in static imagery.

6560-02, Session 1

Bio-inspired visual attention and object recognition

D. Khosla, C. Moore, S. E. Chelian, HRL Labs., LLC

This paper describes a neuro-inspired vision system that can (1) learn representations of objects that are invariant to scale, position and orientation; and (2) recognize and locate these objects in static and video imagery. The system uses modularized neuro-inspired algorithms/techniques that can be applied towards finding salient objects in a scene, recognizing those objects, and prompting the user for additional information to facilitate online learning. The neuro-inspired algorithms are based on models of human visual attention, search, recognition and learning. Most machine vision systems rely on techniques that mandate offline and cannot learn new classes without retraining on all prior knowledge. This is computationally inefficient and prohibits interactive learning. The proposed system can be trained in an online manner, meaning that new classes and instances of classes can be learned by the system without retraining on all prior knowledge. The implementation is highly modular, and the modules can be used as a complete system or independently. The underlying technologies were carefully researched in order to ensure they were robust, fast, and could be integrated into an online system. We evaluated our system's capabilities on the Caltech 101 and COIL 100 datasets, which are commonly used in machine vision, as well as on simulated scenes. Preliminary results are quite promising in that our system is able to process these datasets with good accuracy and low computational times.

6560-03, Session 1

A novel content-based video/image retrieval method for surveillance and forensic applications

K. Vadakkeveedu, R. Fernandes, Knowledge Based Systems, Inc.

The advances in video surveillance technology have lead to the proliferation of surveillance video cameras on looking areas of interest. Counter terrorism and surveillance applications require video forensics capabilities like querying and searching video data for events, people or objects of interest. A human analyst may accurately spot a suspicious activity in a small segment of video. However, due to the large volume of data collected in real-time video surveillance, it is impractical for human analysts to watch or tag the entire video collected as this can lead to human errors, lower through-put and inconsistencies in the level of scrutiny. Alternate approaches like automatic tagging may lead to inaccurate or incomplete tags, which may lead to inadequate querying and searching capabilities. In this paper we explore a content-based video/image retrieval approach.

We propose an event (object) dictionary based video retrieval method. First a dictionary of events (objects) of interest is created. In an event dictionary, every event of interest to the video forensics application is indexed against one or more textual tags. The event data contains a short video clip and feature vectors relevant to event identification. We used a small set of features relevant to video surveillance. Feature extraction, classification and indexing are performed on the real-time video data in short segments. A user's textual query is converted to a content-based query using the event dictionary. Event dictionary creation is computationally constant time activity for a given number of events and features. This method is also modified to realize "object dictionary" based image retrieval.

6560-04, Session 1

Behavior recognition using cognitive swarms and fuzzy graphs

S. Medasani, Y. Owechko, HRL Labs., LLC

Behavior analysis, a critical component of next generation visual surveillance systems, deals with understanding and parsing a video sequence to generate a high-level description of object actions and inter-object interactions. In this paper, we describe a vision-based behavior recognition system that can model and detect spatio-temporal interactions between detected entities in a visual scene. A hierarchical generic event detection scheme is proposed that uses fuzzy graphical models for representing the spatial associations as well as the temporal dynamics of scene entities. The spatial and temporal attributes of associated objects and groups of objects are handled in separate layers in the hierarchy. In the spatial organization layer, fuzzy graphs are used to model the spatial relations between objects while in the temporal organization layer, directed fuzzy graphs are used to model the temporal behaviors of objects. We also describe a new behavior specification language that helps the user analyst easily describe the event that needs to be detected using either simple linguistic queries or graphical queries. We present results that show the performance of the proposed system on complex data sets.

6560-05, Session 1

A multi-camera system for real-time pose estimation

A. E. Savakis, J. M. Hnatow, J. Schimmel, M. J. Erhard, Rochester Institute of Technology

This paper presents a multi-camera system for intelligent computing that performs face detection and pose estimation in real-time and may be used within a visual sensor network for surveillance or human-computer interaction. The system consists of a Scene View Camera (SVC), which operates at a fixed zoom level, and an Object View Camera (OVC), which continuously adjusts its zoom level to match objects of interest. The SVC is set to survey the whole filed of view. Once a region has been identified by the SVC as a potential object of interest, e.g. a face, the OVC zooms in to locate specific features. In this system, face candidate regions are selected based on skin color and face detection is accomplished using a Support Vector Machine classifier. The locations of the eyes and mouth are detected inside the face region using neural network feature detectors. Pose estimation is performed based on a geometrical model, where the head is modeled as a spherical object that rotates upon the vertical axis. The triangle formed by the mouth and eyes defines a vertical plane that intersects the head sphere. By projecting the eyes-mouth triangle onto a two dimensional viewing plane, equations were obtained that describe the change in its angles as the yaw pose angle increases. These equations

are then combined and used for efficient pose estimation. The system achieves real-time performance for live video input. Testing results assessing system performance will be presented for both still images and video.

6560-06, Session 1

Autonomous learning: combining supervising and self-supervising method for on-line incremental learning of discriminative patterns

S. Xia, J. Chen, W. Hu, National Univ. of Defense Technology (China)

Recent researches in object recognition have demonstrated the advantages of representing objects and scenes through localized patterns such as small image templates, which are normalization of image primitives. These primitives may correspond to intuitively understandable object parts. As a basis, in the online setting, these kinds of patterns, whose number and corresponding statistical features, cannot be known beforehand, and it eventually becomes infeasible to memorize all previously seen input samples.

Noticing the nature characteristic of the human brain—an incremental studying style, especially the supervising and self-supervising combined method of studying during the proess of intelligent development, based on an RSOM(Recursive Self-Organizing Mapping) algorithm, a framework of extended autonomous learning is advanced.

In this framework, a pool of discriminable patterns are clusterd into an RSOM tree, and the local statistics of different discriminable patterns are calculated in different leaf nodes of the RSOM tree. For each incoming sample, the Naïve-Bayes-based consistency estimation of a corresponding leaf nodes, will be used to determine if it is a sample of a NEW discriminable pattern. If yes, the sample will automatically labelled as an unknown pattern. If the similar samples are frequently input into the RSOM, the system will ask for supervising. Thus a system can autonomously get KNOWLEDGE according to the experience of itself. The proposed framework is not tied to any specific pattern type or data domain. In this paper, a video image-based intelligent multi-object recognition system is developed, which proves the feasibility and validity of the method.

6560-07, Session 1

Analysis of the map-seeking circuit in early vision applications

J. Jelinek, Honeywell Technology

In his recent book on visual cognition David Arathorn proposes a new computational mechanism for early vision and demonstrates its utility through a number of computer simulations. He calls its basic building block the map-seeking circuit and describes both its algorithmic and neuronal implementations.

In our paper we present mathematical analysis of the circuit. We first derive the nonlinear difference equations describing its dynamics and find their steady state solutions. Next we formulate an image-to-memory matching problem with a straightforward intuitive interpretation and show that the map-seeking circuit transient can be understood as a very fast iterative computation of the best match in the given sense. Recasting the circuit as the matcher also offers another viewpoint at its behavior: Its steady state represents an integral transform of the image with respect to the non-orthogonal basis formed by the predefined memories and thus can be seen as the best image description expressible in terms of the basis.

6560-08, Session 2

Artificial immune system approach for air combat maneuvering

J. T. Kaneshige, K. Krishnakumar, NASA Ames Research Ctr.

Since future air combat missions will involve both manned and unmanned aircraft, the primary motivation for this research is to enable unmanned aircraft with intelligent maneuvering capabilities. During air combat maneuvering, pilots use their knowledge and experience of maneuvering strategies and tactics to determine the best course of action. As a result, we try to capture these aspects using an artificial immune system approach. The biological immune system protects the body against intruders by recognizing and destroying harmful cells or molecules. It can be thought of as a robust adaptive system that is capable of dealing with an enormous variety of disturbances and uncertainties. However, another critical aspect of the immune system is that it can remember how previous encounters were successfully defeated. As a result, it can respond faster to similar encounters in the future. This paper describes how an artificial immune system approach is used to select and construct air combat maneuvers. These maneuvers are composed of autopilot mode and target commands, which represent the low-level building blocks of the parameterized system. The resulting command sequences are sent to a tactical autopilot system, which has been enhanced with additional modes and an aggressiveness factor for enabling high performance maneuvers. Just as vaccinations train the biological immune system how to combat intruders, training sets are used to teach the maneuvering system how to respond to different enemy aircraft situations. Simulation results are presented, which demonstrate the potential of using immunized maneuver selection for the purposes of air combat maneuvering.

6560-09, Session 2

Parameter optimization of LS-SVM for regression using NGA

Q. L. Wang, Z. Feng, K. Shida, Harbin Institute of Technology (China)

Compared with Support vector machine (SVM), Least Squares support vector machine (LS-SVM) has overcame the disadvantage of higher computational burden by solving linear equations instead of a quadratic programming problem. So, it has been widely used in classification and nonlinear function estimation. But there is no efficient method for parameter selection of LS-SVM. This paper uses sharing function based Niche genetic algorithm (SNGA) to optimize the parameter of LS-SVM for regression. In this work, the radial basis function (RBF) function is used as the kernel function. There are two free parameters viz. kernel width parameter, sigma s and regularization parameter ?, which affect LS-SVM generalization performance.

In the SNGA approach, k-folds cross validation is used to evaluate the LS-SVM generalization performance. The inverse of the average test error of the k trials is used as the fitness value, because the smaller the average test error is the better the generalization performance is. Sharing function is introduced to implement niche genetic algorithm. The hamming distance between each two individuals is defined as the sharing function. The proposed SNGA procedure is described as follows:

Step 1: Randomly generate the initial populations. Each individual is encoded in 40 binary bits.

Step 2: Evaluate the fitness values of all individuals using k-folds cross validation and preserve the best four individuals.

Step 3: Calculate the sharing function value between any two individuals and multiply the one with the least fitness value by the penalty function factor if the value is greater than the sharing threshold.

Step 4: Apply selection, crossover and mutation operators to generate the next population.

Step 5: Replace the worst four individuals of the current population with the four best individuals preserved in step2.

Step 6: Go to Step 2 until it has implemented G generations.

Two benchmark problems, SINC function regression and Henon map time series prediction are used as examples for demonstration. It is showed that this approach can escape from the blindness of man-made choice of the LS-SVM parameters. It enhances the efficiency and the capability of regression. With little modification, this approach is also can be used to the parameter optimization of SVM or LS-SVM for classification.

6560-10, Session 2

ASAS: autonomy en route

N. Barraci, U. Klingauf, S. Bauer, M. Hartmann, Technische Univ. Darmstadt (Germany)

As one big decisive step in order to cope with the predicted rise in civil aviation by the factor of 3 ([MW04], [Gmf04]) until 2020, EUROCONTROL and FAA see the development of ASAS applications. A subset of the foreseen ASAS applications is dedicated to allow separation and self-separation support to the flight deck crews and ground controllers. Although the definition and scope of most of those ASAS applications are still under research, two main issues could already been identified.

The first main issue is holding and raising the current safety level for civil aviation, in spite of the heavier usage of airspace due to the rise in air traffic.

The second main issue is the reduction of costs, for example by rising the efficiency for flights over oceanic airspace. The ASAS Application In Trail Procedure in oceanic airspace (ASPA-ITP) is directed primarily towards this issue by allowing flight level changes for specific aircraft. It is foreseen that this will have a significant impact on flight costs.

This paper presents an application which supports pilots in keeping the separation minima [BBKH06], and extends its scope to utilization in oceanic airspace. It describes constraints and aims of algorithms directed towards detecting and solving traffic conflicts and the required data and data transmission means.

Initially the application was intended to support pilots flying in IFBP (In-flight broadcasting procedure) area, and to evaluate self-separation algorithms in TUDs highly configurable fix-based research flight simulator.

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6560-11, Session 2

Organization capable intelligent sensors

E. T. Matson, Wright State Univ. and Univ. of Cincinnati; R. K. Bhatnagar, Univ. of Cincinnati

Sensors are key elements to interface to and interpret an environment. The success of this interface and interpretation is a function of the capability of the sensor. A sensor's capability can be measured by how well it can sense specific environment variables and how it processes the data before forwarding it to another processing agent.

The primary objective of this research is to embed intelligence, using an agent, into a sensor enabling it to report actionable information rather than flows of merely raw data. The agent sensor pair can then be placed into an multiagent organization capable of integrating the capabilities of all intelligent sensor agents. A secondary objective is a flexible architecture allowing any combination of heterogeneous sensors to be utilized in creating an intelligent array. The capability model of the software agent will interface the specific sensor capabilities into the multiagent organization.

An intelligent sensor is the front line application to the Intelligent Sensor Organization System (ISOS). An intelligent software agent will be teamed with a hardware sensor device to construct the intelligent sensor. The software agent will have three main functions; management of the physical sensor, interpretation of the physical sensor's data stream and integration with other intelligent sensor agents participating in the organization. The ISOS is the cooperative integration of all sensors into one functional team, capable of sensing a complex environment and exhibiting traits such as robustness, survivability, and adaptability.

There are two hardware-driven approaches to this research. The first involves embedding the agent into a FPGA using VHDL as the language or implementation. The second approach utilizes a more general purpose hardware platform that allows a number of general purpose programming languages to be used for implementation. The purpose is to determine which combination of hardware and software will lend itself to the development of a effective embedded intelligent agent. Each of these platforms is tied to a set of sensors to measure the validity and effectiveness of both approaches.

The initial conclusion reached is that agents can be developed and embedded on hardware interfaced to one or more sensors. These software agents augment the capability of the hardware sensor and controller with added higher level management and data extraction potential. A second outcome reveals the choice of hardware platform is dependent upon required sensor and software agent capability. The chips which support development using general purpose languages allow a more capable software agents, but require higher levels of resources to support the increase functionality.

6560-12, Session 2

Game theoretical techniques for designing counter-terrorism systems

S. U. Khan, The Univ. of Texas/Arlington

Designing counter-terrorism systems are now almost a necessity. Protecting our investment, national and humanitarian interests are the norm of the day. Essentially, we are aiming to design counter-terrorism systems for reducing the risks and consequences of terrorism.

The objective of the work reported here is to study optimal allocation of resources for protection of systems against intentional (terrorist) attacks. The innovation of this work lies in the use of game theory as an analysis tool for risk modeling. Game theory has widely been used in fields of economics, communication theory, social sciences, etc. This work will be leveraging upon the current state of the art attacker models molded with classical game theoretical models.

The motivation of this work comes from the fact that the attackers can modify their strategies in response the defense investments. Defense will generally be more costly when the adversary (or the attackers) can observe the system defenses. In reality the attackers have a fair enough idea about the defenses owing to our close net social infrastructure. One simply cannot assume that a defensive system can be setup without some leakage of critical information.

If this (the information leakage) is unavoidable, then why do we not incorporate into our defense infrastructure. In other words, we have to determine the optimal defense against an optimal attack. The risk analysis tool, game theory, is a useful model for security and critical infrastructure protection. It is appropriate when protecting against intelligent and adaptable adversaries, and it recognizes that defensive strategies must account for attacker behavior.

To model the system as a game between attackers and defender(s), we need to make assumptions about: 1) the attacker goals and constraints, 2) the defender goals and constraints, and 3) the system design features. These assumptions are necessary when the system at hand has either serial or parallel defenses. Both defenses attract different types of attacks. For instance, in the case of parallel defenses, the attacker must disable all components. This certainly is not the case for serial defenses. An attacker has a wide choice of targets and the defender must protect all the components. The defender must equalize the attractiveness of all the defended components.

Designing counter-terrorism systems would also require making assumptions on the attacker's knowledge. The assumption that the attackers know the defensive mechanism may not be unrealistic, due to the openness of our socio-politically infrastructure. Public demands knowledge of our defenses even when this weakens its effectiveness. This increases the difficulty of defense, since the defensive measures may not be effective if they can easily be observed.

The design of counter-terrorism systems should incorporate redundancy since it reduces attacker flexibility and increases defender flexibility. Game theory has been used as an effective model to realize the goals of traditional reliability design considerations, such as, spatial separation, functional diversity, etc. We leverage upon the existing theory for incorporating such reliability factors to mold daily life systems into a fortified counter-terrorism system. The flexibility of using game theory would allow us to use secrecy and deception as possible attacker (so called) privileges.

The major advantage of using game theory as a risk analysis tool is its ability to adapt to adverse situations. For instance, real world decision makers will want to withdraw (or alter) their decisions in case they guessed wrong about which targets are most attractive to attackers. Recent work has suggested that attackers target the most attractive components. However, the defenders are uncertain about their effectiveness. Attackers will in general have different values for targets than defenders. Also, defending one target can deflect attacks to targets that are less attractive to attackers, but more damaging to defenders. Optimal defense frequently still involves allocating zero resources to targets with a non-zero probability of successful attack, especially if: 1) targets value widely in their values, and 2) defender is highly resource-constrained.

To show the effectiveness of our risk analysis model and the game theoretical technique, three applications have been analytically studied. These include: 1) aviation security, 2) port security, and 3) electric power security. In all the applications, our model shed light on appropriate allocation of resources among targets, with focus on the most attractive and most vulnerable targets. Spend less money on targets that are unlikely to be attacked, etc.

In essence, this work acts as a stepping stone for researchers working in security research and would like to apply game theory for analysis and modeling of real world scenarios. We hope to extend this work to develop a risk analysis toolkit based on our gaming model, cost functions and observations.

6560-13, Session 3

Learning Bayesian network from imperfect data: enhancements to the EM algorithm

K. K. R. G. K. Hewawasam, K. Premaratne, Univ. of Miami

The recent years have seen many developments in uncertainty reasoning taking place around Bayesian Networks (BNs). BNs allow fast and efficient probabilistic reasoning. One of the key issues that researchers have faced in using a BN is determining its parameters and structure for a given problem. Many techniques have been developed for learning BN parameters from a given dataset pertaining to a particular problem. Most of the methods developed for learning BN parameters from partially observed data have evolved around the Expectation-Maximization (EM) algorithm. In its original form, EM algorithm is a deterministic iterative two-step procedure that converges towards the maximum-likelihood (ML) or the maximum a posteriori (MAP) estimates.

The EM algorithm mainly focuses on learning BN parameters from incomplete data where some of the values are missing. However in many practical applications, partial observability results in a wider range of imperfections, e.g., uncertainties arising from incomplete, ambiguous, probabilistic, and belief theoretic data. Moreover, while convergence is to their maximum data likelihood values, the EM algorithm does not guarantee convergence to the underlying true parameters.

In this paper, we propose an approach that enables one to learn BN parameters from a dataset containing a wider variety of imperfections. In addition, by introducing an early stopping criterion together with a new initialization method to the EM-algorithm, we show how the BN parameters could be learnt so that they are closer to the underlying true parameters than the converged maximum data likelihood BN parameters.

6560-14, Session 3

Global stability analysis of competitive neural networks with different time-scales under perturbations

A. Meyer-Bäse, Florida State Univ.

We establish stability results for competitive neural networks with different time-scales under parameter perturbations and determine conditions that ensure the existence of exponentially stable equilibria of the perturbed neural system. The perturbed neural system is modeled as nonlinear perturbations to both a known linear and nonlinear idealized system and is represented by two time-scale subsystems. We derive a Lyapunov function for the coupled system and a maximal upper bound for the fast time scale associated with the neural activity state.

6560-15, Session 3

A system for vehicle recognition in video based on SIFT features, mixture models, and support vector machines

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We present a system for scale and affine invariant recognition of vehicular objects in video sequences. We use local descriptors (SIFT keypoints) from image frames to model the object. These features are claimed in the literature to be highly distinctive and invariant to rotation, scale, and affine transformations. However, since the SIFT keypoints that are extracted from an object are instance-specific (variable), they form a dynamic feature space. This presents certain challenges for classification techniques, which generally require use of the same set of features for every instance of an object to be classified. To resolve this difficulty, we associate the extracted keypoints to the components (representative keypoints) in a mixture model for each target class. While the extracted keypoints are variable, the mixture components are fixed. The mixture models the keypoint features, as well as the location and scale at which each keypoint was detected in the frame. Keypoint to component association is achieved via a switching optimization procedure that locally maximizes the joint likelihood of keypoints and their locations and scales with the latter based on an affine transformation. To each mixture component from a class, we link a (first layer) support vector machine (SVM) classifier which votes for or against the hypothesis that the keypoint associated to the component belongs to the model's target class. A second layer SVM pools the votes from the ensemble of SVM classifiers in the first layer and gives the final class decision. We show promising results of experiments for video sequences from the VIVID database.

6560-16, Session 4

A function model for automated path prediction of entities

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As militaries across the world continue to evolve, the roles of humans in various theatres of operation are being increasingly targeted by military planners for substitution with automation. Forward observation and direction of supporting arms to neutralize threats from dynamic adversaries is one such example. However, contemporary tracking and targeting systems are limited in their ability to serve autonomously, since they do not embody the sophisticated algorithms necessary to accurately predict the future positions of adversaries with the precision offered by the cognitive and analytical abilities of human operators. The need for these systems to incorporate methods characterizing such intelligence is therefore compelling. This paper describes a novel technique to achieve this goal by illustrating real-world methodologies for sensor data acquisition and utilization to model the path of an entity. Such paths are expressed as continuous polynomial functions of multiple variables in the form of Taylor series with a finite number of terms. It demonstrates the method for computing the coefficient of each term to define this function for any given entity, and illustrates its use to determine that entity's position at any time in the future. Furthermore,

the advantages and efficiency of this technique is compared with its forerunners that are based on graph theory and hidden Markov chains. Finally, the requirements for its implementation are described to enable its realization as a deployable tool using commercially available sensors with standard acquisition rates.

6560-17, Session 4

Information retrieval in heterogeneous search spaces using I-FGM

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Intelligent Foraging, Gathering and Matching (I-FGM) combines a unique multi-agent architecture with a novel partial processing paradigm to provide a solution for real-time information retrieval in large and dynamic databases. I-FGM provides a unified framework for combining the results from various heterogeneous databases and seeks to provide easily verifiable performance guarantees. In the previous work, I-FGM had been implemented and validated with experiments on text data, using the internet as the search space. In order to understand the effect of dynamism of documents on the various metrics and resource allocation strategy of I-FGM, a series of experiments were conducted with pseudo-dynamic and full dynamic search spaces. In pseudo-dynamic search space, all documents except for the top 10 documents are available from the beginning of the simulation. The top 10 documents are introduced arbitrarily during the course of the experiment. In fully-dynamic experiments, all the documents are introduced arbitrarily. The results were analyzed to derive valuable insights into I-FGM. In this paper, we provide analysis of the system with a focus on performance. Using analytical methods we show that partial processing saves both time and computing resources. The system is also extended to incorporate images in the search space using a region-based Wavelet Image Retrieval algorithm called WALRUS. A preliminary study on semantically combining the information from images and text using graph structures has been made.

6560-32, Session 4

Intelligent algorithms for persistent and pervasive sensing in systems comprised of wireless ad hoc networks of ground-based sensors and mobile infrastructures

W. S. Hortos, Associates in Communication Engineering Research and Technology

With the development of low-cost, durable unmanned air vehicles (UAVs), it is now practical to perform persistent sensing and data collection autonomously over broad surveillance areas. These vehicles can sense the environment directly through on-board imaging sensors, or indirectly when triggered to target areas by ground-based sensors operating wirelessly as an ad hoc network within the environment. The coupling of the swarm intelligence of the mobile infrastructure comprised of UAVs with the ant-like behavior of the unattended ground sensors creates a level of persistent and pervasive sensing, i.e., continual collection and analysis of sensor data on targets within an arbitrarily wide area can be achieved. In this composite configuration, the UAVs act as intelligent agents using the ground sensors to collect data on targets within the active narrowband phenomena, such as choke points and areas of ingress. To conserve limited power at sensor nodes, the ground sensors apply correlative, statistical data aggregation to the set of the target phenomena to restrict the target's current location within the environment. Ground sensors far from that location are deactivated, while ground sensors near the location remain active. As the UAVs move over the ad hoc network of surveillance area, the still-active sensors form a distributed antenna to uplink the target locations and related information to the nearest vehicles in the swarm for analysis and potential fusion with sensor data from other UAVs. UAVs with knowledge of the ground targets persist in sensing changes in the target(s) using on-board imaging sensors and processors. Reports from these UAVs are then relayed to the mission controllers for further action.

A critical aspect of the operational scenario is the sustained presence of a UAV to communicate with the active ground sensors within ad hoc networks. While a single UAV is useful for deploying new sensors and can provide communications to isolated sensors, a single-point failure of one UAV can destroy the availability of the composite sensing network to the mission. Multiple vehicles in a swarm, however, allow sustained sensing in parallel or sequentially over the same ground sensors, thereby reducing the time required to gather data or enlarging the aperture of sensed data from moving or physically unstable targets. Should one UAV become disabled, the remaining vehicles can continue sensing, increasing the availability of the entire system to the mission, although possibly at a reduced collection rate.

Intelligent algorithms are presented that adapt the operation of the composite system to target dynamics. The algorithms must maintain link availability among the colony of active ground sensors, reduce the ground-based sensor data statistically to locate targets and identify their characteristics, form uplink beams from the ground-based sensors to the nearest UAVs passing overhead in the swarm, and guide the UAVs to continue sensing the active targets reported from the ground. Moreover, the algorithms must also perform these tasks under the severe resource limitations of the ground-based sensor nodes on processing, memory, power, as well as number and types of on-board sensors.

In this paper, network information-theoretic metrics are applied to assess the relative performance of these adaptive algorithms at published and planned resource levels. Simulations of mission scenarios based on published operating characteristics planned for ground sensors and UAVs are performed to establish the performance of the intelligent adaptive routines for the composite sensing network. In each scenario, the estimated network lifetime under static resource allocations is computed and the persistence periods of the target coverage for both mobile and stationary targets are computed.

6560-19, Session 5

Genetic algorithm approach for adaptive power and subcarrier allocation in multi-user OFDM systems

Y. B. Reddy, Grambling State Univ.; M. Naraghi-Pour, Louisiana State Univ.

Orthogonal Frequency Division Multiplexing (OFDM) is a promising technology for high data rate transmission in broadband wireless systems for its ability to mitigate the effects of frequency selective channel and combat inter-symbol interference. Adaptive modulation can greatly improve the system spectral efficiency by changing its modulation constellation and transmit power according to the instantaneous channel state information. In frequency selective fading channels, the combination of OFDM and adaptive modulation can utilize the merits of both technologies and has attracted a great deal of interest in recent years. In this paper a novel genetic algorithm application is proposed for adaptive power and subcarrier allocation in multiuser OFDM systems. To test the application, a simple genetic algorithm was implemented in MATLAB language. With the goal of minimizing the overall transmit power while ensuring the fulfillment of each user's rate and bit error rate (BER) requirement, the proposed algorithm acquires the needed allocation through genetic search.

The subcarrier allocation algorithm [3] was used to calculate the power for the population in each generation. The results show that the system converges after 20 generations with chromosome length 50. The results show that data transfer is efficient in power requirement with allocation of more subcarriers to users [1, 2, 3]. The simulations were tested for BER 0.1 to 0.00001, data rate of 256 bit per OFDM block and chromosome length 50. The results show that SNR converges after 30 generations with improved performance compared to [3]. We also tested the convergence of the genetic algorithm through the method of adding 20% individuals with good genes to the initial population for faster convergence and better results.

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6560-20, Session 5

Security assurances for intelligent complex systems

S. Naqvi, Ctr. of Excellence in Information and Communication Technologies (Belgium); M. Riguidel, École Nationale Supérieure des Télécommunications (France)

Intelligent complex systems are drawing considerable attention of researchers in various scientific areas. These architectures require adequate assurances of security, reliability, and fault-tolerance. The implementation of security functions such as identification, authentication, access control, and data protection can be viewed in terms of a security assurance model. This model relies on the security architecture of a system, which in turn is based on a trusted infrastructure. This assurance model defines the level and features of the protection it offers, and determines the need and relevance of the deployment of specific security mechanisms.

In this article, we first examine how the verification of the security measures, and notably their presence, correctness, effectiveness, the impact of changes in the existing intelligent complex systems with respect to vulnerabilities, systems engineering choices, reconfigurations, patch installations, network management, etc. We then explore how we can evaluate the overall security assurance of a given system. We emphasis that it is desirable to separate the trust providing assurance model and the security architecture, into two separated distributed entities (instrumentations, protocols, architectures, management). We believe that this segregation will allow us to automate and boost the trusted infrastructure and security infrastructure, while the authorizations, exceptions, and security management as a whole, are achieved through their interaction. Finally, we discuss the security metrics for these complex intelligent systems. New mechanisms and tools are needed for assessing and proving the security and dependability of a complex system as the scale of these systems and the kind of threats and assumptions on their operational environment pose new challenges. We conclude with a description of our proposed security management model.

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6560-21, Session 5

Distributed mining on intelligent sensor data

H. Bian, Wright State Univ.; E. T. Matson, Wright State Univ. and Univ. of Cincinnati; R. K. Bhatnagar, Univ. of Cincinnati

Intelligent sensor networks are widely deployed in various applications such as environmental monitoring, intrusion detection and traffic control. One common characteristic of all sensor networks is data streams are continuously sent from the individual sensors in the network. These streams generate huge amounts of data which creates the opportunity to find hidden patterns using data mining techniques.

Sensor network data have several features that pose difficulty in directly using existing data mining algorithms. Data in the network are collected and stored in a distributed manner, and each sensor scans and generates information about the environment continuously. Keeping all data in the repository is not only costly, but also not necessary due to the dynamic nature of the environment. However, historical information can still be useful in various ways. In summary, data from the sensor networks are distributed, streamlined, and of large volume.

We focus on two tasks in this paper, object classification and trajectory prediction. The objective of this research is to apply distributed data mining techniques to stream data gained from the sensor networks. Our model does not need to have a centralized site to compute the target function~(classifier or prediction model). Each sensor performs local computation and sends some aggregate information to its neighbors. The global classifier then is built from the local computations and communication between the sensors. Our model also gives higher weights to readings that are more recent, while older readings are still kept in the system but with smaller weights. By localizing the computation, our method provides better, more secure services. Localizing the computation also helps to reduce the power consumptions of the sensor networks.

6560-22, Session 5

Pattern classification on wireless sensor networks

E. Ertin, The Ohio State Univ.

In this paper we study learning of classification rules from labeled data when the data is retrieved using a sensor network communicating over wireless links. We analyze constraints on communication during the learning stage as well as during the execution of the learned classification rules. We consider fully distributed as well as fusion center based classification rules and characterize the performance of a distributed classification system as a function of the communication rate between the sensors.

6560-23, Session 5

Localized construction of aggregation tree in sensor networks

R. K. Bhatnagar, K. Andra, Univ. of Cincinnati

The recent emergence of the sensor networks technology is significantly impacting the capabilities for automated distributed monitoring of environments. The large deployments of sensors for fine-grained data gathering makes it practically infeasible to transport all data to a central site for processing. Thus, effective localized communication and computation mechanisms need to be designed. Aggregation trees covering complete terrains have been shown to be an effective way of performing computation and communication in sensor networks. In this paper we present a reactive approach to constructing localized aggregation trees, limited to the regions of activity, wherein the sensors within close proximity that sense some phenomenon construct a local aggregation tree for their localized computational use, send the conclusion to the base station, and then the tree structure may be discarded. We have shown an application and simulation results to demonstrate the effectiveness of our suggested approach.

6560-24, Session 6

Fast-varying pitch tracking: a new approach to speech modeling

D. Charalampidis, Univ. of New Orleans

A fast-varying pitch tracking(FVPT) technique suitable for audio and speech is presented. FVPT presents the grounds for a novel approach to speech modeling. Pitch is estimated by identifying sequences of warped sub-segment versions in the signal. If no warping is assumed, the method reduces to the autocorrelation (ACR) method. Results illustrate the superiority of FVPT compared to traditional ACR and harmonic-based detection.

6560-25, Session 6

Universal range bin centroids from SAR imagery for knowledge-aided radar

E. H. Feria, College of Staten Island/CUNY

A universal range bin centroid is derived from a test highly compressed SAR image of nonhomogeneous terrain. This centroid is then used to direct the antenna pattern of a knowledge-aided airborne moving target indicator (AMTI) radar system subjected to severely taxing

environmental disturbances away from the assumed target. Simulation results using a straight forward sample matrix inverse (SMI) approach demonstrate that outstanding signal to interference plus noise ratio (SINR) performance is derived with this rather simple and robust knowledge-aided approach.

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6560-26, Session 6

Real-time PM10 concentration monitoring on Penang Bridge by using traffic monitoring CCTV

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, K. L. Low, Univ. Sains Malaysia (Malaysia)

For this study, an algorithm was developed to determine concentration of particles less than 10μm (PM10) still images captured by a CCTV camera on the Penang Bridge. The objective of this study is to remotely monitor the PM10 concentrations on the Penang Bridge through the internet. So, an algorithm was developed based on the relationship between the atmospheric reflectance and the corresponding air quality. By doing this, the still images were separated into three bands namely red, green and blue and their digital number values were determined. A special transformation was then performed to the data. Ground PM10 measurements were taken by using DustTrakTM meter. The algorithm was calibrated using a regression analysis. The proposed algorithm produced a high correlation coefficient (R) and low root-mean-square error (RMS) between the measured and estimated PM10. Later, a program was written by using Microsoft Visual Basic 6.0 to download still images from the camera over the internet and implement the newly developed algorithm to it. Meanwhile, the program is running in real time and the public will know the air pollution index from time to time. This indicates that the technique using the CCTV camera images can provide a useful tool for air quality studies.

6560-27, Session 7

Automatic pattern recognition applied to thermal imaging for large-scale breast cancer detection

A. L. Perrone, Techniteia Advanced Paradigms S.r.l (Italy) and Pontificia Univ. Lateranense (Italy); P. P. Hoekstra III, Therma-Scan Inc.; G. Basti, Pontificia Univ. Lateranense (Italy)

Malignant breast tumors have characteristic thermal signatures that comport to Hippocrates' cardinal sign of Calor and were empirically recognized since the earliest electronic images. Basic science has revealed the underlying physiologic mechanisms for these thermal signatures and a quantitative and objective method has been developed to improve the reliability of thermal imaging as a diagnostic modality for detection. Intelligent Computation (IC) is now applied to extend the diagnostic parameters, increase reliability and enable large-scale application. Particularly we are applying IC to evaluate the variability of true-positive and false-positive cues by using a specialized proprietary neural network (Dynamic Perceptron) architecture for the analysis of 2000 pre-screened malignancies in a screening population. Moreover, we are applying the technique also to a sample data set of 2000 malignancies with good infrared features but unreliable response to the infrared analysis, due to imperfect techniques by the human operators. Finally, the same architecture is being tested also on an ongoing research on breast cancer screening in hospital environment. Preliminary results are presented and discussed also in relationship with other more classical techniques.

6560-28, Session 7

Evaluation of two key machine intelligence technologies

W. H. Land, Jr., G. J. Tomko, Binghamton Univ.; J. J. Heine, H. Lee Moffitt Cancer Ctr. & Research Institute; R. Thomas, A. Mizaku, Binghamton Univ.

This paper will cover the application of a new technology, Kernel -Partial Least Squares (K-PLS) configured as a learning system, as well as the better known Support Vector Machines (SVMs) to the computer aided diagnosis (CAD) of Breast Cancer using mammogram screen film data. Using K-PLS provides a new and powerful way of ascertaining non-linear relations using linear techniques appropriate for feature space computations. Here, the algorithm designs are decoupled from feature space specifications, which increases paradigm flexibility as well as results in a more tractable learning algorithm design and kernel specification formulation. K-PLS runs in real time for data sets of reasonable size, and does not require as many parameters as do SVMs. CAD beast cancer design "trade offs" will be discussed using several SVM mapping kernels as well as various K-PLS designs. The theory of both K-PLS and SVMs will be summarized as well as the features of the screen film mammogram dataset used. In addition, SVM sensitivity analyses will be used to establish the most significant mammogram dataset discriminators and these findings compared with those obtained with the K-PLS configurations. Receiver Operating characteristic (ROC) curve Az values as well as specificity , sensitivity and positive predictive value (PPV) measures of performance will be used to quantify both SVM and K-PLS classification and diagnostic performance.

6560-29, Session 7

Small mammographic lesions evaluation based on neural gas network

A. Meyer-Bäse, Florida State Univ.

Biologically-motivated novel neural networks represent an important approach in the analysis of complex patterns in signal-intensity (SI)-time series in dynamic breast MR imaging. They enable a subdifferentiation of SI-time courses within the lesion and thus reflect the lesion structure as consisting of many different cell populations. The "neural-gas" neural network was applied to the detection of small lesions since it focuses strictly on the observed complete MRI signal time-series, and enables a self-organized data-driven segmentation of dynamic contrast-enhanced breast MRI time-series w.r.t. fine-grained differences of signal amplitude, and dynamics, such as focal enhancement in patients with indeterminate breast lesions. As a result, we obtain both a set of prototypical time-series and a corresponding set of cluster assignment maps which further provides a segmentation with regard to identification and regional subclassification of pathological breast tissue lesions. The achieved results demonstrate an increase of accuracy predominantly in sensitivity. Sensitivity increased with biological neural network quantization in ductal carcinoma in situ (DCIS) and lobular carcinoma. Specificity slightly decreased in fibroadenomas and scars.

6560-30, Session 7

Performance evaluation of evolutionary computational and conventionally trained support vector machines

W. H. Land, Jr., Binghamton Univ.; J. J. Heine, H. Lee Moffitt Cancer Ctr. & Research Institute; D. Roye, D. Margols, Binghamton Univ.

This paper describes a mutation process used in development of a family of Support Vector Machines (SVMs), trained by Evolutionary Programming (EP) as well as Evolutionary Strategies (ES), for the diagnosis of breast cancer. This EP / ES hybrid was used to train a family of SVMs using an ES mutation strategy designed to "mimic" gradient descent. This mutation strategy was combined with the a rank order selection process as well as the tournament selection processes (with and without replacement) of EP to generate the family of SVMs whose average and maximum fitness increased, until reaching a maximum value, as the number of generations increased. Several sensitivities experiments were designed and evaluated to optimize this process. The process utilized both random and bias mutation of several self-adaptive components. The EP derived SVMs provided an average receiver operating characteristic (ROC) Az value of about 0.925 using the five fold cross validation statistical technique using a mammogram screen film data set. This compares favorably with iteratively derived Az SVM kernel results of about 0.9. However, the important conclusion is that the evolutionary process found SVM parameters that gave slightly more accurate results much quicker than an iterative or conventional method. Total computational and interface time to obtain these slightly more accurate results was reduced by a factor of about 80.

6560-31, Session 7

Intelligent computing in breast cancer detection

P. P. Hoekstra III, Therma-Scan, Inc.

Malignant breast tumors have characteristic thermal signatures that comport to Hippocrates' cardinal sign of Calor and were empirically recognized since the earliest electronic images. Basic science has revealed the underlying physiologic mechanisms for these thermal signatures and a quantitative and objective method has been developed to improve the reliability of thermal imaging as a diagnostic modality for detection. The application of intelligent computing is now applied to extend the diagnostic parameters, increase reliability and enable large-scale application.

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6561-01, Session 1

UGV-based rapid, high-confidence intelligent interior mapping

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This paper describes an intelligent interior mapping capability that generates high confidence maps of building interiors (floor plans plus critical features such as doorways, stairwells, windows, and ceiling heights) rapidly with minimal interior exploration. Such a capability could provide critical support to intelligence gathering and/or life saving operations in the military, law enforcement, disaster response, and commercial sectors where rapid understanding of unknown interior layouts is required to save lives, maintain covertness, or minimize costs.

The fundamental approach relies on an intelligent rule-based inferencing process which requires a minimal set of structure observables to generate high confidence interior layouts. The rules are based on geo-specific design practices and building codes. The process considers known or suspected locations of structural elements and generates a set of alternative layouts. It uses these locations and alternatives to determine the most probable layout and to provide confidence levels for each component therein. This information is then used to determine where to move next within the building so as to minimize the remaining layout uncertainty.

This mapping capability has been demonstrated experimentally on a representative UGV platform. The platform maps its surroundings using a suite of on-board environmental imaging sensors (rangefinders, a 3-D Lidar camera, sonar sensors) and associated sensor fusion algorithms. Although demonstrated as part of a UGV platform, it is envisioned that this intelligent mapping capability could be extended to human-borne (soldier, police officer, urban search and rescue personnel) systems or to low altitude UAVs for 3D mapping of building exteriors in dense urban environments.

6561-02, Session 1

Negative obstacle detection for off-road autonomous navigation

A. L. Rankin, A. Huertas, L. H. Matthies, Jet Propulsion Lab.

Detecting negative obstacles (ditches, holes, washouts, and other depressions) is one of the most difficult problems in perception for unmanned ground vehicle (UGV) off-road autonomous navigation. One reason for this is that the width of the visible portion of a negative obstacle may only span a few pixels at the stopping distance for vehicle speeds most UGV programs aspire to operate at (\>20mph). The problem can be further compounded when negative obstacles are obscured by vegetation or when negative obstacles are embedded in undulating terrain. Because of the variety of appearances of negative obstacles, a multi-cue detection approach is desired. In previous nighttime negative obstacle detection work, we have described combining geometry based cues from stereo range data and heat signature based cues from thermal infrared imagery. Heat signature is a powerful cue during the night since the interiors of negative obstacles generally remain warmer than surrounding terrain throughout the night. In this paper, we further couple thermal and geometry based cues for nighttime negative obstacle detection. Edge detection is used to generate closed contour candidate negative obstacle regions that are geometrically filtered to determine if they lie within the ground plane. Cues for negative obstacles from heat signature, geometry-based analysis of range images, and geometry-based analysis of terrain maps are fused. The focus of this work is to increase the range at which UGVs can reliably detect negative obstacles on cross-country terrain, thereby increasing the speed at which UGVs can safely operate.

6561-03, Session 1

On-the-move independently moving target detection

G. Salgian, J. Xiao, S. Samarasekera, R. Kumar, Sarnoff Corp.

Military vehicles operating in an urban environment are exposed to numerous threats from all directions. Distributed aperture camera systems provide the ability for a vehicle crew to have continuous, closed-hatch 360-degree situational awareness of the immediate surroundings prior to dismount and while on the move. However, it is difficult for an operator to simultaneously monitor the entire sensor array.

This paper describes a system for automatically detecting potential targets (that pop-up or move into view) and to cue the operator to potential threats. Detection of independently moving targets from a moving ground vehicle is challenging due to the strong parallax effects (e.g. occlusion) caused by the camera motion close to the 3D structure in the environment. We present a 3D approach to effectively resolve this ambiguity and detect and track such independently moving targets with multiple monocular cameras. In our approach, we first recover the camera position and orientation by employing a visual odometry method. Next, using multiple consecutive frames with the estimated camera poses, the structure of the scene at the reference frame is explicitly recovered by a motion stereo approach, and corresponding optical flow fields between the reference frame and other frames are also estimated. Third, an advanced filter is designed by combining second order differences between 3D warping and optical flow warping to distinguish the moving object from parallax regions.

We present results of the algorithm on data collected with an eight-camera system mounted on a vehicle under multiple scenarios that include moving and pop-up targets.

6561-04, Session 1

The Army Research Laboratory (ARL) synchronous impulse reconstruction (SIRE) forward looking radar

M. A. Ressler, L. H. Nguyen, F. Koenig, D. C. Wong, G. D. Smith, Army Research Lab.

The Army Research Laboratory (ARL) has designed and fabricated a forward-looking, impulse-based, ultra-wideband (UWB) imaging radar for detection of concealed targets. This proof-of-concept radar system employs a physical array of 16 receive antennas to provide the necessary aperture for sufficient cross-range resolution in the forward-looking geometry. Each antenna feeds a base-band receiver/digitizer that integrates the data from a number of radar pulses before passing it on to the personal computer (PC) based operator's console and display. The innovative ARL receiver design uses commercially available integrated circuits to provide a low-cost, lightweight digitizing scheme with an effective sampling rate of approximately 8 GHz. The design is extensible to allow for growth in the number of channels used and improvements in integrated circuit performance to eventually meet the expected unmanned ground vehicle combat pace. Using modules based on COTS components allows for continued expansion of capabilities of the system based on increasing capabilities of these components.

Down-range resolution is provided by the bandwidth of the transmitted pulse which occupies 300-3000 MHz. Range coverage is designed to be 25 meters with an adjustable start point forward of the vehicle. Modeling studies have shown that a pair of transmitters situated at the two ends of the receive array provides best performance in cross-range resolution. Image processing is done with a back projection algorithm that allows a quick look at the scene ahead. However, radar data is continuously collected so that a horizontal two-dimensional synthetic aperture is formed for 3-D image formation. This allows focusing of the data to yield estimates of target height as well as position to tag potential obstacles as being negative (e.g. holes, ditches) or positive (e.g. tree stumps).

Initial testing of the radar system will be done using a Ford Expedition as the mobile platform. The vehicle has an onboard 110 VAC inverter system that can be operated from batteries if needed and an antenna support structure that will allow positioning the antenna at various locations with respect to the roof and front of the vehicle. Integrated radar data from all 16 channels is collected and stored onboard the PC system with 3-D focusing of the data taking place offline. A differential GPS system provides the positioning information needed to allow the data to be focused in a known coordinate system.

6561-05, Session 1

Detection, tracking, and avoidance of moving objects from a moving semi-autonomous vehicle

E. J. Rigas, B. A. Bodt, J. A. Bornstein, Army Research Lab.

The Army's family of Unmanned Ground Vehicle (UGV) platforms for the Future Combat Systems (FCS) is currently being developed to support mounted and dismounted troop operations within the Unit of Action (UA). In accomplishing their missions, it is necessary for UGVs to operate in complex and hostile environments. UGVs must reliably, consistently, and safely sense and respond to objects that are typically encountered by manned vehicles such as other moving vehicles and humans.

ARL is developing the autonomous capability to directly support the Army's FCS program. The purpose of this paper is to document and benchmark the current ARL Collaborative Technology Alliance (CTA) capabilities in detecting, tracking and avoiding moving objects. For this experiment ARL and GDRS conducted a series of trials involving an ARL eXperimental Unmanned Vehicle (XUV) operating in proximity to a number of moving mannequins and vehicles.

The experimentation was divided into two portions. The first portion examined the performance of a number of algorithms using a series of sensor modalities to detect moving objects, i.e., people and vehicles, from a moving platform. The second portion of the experiment focused on the ability of the dynamic planner to utilize detection data in order to plan appropriate routes that will avoid moving pedestrians and vehicles. This analysis was conducted in simulation using input data obtained from a subset of the detection data that includes the best performing algorithms from the first part of the experiment.

6561-06, Session 1

A new SMART sensing system

D. C. Zhang, P. Yu, P. Qing, S. J. Beard, Acellent Technologies, Inc.

It is essential to ensure the safety and reliability of in-service structures, such as unmanned vehicles, by detecting structural cracking, corrosion, delamination, material degradation and other types of damage in time. Utilization of an integrated sensor network system developed by Acellent Technologies can enable automatic inspection of such damages ultimately. Using a built-in network of actuators and sensors, Acellent is providing tools for advanced structural diagnostics. Acellent's integrated structural health monitoring system consists of an actuator/sensor network (SMART Layer(r)), supporting signal generation and data acquisition hardware (SMART Suitcase), and data processing, visualization and analysis software (ACESS).

This paper describes the new features of Acellent's latest SMART Suitcase sensing system, which include through-transmission, pulse-echo, temperature measurement, system self-diagnosis, multi-channel I/O, etc. The new system is USB-port based and is ultra-portable. Test results of the new system on several structures are provided.

6561-07, Session 1

Precise visual navigation in unknown GPS-denied environments using multi-stereo vision and global landmark matching

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Traditional vision-based navigation system utilizing only one pair of stereo camera often drifts over time. In this paper, we propose a set of techniques to improve the robustness and accuracy of visual navigation systems. First, two pairs of stereo cameras are integrated to form a forward/backward multi-stereo camera system. As a result, the Field-Of-View of the system is extended significantly to capture more natural landmarks from the scene, which gives great robustness in challenging conditions such as when there are many confusers and other moving objects in the scene occluding one or more cameras or when there is lack of image texture in portions of the scene. Second, a global landmark matching technique is proposed to recognize the previously visited locations during navigation. The landmarks are automatically detected and placed in a 3D geo-spatial database. A pose correction technique is activated to reduce drift errors accumulated in the navigation position by matching to previously detected landmarks. Finally, in order to further improve the robustness of the system under certain special scenes without rich textures, both IMU and GPS sensors are integrated with the visual odometry system within an extended Kalman filtering framework to prevent the possible failures due to the lack of natural landmarks. Using these techniques, the developed system is significantly more accurate and robust over long-distance navigation both indoors and outdoors. Real navigation tasks demonstrate that we are able to locate the user within 1 meter in an unknown GPS denied environments during navigation tasks over 500 meters long.

6561-08, Session 1

Angularly sensitive micro-sensor construction and new processing paradigm

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Discussed is a novel method of manufacturing[1] an Angularly Sensitive Micro-Sensor (ASMS). The process employed utilizes excimer laser ablation to write out the microlens on the curved surface of the master lens. This master lens element is manufactured with fused optical fibers, such that if the registration is maintained, the light from each microlens goes via the fiber to a specific pixel. If local imaging is required for specific tasks the fiber can send the angularly localized image to a pixel set. Image fusing may then be required.

Infrared and ultraviolet versions can be manufactured. A more general application allows for a mult-spectral sensor. After one ASMS is constructed, then an inverse mask (mould) can be created and the monolithic sphere, retaining its' registration, is covered in liquid plastic and placed into the mould and the exact replica is re-created. The advantage is low cost and rapid manufacture of the ASMS. An important aspect of this approach is that the sensor samples amplitude and angular space rather than amplitude and position space as conventional sensors currently do. This makes the ASMS processing paradigm completely different from conventional image processing. For example using several fiber/pixel elements to comprise a UV polarimeter allows for simple storage and processing of vector elements for simple navigation. The home position may be treated as "Look up table" reference matrix (RM). That base table can be modified to account for the passage of time (and hence change in solar position from the UV polarimeter, as appropriate). A second "real time" travel matrix (TRM) is then created. Eventually, a target matrix (TAM) would also be created. Simply driving changes in the TRM towards the RM would be used for navigating the return trip back to home base. When the difference between the two matrices goes to a null matrix the platform would be home.

1. U.S. Patent Application No. 11/110,992, Entitled "Method or Manufacture for a Compound Eye", NVESD Ref: NVL 3304 was filled 20 April 2005.

6561-09, Session 1

Terrain perception for robot navigation

R. E. Karlsen, U.S. Army Tank-Automotive Research, Development and Engineering Ctr.; G. Witus, Turing Associates

Unstructured vision-based navigation continues to be an especially difficult problem for small robotic systems. If they are even equipped with a vision system, monocular and stereovision video remain the systems of choice for small inexpensive robots. This paper presents a software system for image-based terrain segmentation and associated vehicle-terrain interaction prediction. The system identifies a set of image chips (or exemplars) in the training images that span the range of terrain appearance. Exemplar statistical quantities are used to measure chip differences. Each chip is assigned a vehicle performance feature vector tag that is measured through on-board sensors and extrapolated into the scene. The system uses the exemplars to segment novel images and assigns an appropriate feature vector tag to them. Offline learning is accomplished through a fuzzy c-means clustering algorithm, while online learning and prediction is performed through a fast heuristic methodology. The system provides online prediction of vehicle performance on upcoming terrain.

6561-10, Session 1

Daredevil: ultra-wideband radar sensing for small UGVs

B. M. Yamauchi, iRobot Corp.

For the TARDEC-funded Daredevil Project, iRobot is integrating inexpensive, low-power, ultra wideband radar sensors with higher-resolution range sensors (LIDAR, stereo vision) to provide sensing for small UGVs. The key objectives are to develop sensor configurations and processing algorithms to enable the system to reliably detect obstacles through foliage and through rain and snow. A unique feature of our approach is the use of polarimetric radar to distinguish foliage from solid objects. Common types of foliage (tall grass, open fields, crop fields) provide strong radar returns for vertically-polarized radar pulses and weak radar returns for horizontally-polarized radar pulses. In contrast, objects such as rocks reflect radar roughly equally regardless of pulse orientation. By computing the differential reflectivity of the target object, we expect to reliably distinguish vertically-oriented vegetation from other solid objects. In this paper, we will describe current results from real-world experiments using polarimetric radar to perceive solid obstacles through foliage, rain, and snow.

6561-11, Session 1

Non-GPS navigation with the personal dead-reckoning system

L. V. Ojeda, J. Borenstein, Univ. of Michigan

This paper presents our recently developed Personal Dead-reckoning (PDR) system for walking persons. The system uses a 6-DOF inertial measurement unit (IMU) attached to the user's shoe. The IMU provides rate and acceleration measurements that are used to estimate the location of the user in real-time. The core principle of our system is a technique known as Zero Velocity Updates (ZUPTS), which allows for the correction of errors due to drift in the accelerometers of the IMU. Accelerometer drift is the most significant error in a system like ours, and the successful correction of such errors is the key to successful dead-reckoning.

Using ZUPTS and additional mathematic techniques, the overall error of our PDR system has been consistently less than 2% of distance traveled, independent of the user's walking gait or speed. Our system works just as well on sloped terrain or stairs as it does on flat terrain. On non-flat terrain the PDR system also estimates the vertical position of the user, although with larger errors than 2% of distance traveled.

Since IMUs do not require any external beacons or signals, our system is usable in any environment, without any preparation. Of particular interest are GPS-denied environments such as inside buildings, tunnels, urban canyons, or under dense foliage. Our system is useful for first responders and military or security personnel.

The paper here describes the PDR system briefly and then focuses on extensive experimental results and field testing.

6561-12, Session 1

A novel routing and sensor control optimization algorithm for target search and classification

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Two typical problems in unmanned air vehicle (UAV) and sensor control are: locating target(s) in minimum time, and classifying target(s) with maximum certainty. Current methods solve the optimization of UAV routing control and sensor management independently. While this decoupled approach makes the target search problem computationally tractable, it is suboptimal.

In this paper, we explore the target search and classification problems by formulating and solving a joint UAV routing and sensor control optimization problem. The routing problem is solved on a graph using receding horizon optimal control. The objective function for the routing optimization is in turn the solution of a sensor control optimization problem. In particular, an optimal sensor schedule (in the sense of maximizing the viewed target probability mass or minimizing the Shannon entropy) is constructed for each candidate flight path in the routing control problem.

The probability distribution function (pdf) of the target state is represented with a particle filter and an "occupancy map" for any undiscovered targets. The tradeoff between searching for undiscovered targets and locating tracks is handled automatically and dynamically by the use of an appropriate objective function. In particular, the objective function is based on the expected amount of target probability mass to be viewed. In the target classification problem, one needs to consider the existence of multiple target types simultaneously. In this case, we use an objective function based on Shannon entropy. Again, the tradeoff between searching for undiscovered targets and classifying existing tracks is handled automatically and dynamically.

6561-13, Session 2

Intelligent unmanned vehicle systems suitable for individual and cooperative missions

M. O. Anderson, M. D. McKay, D. C. Wadsworth, Idaho National Lab.

The Department of Energy's Idaho National Laboratory (INL) has been researching autonomous unmanned vehicle systems for the past several years. Areas of research have included unmanned ground and aerial vehicles used for hazardous and remote operations as well as teamed together for advanced payloads and mission execution. Areas of application include aerial particulate sampling, cooperative remote radiological sampling, and persistent surveillance including real-time mosaic and geo-referenced imagery in addition to high resolution still imagery. Both fixed-wing and rotary airframes are used possessing capabilities spanning remote control to fully autonomous operation. Patented INL-developed auto steering technology is taken advantage of to provide autonomous parallel path swathing with either manned or unmanned ground vehicles. Aerial look-ahead imagery is utilized to provide a common operating picture for the ground and air vehicle during cooperative missions. This paper will discuss the various robotic vehicles, including sensor integration, used to achieve these missions and anticipated cost and labor savings.

6561-14, Session 2

Intelligent mobility research at Defence R&D Canada for UGV mobility in complex terrain

M. Trentini, B. H. Beckman, B. L. Digney, Defence Research and Development Canada (Canada)

The objective of the Autonomous Intelligent Systems Section (AISS) of Defence R&D Canada -Suffield is best described by its mission statement, which is "to augment soldiers and combat systems by developing and demonstrating practical, cost effective, autonomous intelligent systems capable of completing military missions in complex operating environments." Defence R&D Canada envisions autonomous systems contributing to decisive operations in the urban battle space. In this vision, teams of unmanned ground, air, and marine vehicles (UAVs, UGVs, and UMVs) will gather and coordinate information, formulate plans, and complete tasks. On the ground, it will be the UGVs that will be called upon first to enter unknown city blocks if they are to keep soldiers out of harms way. The mobility requirement for UGVs operating in urban settings must increase significantly if they are to navigate unknown, highly complex environments. To achieve its objective, the AISS program is pursuing intelligent mobility research designed to improve robot mobility. Intelligent mobility uses sensing, control, and learning algorithms to extract measured variables from the world, control vehicle dynamics, and learn by experience. These algorithms seek to exploit available world representations of the environment and the inherent dexterity of the robot to allow the vehicle to interact with its surroundings and produce locomotion in complex terrain. This paper documents the progress and future direction of intelligent mobility research at Defence R&D Canada to address autonomous UGV mobility in unknown, highly complex terrain. The paper updates the status of novel mobility platforms developed for real-world testing.

6561-15, Session 2

Cohort: critical science and immediate realities

B. L. Digney, Defence Research and Development Canada (Canada)

Cohort is a major Applied Research Program (ARP) led by DRDC Suffield and its goal is to develop coordinated teams of unmanned vehicles (UxVs) for urban environments. While Cohort is predominately a Horizon III project that delivers technology in the 20 year time frame., current operational realities are placing ever greater urgency to field effective unmanned vehicles and systems.

Unmanned vehicle systems have been an attractive technology for the military, but whose promises have remained largely undelivered. There are fielded remote controlled UGVs and high altitude UAV whose benefits are based on standoff in low complexity environments with low reaction time requirements. While effective within there limited operational niche such systems do not meet with the vision of future military UxV scenarios. There are clearly gaps in the critical science required to move unmanned systems from sluggish drones that are a burden to employ to the agile and information savvy systems required. This paper will discuss the critical science being addressed by Cohort, through DRDC research, academic, industry and international partnerships. Critical science includes:

1. Real World Learning: Learning UxVs is required not only to adapt to the irregularities and inconsistencies of the real environments, but to autonomously generate solutions to problems and refine those solutions with increasing experience. Learning will play major roles in sensor interpretation, planning, control, action and multi-vehicle coordination.

2. Self Defining Perceptual Abstractions. The reduction of sensor data (vision, tactile, proprioceptive ..) to useful and relevant abstractions is done using a priori knowledge and human insight into the utility and needs of the vehicle/mission and knowledge as to what are good indicator features in the sensation stream. For broadly applicable vehicle intelligence these abstractions need to be determined during operation by the vehicle and be based upon each vehicle's individual capabilities and changing needs.

3. Planning and Coordination with Complex and Acquired Action-Effects-Cost models: Current single and multi-vehicle mission planners require a priori defined action-effect-cost models. These models are handcrafted and only possible with known and easy to define effects such as spatial location and vehicle movement costs. Effective planning systems must be able to acquire and use models of complex real vehicle - world interactions well beyond simplistic models must be developed.

4. Distributed /Centralized Control: Coordination of vehicle is communication and information impoverished situation will require a tolerance to isolation and ignorance. Advances in distributed control and distributed planning are required to insure operation in these conditions. On board UxV intelligence will need to make decisions on coordination and planning paradigms they operate under and when to switch.

5. C2 and Interfaces: The C2 system must be flexible to accommodate diverse capabilities of many types of UxVs and a broad range of missions and extensible to accommodate new and self generated intelligent and capabilities. New interfaces must be developed for highly independent UxVs and support transfer of knowledge via learning/training between humans and machines and informal direction from humans.

6561-16, Session 2

Establishment of a center for defense robotics

D. J. Thomas, U.S. Army Tank-automotive and Armaments Command

During the past decade, significant strides in the development of ground robotic systems for defense applications have been achieved. Advances in perception, control, interfaces and payload integration has provided the basis for a true military operational capability. Numerous applications that assist the soldier in the dull dangerous and dirty missions are being identified with emerging prototype platforms under evaluation. To meet the emerging need in defense robotics, a center for ground robotics is being grown at the Detroit arsenal in Warren, Michigan. This presentation will outline the vision and progress in establishment of the new center.

6561-17, Session 3

Preparing for UGV tests with human object detection

S. Fish, J. Ruedin, Science Applications International Corp.; M. R. Perschbacher, Defense Advanced Research Projects Agency; J. E. Bares, Carnegie Mellon Univ.

As Unmanned Ground Vehicle technology matures and newer and larger UGV's are developed for a variety of applications, their operation among humans will grow. Current UGV's are operated safely in the presence of humans by implementing one or more of the following restrictions: a) the system is small enough or slow enough that it's kinetic energy presents only a minor hazard to humans if contact is made, b) the system is operated at slow enough speeds that any humans nearby have plenty of time to avoid it, c) humans are required to remain outside a certain radius with respect to the vehicle and monitor the UGV's activity when it is "on", d) the UGV avoids all objects within a certain radius and stops if any object is detected within a smaller (but still large radius) to insure it stays away from humans. To increase the utility of UGV's for tasks where one would like to have humans and robots operating in close proximity, one must find a paradigm that is improved over d) to reduce the burden on humans for monitoring and avoiding their UGV partners. This paper describes initial experiments conducted to collect data needed for evaluation of the detection performance of a Ladar and camera sensor suite for stationary and moving humans from a large stationary and moving UGV. Of importance here, is not the actual performance of the sensors (which will evolve over time), but the method used to insure that the test itself can be conducted safely. The paper describes how the tests were planned and how simulations can be used to enhance preparation for experiments of this type.

6561-18, Session 3

Objective test and performance measurement of automtotive crash warning systems

S. M. Szabo, National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST), under an interagency agreement with the United States Department of Transportation (USDOT), is supporting development of objective test and measurement procedures for vehicle-based warning systems intended to warn an inattentive driver of imminent rear-end, road-departure and lane-change crash scenarios. The work includes development of track and on-road test procedures, and development of an independent measurement system, which together provide data for evaluating warning system performance. This paper will provide an overview of DOT's Integrated Vehicle-Based Safety System (IVBSS) program along with a review of the approach for objectively testing and measuring warning system performance.

6561-20, Session 3

Micro-UAV collision avoidance

J. Merchant, RPU Technology; F. Pope, Kanasaska Technology, LLC

A Bio-Inspired Collision Avoidance System (BICAS) is described that derives range images from the output of a conventional camera as it moves relative to the scene. The range images from BICAS, installed on a micro UAV, can warn of looming collisions and help determine a safe evasive maneuver. This will reduce operator workload and may preserve the vehicle during a temporary loss of the video link to the ground station controller. A range image of the scene may be essential for semiautonomous or autonomous operation. The range image is derived by tracking the range-dependent displacement of scene detail over a sequence of camera images. The effect of any rotation of the camera, or of any change in the direction of its velocity vector during the sequence, is removed using information from an IMU. The motion of scene detail is then along a known set of optic flow lines, and its displacement can be measured by simple one-dimensional tracking. BICAS is bio-inspired by its use of a new low density image sampling protocol (variance sampling), derived from human vision. Variance sampling captures high spatial frequency information (as needed for example to sense power lines) in spite of its low pixel density. A mass of irrelevant point-by-point detail is eliminated that greatly simplifies the tracking task and reduces the processing load.

6561-21, Session 3

Layered-mode selection logic control with fuzzy sensor fusion network

T. E. Born, A. B. Wright, Univ. of Arkansas/Little Rock

Robots developed from the 60's to the present have been restricted to highly structured environments such as work cells or automated guided vehicles, primarily to avoid harmful interactions with humans. Next generation robots must function in unstructured environments. Such robots must be fault tolerant to sensor and manipulator failures, scalable in number of agents, and adaptable to different robotic base platforms. The Central Arkansas Robotics Consortium has developed a robot controller architecture, called Layered Mode Selection Logic (LMSL), which addresses all of these concerns. The LMSL architecture is an implementation of a behavior based controller fused with a planner. The architecture creates an abstraction layer for the robot sensors through a Fuzzy Sensor Fusion Network (FSFN), and it creates an abstraction layer for the robot manipulators through a reactive layer. The LMSL architecture has been implemented and tested on the J5 robotics research platform. A FSFN combines acceleration and force signals for collision detection. The output of the FSFN switches among low level behaviors to accomplish obstacle avoidance and obstacle manipulation. Comparable results are achieved with all sensors functioning, with only the acceleration sensor (force sensor faulted), and with only the force sensor (acceleration sensor faulted). In this paper, results for the J5 robotics research platform are presented.

6561-22, Session 3

Effect of collision avoidance for autonomous robot team formation

M. Seidman, S. J. Yang, Rochester Institute of Technology

Technological advances have allowed for the creation of cost effective yet highly mobile and precise moving robots that are capable of sensing and communication. These robots may cooperate to perform tasks never achievable by a single robot. A robot team formation problem is one that seeks autonomous actions taken by individual robots so as to form into a geographical shape with limited knowledge and with no reference point. A typical shape considered in the literature is a circle or n-polygon, where n is the number of robots forming the shape. Forming into a circle may be considered as a starting point for the robot team to perform a cooperative task. Applications of cooperative robot teams include intruder detection and containment of chemical spills or forest fires. Existing work on robot team formation focuses on theoretical analysis where real-world factors, such as the size of the robots, are not considered. It is unclear whether proposed theoretical algorithms are valid or perform well in real-world settings.

This research reviews and selects an autonomous robot shape formation algorithm that doesn't require global sensing, and examines the effect of different sensing and collision avoidance technologies on the performance of the algorithm. Three different collision avoidance scenarios are presented and analyzed when accounting for the robot sizes. The three scenarios represent increasing sensing and communication capabilities required for the cost-effective autonomous robots. The performances of the original algorithm, which doesn't account for collisions, and that achieved by the same ideal algorithm with the three collision avoidance scenarios are compared. Our results suggest that adding communication does not necessarily enhance the success rate and the convergence speed of shape formation as long as the robots are capable of detecting and avoiding imminent collisions. Moreover, in the case where only limited robots are available, it is the collision avoidance that relies on conservative yet complex algorithmic approaches outperforms robots with advance sensing and communication.

6561-23, Session 3

Toward safe navigation in urban environment

C. Ye, Univ. of Arkansas/Little Rock

This paper presents a method for autonomous navigation of a mobile robot in urban environment. An urban environment is defined as one having hard surface and comprising curbs, ramps and obstacles. The robot is required to move on the flat ground or ramps but avoid curbs and obstacles. To guide the robot in an urban environment, a 3-D terrain map is needed. In this paper, a 2-D laser rangefinder (Sick LMS 200) is used for 3-D terrain mapping because it has a long range capability and has accurate range measurement. The terrain mapping system uses a single sensor modality and is therefore affordable. However, it is susceptible to erroneous sensory data (mixed pixels and random noise). In the author's previous work [1], a filtering method based on the elevation and certainty information of cells in a grid-type map was proposed to remove the erroneous laser range data. The filtering method incurs computational cost and its performance may be degraded when the robot turns quickly. In this paper, an alternative mixed pixel removal method is proposed. It uses the distinctive physical features of mixed pixels * the discontinuities in intensity and range measurement. Differing from the intensity discontinuity of other laser rangefinders, the Sick LMS 200's intensity value increases abruptly at a corner shot (a mixed pixel), i. e. the intensity value of a mixed pixel is much bigger than those of its neighboring measurements (at the front object and the background object). This property together with the discontinuity of range measurement can be used as the signature of a mixed pixel and used to remove mixed pixels.

An Extended Terrain Map (ETM) is built using the filtered laser scan data. Each ETM consists of a regular elevation map and a so-called certainty map where each cell holds a value representing the confidence of the elevation information of the corresponding cell in the elevation map. When building the certainty map the motion continuity constraint [1] is used to update each cell. Therefore, a cell corrupted by random noise has relatively smaller certainty, and the error can be removed by simply using a median filter. The certainty information can also be used to enhance the robustness of the navigation method. For an example, cells in an unperceived area usually have zero certainty value and must be treated as untraversable. This prevents the robot from falling off an elevated area. A local obstacle negotiation method, called Traversability Field Histogram [2], is then used to determine the robot motion. The method first transforms a local terrain map into a traversability map, and then transforms the traversability map into a Traversabiliy Field Histogram (TFH). Each value in the TFH represents the overall difficulty traversing the corresponding direction. As the robot's heading (yaw) angle is taken into account when computing the traversability index of each cell, the TFH algorithm allows the robot to snake through a steep slope. The local convergence property of the TFH algorithm is proven in this paper.

6561-24, Session 3

Simulating and testing autonomous behavior in multiple airborne sensor systems

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The Multiple Airborne Sensor Targeting and Evaluation Rig (MASTER) is a high fidelity simulation environment in which data fusion, tracking and sensor management algorithms developed within QinetiQ Ltd. can be demonstrated and evaluated. In this paper we report an observer trajectory planning tool that adds functionality to MASTER. This trajectory planning tool controls each sensor by applying instantaneous thrusts, the magnitude of which is chosen to gain maximum observability of the target. The target itself has the capability of being evasive, and can switch between a constant velocity model and a number of quantised acceleration models (of varying magnitude). We use an efficient search technique to determine the thrust that should be applied to each platform at each time step, and the planning horizon can be either one-step (greedy) or two-step. The measure of performance used in evaluating each potential sensor manoeuvre (thrust) is the posterior Cramer-Rao lower bound (PCRLB), which gives best possible (lowest mean square error) tracking performance. In this paper we exploit a recent novel approach to approximating the PCRLB for manoeuvring target tracking (Hernandez et al., 2005). The basis of this technique is to replace the multi-modal target probability density function with a best-fitting Gaussian (BFG) distribution. In a recent paper, this approach was shown give an accurate measure of performance that closely matches state-of-the-art filter performance. Furthermore, a closed-form expression gives the BFG approximation at each sampling time. Hence, the PCRLB can be approximated with a very low computational overhead, and therefore implemented in time critical scenarios.

6561-25, Session 4

Supervised autonomy for robotic inspection

K. L. Moore, Colorado School of Mines

Experience deploying robots for security and inspection tasks shows that often the activity of “driving” the robot interferes with the activity of observing the sensor data (often visual) collected by the robot. It has been suggested that the supervised autonomy paradigm can improved system performance. In this approach, some aspects of the robot’s actions are automated, particularly motion control, freeing the operator to focus on the inspection task. In this paper we describe the development and implementation of a semi-autonomous mode for the ODIS robot, whereby, under the direction and supervision of an operator, the robot can self-navigate underneath automobiles and other vehicles, sending back video images for operator inspection. The operational concept is as follows: in “manual mode” robot is tele-operated by the operator visually or by navigating with the robot’s camera to the driver-side front wheel of the vehicle to be inspected. Then, using its inspection camera, the robot visually localizes itself to the vehicle to be inspected and from that localization, computes and drives an inspection path under the vehicle. Experimental results show the effectiveness of the approach, including improvements in inspection time and performance that are possible using supervised autonomy.

6561-26, Session 4

Integration of an intelligent systems behavior simulator and a scalable soldier-machine interface

T. G. Johnson, DCS Corp.; T. M. Tierney, U.S. Army TARDEC/ RDECOM

As the Army’s Future Combat Systems (FCS) introduce emerging technologies and new force structures to the battlefield, soldiers will increasingly face new challenges in workload management. The next generation warfighter will be responsible for effectively managing robotic assets in addition to performing their primary mission. Studies of future battlefield operational scenarios involving the use of automation, including the specification of existing and proposed technologies, will provide significant insight into potential problem areas regarding soldier workload.

The US Army Tank Automotive Research, Development, and Engineering Center (TARDEC) is currently executing an Army technology objective program to analyze and evaluate the effect of automated technologies and their associated control devices with respect to soldier workload. The Human-Robotic Interface (HRI) Intelligent Systems Behavior Simulator (ISBS) is a human performance measurement simulation system that allows modelers to develop constructive simulations of military scenarios with various deployments of interface technologies in order to evaluate operator effectiveness. One such interface is TARDEC’s Scalable Soldier-Machine Interface (SMI). The scalable SMI provides a configurable machine interface application that is capable of adapting to several hardware platforms by recognizing the physical space limitations of the display device.

This paper describes the integration of the ISBS and Scalable SMI applications, which will ultimately benefit both systems. The ISBS will be able to use the Scalable SMI to visualize the behaviors of virtual soldiers performing HRI tasks, such as route planning, and the scalable SMI will benefit from stimuli provided by the ISBS simulation environment. The paper describes the background of each system and details of the system integration approach.

6561-27, Session 4

Augmented tele-operation for soldier-robot checkpoint inspection systems, phase I: test results

G. Witus, Turing Associates, Inc.; R. E. Karlsen, G. R. Gerhart, U.S. Army TARDEC/RDECOM

Small teleoperated mobile robots are beginning to be used in checkpoint operations. Troops can conduct the initial inspection from a remote location, safe from potential sniper fire and car bomb detonation. Visual inspection is currently the primary initial screening procedure. Handheld sensors capable of detecting explosives, chemical/biological threats, and objects concealed in hollow compartments are also beginning to be used in the field. The logical next step is to deploy these sensors on the robots. However the sensors must be positioned close to the suspected trace, vapor source, or compartment. Teleoperation is fatiguing and stressful even without the requirement for close positioning. The TARDEC Robotic Mobility Laboratory (TRML) is investigating approaches to reduce workload and improve performance through augmented teleoperation.

This paper reports on the results of preliminary experiments to assess the relative effectiveness of 3 degree-of-freedom (DoF) versus 2 DoF motion control, on-board egocentric viewing perspective versus overwatch perspective, and a distance and orientation visual cueing system. Three DoF motion control (rotation and omnidirectional translation) produced substantially shorter response times than 2 DoF motion control. Laser cueing significantly reduced positioning errors without affecting response time for both 2 DoF and 3 DoF control. In the absence of laser cuing, 3 DoF motion control reduced positioning errors relative to 2 DoF control, but had only a small effect in the presence of laser cueing. Viewing perspective had small and inconsistent effects on response time and components of spatial error.

6561-28, Session 4

Results from a long-term study of portable field robot in urban terrain

C. Lundberg, Kungliga Tekniska Högskolan (Sweden) and National Defence College (Sweden); R. Reinhold, H. I. Christensen, Kungliga Tekniska Högskolan (Sweden)

Military possesses a considerable amount of experience from using robots for mine clearing and bomb removal. But as new technology emerges it is also necessary to investigate the possibly to expand robot use to further remove soldiers from risk, to perform more efficiently or at lower cost and to enable missions unsuited to humans. In the evaluation process the profits of robots have to be valued against costs for acquisition, integration, training, maintenance as well as mission efficiency and reliability.

This study has investigated an Army company specialized in urban operations while solving their tasks with the support of a PackBot Scout. The robot was integrated and deployed as an ordinary component of the company, which included modifying and retraining a number of standard behaviors to include the robot. The reported results were acquired under a long-term test ranging over a period of six months during which the company participated in training maneuvers with 200 to 6000 soldiers.

The results show that the implemented robot may well be of value but only in specific situations. The robot cannot simply take the place of a soldier. Most commonly was the robot used for exploration inside building while no obvious enemy threat or time pressure was prevailing. It was found that the users needed to have precise knowledge of the systems performance to rightfully decide in which cases to deploy the robot. For example, performing exploration with the robot would at least take twice the time of traditional methods but may well entail a faster mission realization as a result of information increase. The soldiers also needed to thoroughly train the new schemes, which were required for integration of the robot in their activities. Finally, the study pointed out what technical properties that constrain the system and what new abilities would be of most value.

6561-29, Session 4

Layered augmented virtuality

G. Ahuja, B. Sights, G. T. Kogut, E. B. Pacis, H. R. Everett, F. Birchmore, Space and Naval Warfare Systems Ctr., San Diego

Advancements to robotic platform capabilities and autonomy make it necessary to enhance the current capabilities of the OCU for better perception of the information provided by the robot. Augmented virtuality is one technique used to improve the user interface, augmenting a virtual-world representation with information from on-board sensors and human input. Standard techniques for displaying information, such as embedding information icons from sensor payloads and external systems (other robots), could result in serious information overload, making it difficult to sort out the relevant aspects of the tactical picture. This paper illustrates a unique layered approach to augmented virtuality that specifically addresses this need for optimal situation awareness. We describe the efforts to implement three display layers that sort the information based on the component, platform, and mission needs. Two gathering-sharing layers are also investigated as a means to contribute to one common operating picture between multiple robots and operators.

6561-30, Session 4

Layered autonomous overwatch: the necessity and feasability of multiple unmanned systems in combat support

S. P. Monckton, Defence Research and Development Canada (Canada)

Unmanned systems simultaneously reduce risk and magnify the impact of soldier-operators. For example, in Afghanistan UAVs routinely provide overwatch to manned units while UGVs support IED identification and disposal roles. Expanding these roles requires greater autonomy with a coherent unmanned “system of systems” approach that leverages one platform’s strengths against the weakness of another. Though teleoperation makes unmanned systems useful today, expanding unmanned systems adoption will require substantially greater autonomy to reduce operator work loads. Together ground, fixed and rotor wing UVs may provide an important mixture of range, speed, payload, and endurance to provide services ranging from comms rebroadcast, medium range reconnaissance, high-speed low-altitude route inspection, large-payload route clearing. This paper explores the unmanned system strengths and weaknesses in specific combat support roles and examines composite joint (Fixed-Rotor-Ground) systems as a solution.

6561-31, Session 4

Head-aimed remote vision for EOD robots

K. Massey, Chatten Associates, Inc.

Several different typical Explosive Ordnance Disposal missions were studied using current vision systems and a newly developed Head-Aimed Remote Vision (HARV) system. Tasks included looking for hidden secondary Improvised Explosive Devices (IED’s) while the EOD robot is moving downrange to investigate a known IED location. The night vision capability of the HARV system was also studied, including a mission performance comparison of a thermal imager (320 x 240 microbolometer) versus a low-light camera (0.00005 lux near-IR). All simulated missions were performed by experienced Army EOD soldiers in a realistic setting. Impact of vision system on mission performance is presented.

6561-32, Session 4

An agent-based approach to decluttering the interfaces of multi-UAV command and control systems

S. O’Hara, N. Dwyer, 21st Century Systems, Inc.

Information overload and cluttered user interfaces can lead to decreased situational awareness and lowered performance of human operators. Irrelevant data increases searching times for tasks requiring the identification of threats, causing delayed decisions. Cognitive burden on the user increases as displays become more cluttered, which results in increased operator stress leading to poor decision-making ability.

To address this issue, we have proposed an intelligent agent-based system for the automatic de-cluttering of a representative net-centric interface designed for controlling multiple unmanned aerial vehicles (UAVs) by a single operator. Our concept is called ARID, for Agent-based Reduction of Information Density. The ARID hypothesis is that intelligent agents can improve operator performance by de-emphasizing those aspects of a display that can be inferred as less-important to the mission goals.

The ARID agent receives information about the world via data feeds provided by various net-centric sources. The agent has an understanding of the user interface symbols that are used to represent various entities, terrain features, and zones. The agent also is provided with a mission goal which is used for inferring the relevance of a given symbol to the success of the mission goal. First level facts, such as spatial relationships, are calculated by monitoring agents and assigned a BDU (belief/disbelief/uncertainty) value. A dynamic set of rules provides an inference mechanism by which an agent can infer new facts from the given assertions. We have developed a forward-chaining reasoner that explicitly deals with belief and uncertainty in the knowledge base, and is used to derive a relevancy belief for every UI symbol in the map display. Subjective Logic is used to combine values when different rules provide different results for the same symbol. The user interface of the display is programmed to alter the opacity of the symbol based upon the current relevancy BDU value at each tick of the simulation. More relevant symbols are more opaque, and less relevant ones are more transparent.

Our paper discusses the development of an initial knowledge representation of the problem domain and user interface elements, the design of the ARID agents and reasoning engine, and the evaluation of a test-bed implementation. We conclude with experimental evidence to demonstrate the effectiveness of the system.

6561-33, Session 4

Stereo-vision based 3D modeling for unmanned ground vehicles

S. Se, P. Jasiobedzki, MacDonald, Dettwiler and Associates Ltd. (Canada)

Instant Scene Modeler (iSM) is a system capable of generating calibrated photo-realistic 3D models of unknown environments quickly using stereo image sequences. Equipped with iSM, unmanned ground vehicles (UGVs) can capture stereo images and create 3D models to send back to the base station while they explore unknown environments. The 3D models allow mission reconnaissance, as they can be visualized from

different views and measurements can be performed.

Current military operation of UGVs in urban warfare threats involves the operator hand-sketching the environment from live video feed. iSM eliminates the need for an additional operator as the 3D model is generated automatically. The photo-realism of the models enhances the situational awareness of the mission and the models can also be used for change detection. iSM has been tested on our autonomous vehicle to create photo-realistic 3D models while the rover traverses in unknown environments.

Moreover, a proof-of-concept iSM payload has been mounted on iRobot Wayfarer Packbot with autonomous urban reconnaissance capabilities. Wayfarer uses wheel odometry for localization and builds 2D occupancy grid maps from a laser sensor. While Wayfarer is following walls and avoiding obstacles, iSM captures and processes images to create photo-realistic 3D models. Experimental results show that iSM can complement Wayfarer's autonomous navigation in two ways. The photo-realistic 3D models provide better situational awareness than 2D grid maps. Moreover, iSM also recovers the camera motion, also known as the visual odometry. As wheel odometry error grows over time, this can help improve the wheel odometry for better localization.

6561-34, Session 4

A scalable soldier-machine interface for human-robotic interaction

S. Scheiner, DCS Corp.

As part of the Crew-Automated and integration Testbed (CAT) Advanced Technology Objective (ATO), the US Army Tank-automotive and Armaments Research, Development, and Engineering Center (TARDEC) developed crew stations that provided soldiers the ability to control both manned and unmanned vehicles. The crew stations were designed to optimize soldier workload and provide the ability to conduct mission planning, route planning, reconnaissance, surveillance, and target acquisition (RSTA), and fire control capabilities. The crew station software is fully configurable, portable (between crew stations), and interoperable with one another. However, the software architecture was optimized for the specific computing platform utilized by each crew station and user interfaces were hard coded. Current CAT crew station capabilities are required to execute on other crew station configurations as well as handheld devices to meet the needs of expanded soldier roles, including dismounted infantry. TARDEC is currently exploring ways to develop a scalable software architecture that is able to adapt to the physical characteristics of differing computing platforms and devices. In addition, based upon a soldier's role, the software must be able to adapt and optimize the displays based upon individual soldier needs. And finally, the software must be capable of applying a unique style to the presentation of information to the soldier. Future programs require more robust software architectures that take these requirements into account. This paper will describe how scalable software architectures can be designed to address each of these unique requirements.

6561-35, Session 4

Unmanned multi-control based on voice recognition of mobile robot

S. Cho, UREATac Co., LTD. (South Korea)

In this paper it is presented a new approach to the design of cruise control system of a mobile robot with two drive wheel. The proposed control scheme uses a Gaussian function as a unit function in the fuzzy neural network, and back propagation algorithm to train the fuzzy neural network controller in the framework of the specialized learning architecture. It is proposed a learning controller consisting of two neural network-fuzzy based on independent reasoning and a connection net with fixed weights to simply the neural networks-fuzzy. The performance of the proposed controller is shown by performing the computer simulation for trajectory tracking of the speed and azimuth of a mobile robot driven by two independent wheels.

6561-36, Session 5

BigDog

M. Raibert, M. G. Buehler, R. R. Playter, Boston Dynamics

This paper provides a status report on BigDog, a self-contained quadruped robot designed for rough-terrain locomotion. The purpose of BigDog is to provide a robot that can go where the dismounted soldier goes, traveling at soldier speed on terrain too rough for any existing wheeled or tracked vehicle. BigDog is designed to be power autonomous, to carrying significant loads, and to operate in outdoors and urban settings. The latest version of BigDog is about 1 m tall, 1 m long and 0.3 m wide, and weighs about 90 kg. BigDog has demonstrated walking, trotting, bounding and pronking gaits, as well as standing up and sitting down. It has walked up and down 35 degree inclines, walked on rocky surfaces, carried a 60 kg load and reached a top speed of 3.1 m/s (6.8 mph) (not all at the same time). Since first operation in 2004, BigDog has logged over one hundred hours of walking, climbing and running time. We are currently expanding BigDog's rough-terrain mobility to include steeper inclines, scree surfaces, and a variety of obstacle-cluttered environments. BigDog is funded by DARPA, with additional funding from the US Army and US Marine Corps.

6561-37, Session 5

Heading stabilization and anti-rollover for chaos

M. Berkemeier, E. Poulson, S. King, Autonomous Solutions, Inc.

Chaos is a 2-man-portable tele-operated vehicle designed for crossing rugged terrain. Chaos is capable of crossing large piles of cinder blocks, picnic tables, and steep hills of loose soil. These feats are accomplished through use of 4 independent track arms, each of which can be articulated at an arbitrary angle and driven at an arbitrary speed. These make the vehicle extremely capable but also demand significant skill on the part of the user. It is therefore desirable to automate the arm angles and track speeds to ease operator burden. This paper reports on preliminary efforts to implement 2 "intelligent behaviors" along these lines. The first involves heading stabilization: A gyroscope is used to sense yaw and yaw rate, and these are compared with the operator's commands. Deviations are then used to automatically correct the heading. This is useful when Chaos is climbing stairs or other bumpy terrain, which can cause the vehicle to veer off in unwanted directions. We call the other behavior "anti-rollover." In this case, the output of a gyroscope is monitored to detect if roll or pitch thresholds are exceeded. When they are, the track arms are automatically positioned to stabilize the vehicle and keep it right side up. Experimental results for both algorithms are included.

6561-38, Session 5

The OmniTread OT-4 Serpentine Robot: new features and experiments

J. Borenstein, Univ. of Michigan

Serpentine robots are slender, multi-segmented vehicles designed to provide greater mobility than conventional wheeled or tracked robots. Serpentine robots are thus ideally suited for urban search and rescue, military intelligence gathering, and for surveillance and inspection tasks in hazardous and hard-to-reach environments. One such serpentine robot, currently under development at the University of Michigan, is the "OmniTread OT-4." The OT-4 comprises seven segments, which are linked to each other by 2-degree-of-freedom joints. Moving tracks on all four sides of each segment assure propulsion even when the vehicle rolls over. The OT-4 climbs over high obstacles propel itself inside pipes of dif-ferent diameters, even vertically, and traverse difficult terrain such as rocks or the rubble of a collapsed structure.

The foremost and unique design characteristic of the OT-4 is the use of pneumatic bellows to actuate the joints. The pneumatic bellows allow the simultaneous control of position and stiffness for each joint. Controllable stiffness is of crucial importance in serpentine robots, which require stiff joints to cross gaps and compliant joints to conform to rough terrain for effective propulsion.

Another unique feature of the OmniTread design is the maximal coverage of all four sides of each segment with driven tracks. This design makes the robot indifferent to roll-overs, which are bound to happen when the slender bodies of serpentine robots travel over rugged terrain.

This paper describes the design features of the OT-4 in detail and an extensive Experiment Results Section documents the OT-4's performance.

6561-39, Session 5

Development of a convertible wheeled robot

D. Danknick, Applied Minds Inc.

Under funding provided by the US Army/TACOM and Northrop Grumman, AMI engineers designed, fabricated and built an 800 lb. walking/rolling robot with an integrated power system. It was intended to test hybrid locomation designs on varying road surfaces using COTS actuation and motion control. Design considerations were given to the current military fuel infrastructure, easy maintenance and functional abstraction for future upgrades.

6561-40, Session 5

Design and analysis an omnidirectional mobile robot in rough terrain

M. R. Udengaard, K. D. Iagnemma, Massachusetts Institute of Technology

Mobile robots are finding increasing use in military, disaster recovery, and exploration applications. Conventional wheeled and tracked mobile robots can find navigation in cluttered, rocky, or obstacle dense urban environments can be difficult or impossible. This is partly due to the fact that traditional tracked and wheeled vehicles must reorient to perform some maneuvers, such as lateral displacement. Omnidirectional mobile robots have the ability to track near-arbitrary motion profiles regardless of pose. To date, nearly all designs and analyses of omnidirectional robots have considered the case of motion on flat, smooth terrain. This paper presents a design for an omnidirectional mobile robot driven by active split offset casters to be operated on rough, uneven terrain. Robot isotropy characteristics are analyzed as a function of vehicle geometry and configuration on both flat and rough terrain. A simple kinematic control scheme that considers the effects of terrain unevenness is presented. The performance of the algorithm in rough terrain is studied in simulation. It is shown that an omnidirectional mobile robot can be designed to maintain a high level of mobility over rough terrain.

6561-41, Session 5

Design and control of a 12 DOF bipdal robot

B. T. Krupp, Yobotics, Inc.; J. E. Pratt, Institute for Human and Machine Cognition; A. Vesper, Yobotics, Inc.

We propose an iterative design approach, combining dynamic computer simulation with computer aided design, to develop a battery powered, electrically actuated, twelve degree of freedom bipedal robot. In order to achieve high force fidelity and low impedance, Series Elastic Actuation techniques are applied to the electric actuators. In order to reduce cable harness requirements, a CAN Bus interface is implemented using real time Java running on a PC104 computer system.

The design process begins with estimation of the robot's physical parameters. These estimations, which are based primarily on intuition and experience, are used to create a physically realistic simulation model of the robot. Next, a control algorithm is implemented in simulation to produce the desired gait; in this case, bipedal walking. Using the joint power requirements and range of motions from simulation, designers are able to work backward calculating actuator stroke, force and speed. Components that meet or exceed these specifications are chosen and an electro-mechanical framework is designed to combine the components into a working machine. Using CAD software, the physical parameters of the robot are calculated. The original physical parameter estimates are replaced with the CAD estimates and new joint power requirements are produced. The process continues until and acceptable design has been achieved. The design is then migrated from paper to the real world.

6561-43, Session 5

Tetrahedral robotics based on addressable reconfigurable architecture

G. L. Brown, Jr., NASA Goddard Space Flight Ctr.

GSFC is developing a family of Tetrahedral robots based on the Addressable Reconfigurable Architecture (ART). The basic unit of ART is a reconfigurable tetrahedron with variable length struts connected by flexible joints. We completed a demonstration prototype of a single-tetrahedron walker (1-TET) in 2004-2005 that walks by shifting its center of gravity and tumbling in alternating directions. Multiple reconfigurable tetrahedra can be connected together to form complex multi-functional structures. This highly integrated three-dimensional mesh of actuators and structural elements are addressable like pixels in an LCD screen and can be choreographed to exhibit complex behaviors like climbing, rolling, slithering, and tunneling. The architecture is modular, scalable, self-similar, and provides great flexibility and failsafe redundancy.

Presently, we are building a 12-tetrahedral walker (12-TET) with 9 nodes and 26 struts. Each strut is designed with a 5.3:1 extendable length ratio which enables the robot structure to assume a wide array of shapes and configure itself to move with a variety of gaits over a variety of terrain. The walker can stretch or contract to conform to the terrain, move up a 40° incline or stairs, and climb over obstacles 1.2 times its contracted height which eliminates many of the disadvantages of wheeled rovers.

The scalable technology can be implemented in large scale structures or miniaturized to MEMS-based ART structures (MART) and in future, nanotechnology-based Super Miniaturized ART structures (SMART). The near- and mid-term implementations of this architecture provide a new pathway for enabling extensive reconfigurable robotic terrestrial and planetary exploration, which an emphasis on supporting the NASA Exploration Initiative, with sustained human presence on the Moon and Mars. The ART's maneuverability and ability to reconfigure itself make it particularly useful in (but not limited to) situations where tasks must be performed in inhospitable environments (e.g., gathering environmental samples, finding and defusing bombs, search and recovery, etc.). Other ART applications are collapsible habitat structures or adjustable mirrors and antennas.

We propose to demonstrate the 1-TET and/or 12-TET prototypes at SPIE 2007. We also plan to have a Technology Exhibit. A video of the 1-TET walking in GSFC can be viewed at: http://ants.gsfc.nasa.gov/features/steppin.mpg.

6561-44, Session 5

Fuel-cell powered UGV

J. S. Meldrum, Sr., Michigan Technological Univ.

Under contract with the Army Research Labs the Keweenaw Research Center of Michigan Tech University designed and built an unmanned ground vehicle utilizing only fuel cell power. The vehicle attributes include high mobility, quiet operation, and zero emissions. The paper will review the decision criteria for high mobility and the minimum power requirements needed. Implementation of the fuel cell requires special considerations for hydrogen supply, humidification, heat transfer, and power management. The vehicle mission includes carrying and powering a directed energy device for neutralizing improvised explosionary devices. Other missions might include long range detection of nuclear and biological contamination or measurements of soil strength for mobility prediction of heavy military vehicle systems. Future work includes the design of a larger hybrid system employing a diesel engine and fuel cell power for extended range, load capacity, as well as silent operation.

6561-45, Session 5

Slider walker

P. L. Muench, U.S. Army Research, Development and Engineering Command

Over the past several years, TARDEC has undertaken a sustained effort in legged robotics research. The reason is to make a robot go where the soldier can go: up stairs, through forested and urban terrain, past narrow hallways and corridors, and across rocky and mountainous terrain.

This paper looks at a novel twist on wheeled/walker hybrids. We are building and modeling a walker which will allows for simple design and construction, yet still retains much of the functionality of walking dynamics.

6561-47, Session 5

Solving the mobility issues of unmanned ground vehicles

S. Odedra, S. Prior, M. Karamanoglu, Middlesex Univ. (United Kingdom)

Unmanned Ground Vehicles (UGV), whether autonomous or tele-operated, can carry out tasks using the hardware available to the system. Even though this hardware gives the system the capabilities to carry out specific tasks, it also means that it is limited to these tasks. This is important when looking at a UGV's locomotive ability, for example tracks give a system the ability to drive over rough terrain, but in turn the use of tracks hampers the vehicles speed and its ability to manoeuvre on indoor surfaces such as carpet.

This paper focuses on the research being carried out to develop innovative solutions to give unmanned ground vehicles the ability to be able to cope with potentially any task in any condition whether known or unknown. Our research will lead to a mobility system, which can transform in order to cope with transitions between environments or encountering obstacles such as stairs. These mobility systems will have incorporated sensors used to feel the immediate environment and feedback important information to either the user, or the system in the case of autonomy, and then decisions can be made on which mobility type or configuration would best suite the conditions. This will ultimately increase any systems potential and create an intelligent, multifunctional platform with high mission capabilities.

6561-48, Session 6

A man portable hybrid UAV/UGV system

P. Rudakevych, B. M. Yamauchi, iRobot Corp.

The range of existing UGVs is limited, restricting them from tactical use. We developed a prototype air mobility system that attaches to a PackBot that allows the PackBot to be delivered tens of miles away from the operator, at which point the PackBot is deployed to the ground and the air mobility system loiters as a radio link above the area of operations.

The man portable UAV portion is unique in that it can carry 50 lbs of payload and still be carried and operated by a single soldier, from an unimproved field. The UAV continues to operate after a substantial mass change when deploying the PackBot. This is accomplished by using a powered parafoil.

We present the concept, variations on possible missions, and results from our proof of concept vehicle trials, including some videos.

6561-49, Session 6

Multi-UAV autonomous collaborative behaviors for convoy protection

Y. Chen, M. A. Peot, J. Lee, V. Sundareswaran, T. W. Altshuler, Teledyne Scientific Co.

Multi-UAV autonomous collaborative operation is a key capability for efficient and effective deployment of large numbers of UAVs per FCS Unit of Action (UoA) under U. S. Army's vision for Force Transformation. We have been developing an extensible architecture and behavior planning / collaborative approach, named Autonomous Collaborative Mission Systems (ACMS), to achieve this level of capability. The architecture is modular and the modules may be run in different locations/platforms to accommodate the constraints of available hardware, processing resources and mission needs. The modules and uniform interfaces provide a consistent and platform-independent baseline mission collaboration mechanism and signaling protocol across different platforms. Further, the modular design allows flexible and convenient insertion of new autonomous collaborative behaviors to the ACMS. In this article, we present our simulation results and analysis in applying various autonomous collaborative behaviors developed in the ACMS to an integrated convoy protection scenario.

6561-50, Session 6

Development of a GPS/INS/MAG navigation system and waypoint navigator for a VTOL UAV

O. Meister, R. Mönikes, J. Wendel, N. M. Frietsch, C. Schlaile, G. F. Trommer, Univ. Karlsruhe (Germany)

Unmanned aerial vehicles (UAV) can be used for versatile surveillance and reconnaissance missions. If a UAV is capable of flying automatically on a predefined path, the range of possible applications is widened significantly.

This paper addresses the development of the integrated GPS/INS navigation system and a waypoint navigator for a small vertical take-off and landing (VTOL) unmanned four-rotor helicopter with a take-off weight below 1 kg.

The core of the navigation system consists of low cost inertial sensors which are continuously aided with GPS, magnetometer compass, and a barometric height information. Due to the fact that the yaw angle becomes unobservable during hovering flight, the integration with a magnetic compass is mandatory.

This integration must be robust with respect to errors caused by the terrestrial magnetic field deviation and interferences from surrounding electronic devices as well as ferrite metals. The described integration concept with a Kalman filter overcomes the problem that erroneous magnetic measurements yield to an attitude error in the roll and pitch axis. The algorithm provides long-term stable navigation information even during GPS outages which is mandatory for the flight control of the UAV.

Details of the developed waypoint navigation algorithms are discussed. Flight test results of the implemented modes of operation with different levels of autonomy are shown. In a position hold mode the helicopter maintains its position regardless of wind disturbances which ease the pilot job during hold and stare missions. Flight test result shows that the presented waypoint navigator overcomes limitation of operation within line of sight as well as the range of the radio link.

6561-51, Session 7

Deployable reconnaissance from a VTOL UAS in urban environments

S. Barnett, A. Culhane, A. Sharkasi, J. Bird, C. F. Reinholtz, Virginia Polytechnic Institute and State Univ.

Reconnaissance collection in unknown or hostile environments can be a dangerous and life threatening task. To reduce this risk, the Unmanned Systems Group at Virginia Tech has produced a fully autonomous reconnaissance system able to provide live video reconnaissance from outside and inside unknown structures. This system consists of an autonomous helicopter which launches a small, reconnaissance pod inside a building and an operator control unit (OCU) on a ground station. The helicopter is a modified Bergen Industrial Twin using a Rotomotion flight controller and can fly missions of up to one half hour. The mission planning OCU can control the helicopter remotely through teleoperation or fully autonomously by GPS waypoints. A forward facing camera and template matching aid in navigation by identifying the target building. Once the target structure is identified, vision algorithms will center the UAS adjacent to open windows or doorways.

Tunable parameters in the vision algorithm account for varying launch distances and opening sizes. Launch of the reconnaissance pod may be initiated remotely through a human in the loop or autonomously. Compressed air propels the half pound stationary pod or the larger mobile pod into the open portals. Once inside the building, the reconnaissance pod will then transmit live video and audio back to the helicopter. The helicopter acts as a repeater node for increased video range and simplification of communication back to the ground station.

6561-52, Session 7

Macro-fiber composites for wing morphing micro-air vehicles

O. Bilgen, D. J. Inman, A. J. Kurdila, Virginia Polytechnic Institute and State Univ.

Conventional surface control techniques have been used in carbon fiber composite, membrane-wing autonomous micro-air-vehicles (MAV). However, articulated lifting surfaces and articulated wing sections are difficult to instrument in a repeatable fashion. Assembly is complex and time consuming. The authors aim to implement morphing wings on autonomous MAVs that are actuated via active materials. The resultant designs are advantageous in that they are (1) solid state and (2) capable of highly agile maneuver. Active actuation is achieved via a type of piezoceramic composite called Macro Fiber Composite (MFC).

Initial experimental results show that MFC actuation does have authority to control aerodynamic forces for MAVs. Due to unsteady forces caused by air flow, signal to noise ratio was low at the experiments where either actuation or air velocity was low. As the air velocity or the actuation voltage was increased, the changes in the net force on the MAV were clearly visible. Wing actuation was also quantified by simply actuating the wing with MFC and measuring the maximum deflection in the wing. The experiments proved that MFC is suitable for surface control of flexible wing micro air vehicles.

The completed paper will investigate the roll actuation and control of MFC actuated MAV in unsteady air flow. The current MAVs are controlled by servos, accelerometers and gyros. MFC will be used to replace these components since the MFC can be used both as a sensor and actuator. This is considered unique in the field of micro air vehicles. A control mechanism will be constructed by analytical and FEM methods.

6561-53, Session 7

Toward distributed ATR using subjective logic combination rules with networked UAVs

S. O'Hara, 21st Century Systems, Inc. and Univ. of Nebraska/Omaha; M. Simon, 21st Century Systems, Inc.; Q. Zhu, Univ. of Nebraska/Omaha

In this paper, we present our initial findings demonstrating how networked video cameras augmented with limited computational capabilities can be used to provide ATR services in a computationally distributed manner. We call this Distributed ATR (DATR). Our paper describes the utility of DATR for autonomous Unmanned Aerial Vehicle (UAV) operations and shows how we implemented a proof-of-concept using an inexpensive gumstick-sized computing device.

Our technology is aimed towards small and micro UAVs where platform restrictions allow only a modest quality camera and limited on-board computational capabilities. It is understood that an inexpensive sensor coupled with limited processing capability would be challenged in deriving a high Pd/Low Pfa classification. Our hypothesis is that the consensus opinion of multiple DATR platforms, observing approximately the same scene, can raise the Pd and lower the Pfa sufficiently in order to provide a cost-effective ATR capability. This capability can lead to practical implementations of autonomous, coordinated, multi-UAV operations.

The individual UAV produces a temporally-indexed belief/uncertainty value based upon an on-board ATR algorithm, yielding a set of possible classifications for the object over the possibility space defined by a set of exemplars. We remove the very low confidence classifications and generate a weighted belief mass assignment over the remaining classifications. We repeat the process for a small number of consecutive frames representing a fraction of a second, and use subjective logic operators to combine the belief mass assignments over the sample. This allows us to discard outliers and potentially boost a weaker classification that is consistent across the sampling period. The output would be a set of classifications for each object, with an explicit measure of belief and uncertainty for each classification.

When multiple platforms observe approximately the same scene, such as when a group of UAVs flies over an area of interest, we can further improve our ATR confidence by combining the results of the individual platforms, again using subject logic algebra over the belief statements.

6561-54, Session 7

Detection and tracking of objects in an image sequence captured by a VTOL-UAV

N. M. Frietsch, O. Meister, C. Schlaile, J. Wendel, G. F. Trommer, Univ. Karlsruhe (Germany)

The research activities in the field of unmanned aerial vehicles (UAV) have increased constantly over the last years. Especially small UAVs are essential for surveillance and reconnaissance purposes. For efficient use of the onboard video camera the ability to hover is desirable.

This paper focusses on the automated detection and tracking of multiple objects in a camera sequence, that is provided by a small, electrically powered four-rotor helicopter in a hover-and-stare scenario. After an appropriate preprocessing of the raw image data, independently moving areas are identified. Two different approaches are investigated and compared. The first approach is based on the compensation of the camera movement by estimation of homographies. Moving regions are extracted by image subtraction and appropriate filtering. The second approach is based on the optical flow field. Single points that move not consistently with the background plane are identified and merged into objects by a cluster analysis algorithm.

A Kalman filter is used to estimate characteristic object parameters, that allows the continuous tracking of an object. Due to several reasons, not every extracted area corresponds to an independently moving object. A joint probabilistic data association as well as a heuristic rule-set are used to sort out artefacts.

After a detailed description of the image processing and tracking algorithms, the performance of the developed algorithms is illustrated using in-flight UAV camera sequences with focus on the detectability of objects with different sizes and speeds.

Finally, first steps towards a simple geographically referencing of the tracked objects are described.

6561-55, Session 7

An intelligent algorithm for unmanned aerial vehicle surveillance

A. Bhargave, B. E. Ambrose, F. S. Lin, Broadata Communications, Inc.

A intelligent swarm-based guidance and path planning algorithm is described for the Uumaned Arieal Vehicles (UAV) to efficiently carry out grid surveillance, taking into account specific UAV constraints such as maximum speed, maximum flight time and battery re-charging intervals to allow for continuous surveillance. The swarm-based flight planning is based on enhancements of distributed computing concepts that have been developed for NASA's launch danger zone protection. The algorithm is a modified version of ant colony optimization theory describing ant food foraging. Ants initially follow random paths from the nest, but if food is found, the ant deposits a pheromone (modifying the local environment), which influences other ants to travel the same path. Once the food source is exhausted, the pheromone decays naturally, which causes the trail to disappear. When an ant is on an established trail, it may at any time decide to follow a new random path, allowing for new exploration. Using these concepts, in our system for UAV, we use two units, the Rendezvous unit and the Patrol unit. The Rendezvous units will act as pheromone deposit sites keeping a record of trails of interest (extra pheromone that decays over time), and obstacles (no pheromone). The search area is divided into a grid of areas. Each area unit is assigned a pheromone weight. The patrol unit picks an area unit based on a probabilistic formula consisting of parameters like the relative weight of trail intensity, area visibility to the unit, the distance of the patrol unit from area, and the pheromone decay factor. Simulation of a UAV surveillance system based on the above algorithm showed that it had the ability to perform independently and reliably without human intervention, and the emergent nature of algorithm had the ability to incorporate important aspects of unmanned surveillance.

6561-56, Session 7

Cooperative control architectures for a team of UAVs subject to communications failures

K. Khorasani, Concordia Univ. (Canada)

To utilize the full capabilities of UAVs, a large body of research have been conducted on development of UAV cooperative control strategies. In this paper cooperative control implies coordinating the activities of a team of vehicles so that they work together to complete tasks in order to achieve a common goal. However, coordinating the operations of a team of vehicles requires that information be shared among the team members. One of the most significant hurdles for this is to develop cooperation strategies that incorporate strict communication constraints a UAV is subjected to. Other challenges associated with developing cooperation strategies for UAVs are development of decentralized cooperation strategies, and robustness of these strategies to either a failure or gradual performance degradation of individual team members. In this paper UAV cooperative control problems are investigated that involve several sub-problems such as cooperative path planning and trajectory generation, multiple UAV task allocation, multiple UAV cooperative timing problems, and cooperative UAV target search. Different architectures are developed to address the cooperative rendezvous problem, which requires multiple UAVs to arrive simultaneously at their destination(s) to maximize survivability. The cooperative control strategies developed are based on the notion of coordination variable and coordination functions. For the rendezvous problem, the coordination variable is the team-optimal time over target, which is the minimal amount of information needed by the vehicles to achieve the task of simultaneous intercept. The coordination functions (different for each vehicle) parameterize the effect of changes in the coordination variable on the objectives of the individual vehicles.

Centralized and decentralized methodologies are proposed for solving the rendezvous problem. In the centralized solution a centralized rendezvous manager is required that selects the team coordination variable based upon the coordination functions, and a set of feasible time over target ranges of all the UAVs. None of the vehicles are aware of each other's coordination functions and set of feasible time over target ranges. Hence, if a failure were to occur at the rendezvous manger, the entire scheme will fail. In the decentralized solution, the team coordination variable is calculated by the (identical) coordination manager residing on each vehicle. As in the centralized solution, each vehicle calculates its coordination function and a set of feasible time over target ranges, which it then communicates (through its communication manager) to all the other vehicles comprising the team. Hence, the decentralized approach, unlike the centralized solution, increases the team's robustness to a single-point failure. Since the rendezvous strategies developed thus far in the literature do not formally address faults in the system, one of the contributions of this paper involves the incorporation of faults (sensor, actuator, or communication) into the development of the cooperative rendezvous algorithms.

6561-57, Session 7

Vision-based sensing for autonomous in-flight refueling

D. A. Scott, M. Toal, J. L. Dale, Octec Ltd. (United Kingdom)

A significant capability of unmanned airborne vehicles (UAV's) is that they can operate tirelessly and at maximum efficiency in comparison to their human pilot counterparts. However a major limiting factor preventing ultra-long endurance missions is that they require landing to refuel. Development effort has been directed to allow UAV's to automatically refuel in the air using current refueling systems and procedures. The 'hose & drogue' refuelling system was targeted as it is considered the more difficult case. Recent flight trials resulted in the first-ever fully autonomous airborne refuelling operation.

Development has gone into precision GPS-based navigation sensors to manoeuvre the aircraft into the station-keeping position and onwards to dock with the refuelling drogue. However in the terminal phases of docking, the accuracy of the GPS is operating at its performance limit and also disturbance factors on the flexible hose and basket are not predictable using an open-loop model. Hence there is significant uncertainty on the position of the refuelling drogue relative to the aircraft, and is insufficient in practical operation to achieve a successful and safe docking.

A solution is to augment the GPS based system with a vision-based sensor component through the terminal phase to visually acquire and track the drogue in 3D space. The higher bandwidth and resolution of camera sensors gives significantly better estimates on the state of the drogue position. Disturbances in the actual drogue position caused by subtle aircraft manoeuvres and wind gusting can be visually tracked and compensated for, providing an accurate estimate.

This paper discusses the issues involved in visually detecting a refuelling drogue, selecting an optimum camera viewpoint, and acquiring and tracking the drogue throughout a widely varying operating range and conditions.

6561-58, Session 8

Urban search and rescue robot performance standards: progress update

E. R. Messina, A. Jacoff, National Institute of Standards and Technology

In this paper, we describe work in performance standards for urban search and rescue (US&R) robots, begun in 2004 by the Department of Homeland Security. This program is being coordinated by the National Institute of Standards and Technology and will result in consensus standards developed through ASTM International, under the Operational Equipment Subcommittee of their Homeland Security Committee. A comprehensive approach to performance requirements and standards development is being used in this project. Formal test methods designed by several working groups in the standards task group are validated by the stakeholders. These tests are complemented by regular exercises in which responders and robot manufacturers work together to apply robots within realistic training scenarios. This paper recaps the most recent exercise, held at the Federal Emergency Management (FEMA) Maryland Task Force 1 training facility, at which over twenty different robots were operated by responders from various FEMA Task Forces. The exercise included candidate standard test methods being developed for requirements in the areas of communications, mobility, sensors, and human-system interaction for US&R robots.

6561-59, Session 8

Unified plan language

J. J. Ackley, Science Applications International Corp.; R. L. Wade, U.S. Army Aviation and Missile Research, Development and Engineering Ctr.

With the steady increase in the numbers of unmanned systems deployed, the problem of representing and communicating plans for individual and teams of unmanned systems is reaching a critical stage. Numerous attempts have been made to create a plan representation language for manned and unmanned systems each with their own strengths and weaknesses. This paper presents the Unified Plan Language (UPL), an attempt to leverage the strengths of the previous efforts while diminishing their weaknesses.

A plan is a set of objectives to be achieved, a series of activities to perform in order to achieve the objectives, and a set of constraints that must hold throughout the execution of the plan. It is difficult to arrive at a common representation for plans because each domain and environment will have its own terminology for activities, scope and nature of the objectives, and the types of constraints. The semantics of each term must be agreed to by all, and yet the representation language must be extensible to support new and expansion of existing domains.

The paper begins with a discussion of the problem of representing and communicating plans and why it is so difficult, followed by a statement of requirements for representing plans and a review of existing plan languages. It proceeds with a look at the technologies UPL leverages, and how UPL satisfies the stated requirements. Several applications and examples are explored to demonstrate the language, followed by a review of findings and a discussion of future work.

6561-60, Session 8

USARSim: a RoboCup Virtual Urban Search and Rescue competition

S. B. Balakirsky, C. Scrapper, National Institute of Standards and Technology; S. Carpin, International Univ. Bremen GmbH (Germany); M. Lewis, Univ. of Pittsburgh

Research efforts in Urban Search And Rescue (USAR) robotics have grown substantially in recent years. A virtual USAR robotic competition was established in 2006 under the RoboCup umbrella to foster collaboration amongst institutions and to provide benchmark test environments for system evaluation. In this paper we describe the software simulation framework that is used in this competition and the rules and performance metrics used to determine the leagues winner. The framework allows for the realistic modeling of robots, sensors, and actuators, as well as complex, unstructured, dynamic environments. Multiple heterogeneous agents can be concurrently placed in the simulation environment thus allowing for team or group evaluations.

6561-61, Session 8

Characterizing unmanned system autonomy: the autonomy levels for unmanned systems (ALFUS) framework

H. Huang, National Institute of Standards and Technology

The Autonomy Levels for Unmanned Systems (ALFUS) workshop series addresses the vehicle's autonomy issues. Practitioners have different perceptions or different expectations for the systems. The requirements on human interactions, the types of tasks, the teaming of the unmanned systems (UMS) and the humans, and the operating environment are just a few of the issues that need to be clarified. Also needed are a set of definitions and a model with which the autonomy capability of the UMS can be described. This paper reports the current results and status of the ALFUS framework, which practitioners can apply to analyze the autonomy requirements and to evaluate the performance of their robotic programs.

6561-62, Session 8

Prediction in dynamic environments: algorithmic performance evaluation in urban driving scenarios

C. I. Schlenoff, Z. Kootbally, R. Madhavan, National Institute of Standards and Technology

In this paper, we provide an overview of the PRIDE (Prediction in Dynamic Environments) framework and describe a series of steps that were taken to validate the performance of the moving object prediction algorithms within this framework.

PRIDE (Prediction In Dynamic Environments), a hierarchical multiresolutional framework for moving object prediction that incorporates multiple prediction algorithms into a single, unifying framework. PRIDE is based upon the 4D/RCS (Real-time Control System) reference model architecture and provides information to planners at the level of granularity that is appropriate for their planning horizon. This framework supports the prediction of the future location of moving objects at various levels of resolution, thus providing prediction information at the frequency and level of abstraction necessary for planners at different levels within the hierarchy. To date, two prediction approaches have been applied to this framework.

The performance evaluation of PRIDE was performed by comparing the results of its prediction algorithms to known recorded time intervals and trajectories of a vehicle on public roadways. The public roadways were modeled in USARSim. USARSim is a high-fidelity simulation of robots and environments based on the Unreal Tournament game engine. The location of the vehicle at a predetermined start point was placed in the simulated roadways to correspond to its actual position on the physical roadway. The results of the prediction algorithms were then compared to the actual velocity and trajectory of the vehicle to judge the performance of the prediction algorithms.

6561-63, Session 8

A time-slotted on-demand routing protocol for mobile ad hoc unmanned vehicle systems

J. H. Forsmann, Idaho National Lab.; R. Hiromoto, Univ. of Idaho; J. M. Svoboda, Idaho National Lab.

Successful deployment of Unmanned Vehicle Systems (UVS) in military operations has increased their popularity and utility. The ability to sustain reliable mobile ad hoc formations dramatically enhances the usefulness and performance of UVS. Formation movement increases the amount of ground coverage in less time, decreases fuel consumption of the individual nodes, and provides an avenue for mission expansion through cooperative maneuvers such as refueling.

In this paper, we study the resulting wireless communication demands from formation and maintenance of UVS within the context of a mobile ad hoc network (MANET). A MANET in formation is typically characterized by tradeoffs between network congestion and the maintenance of useful communication bandwidth. The maintenance of UVS formations requires each node in the network to be peer-aware, which places a heavy demand on inner node communication.

In order to mitigate the inner node network congestion, we introduce a time-slotted communication protocol. The protocol assigns time-slots and allows the designated nodes to communicate directly with other peer-nodes. This approach has been introduced within the context of the Time-Slotted Aloha protocol for station-to-station communication. The approach taken here is to embedded the time-slotted reservation protocol into a standard on-demand routing protocol to also address the need to reactively and proactively respond to formation maintenance.

The time-slotted on-demand routing protocol is shown to eliminate collisions and, therefore, enhance quality of service as well as ensure necessary support for formation movement. A worst-case scenario is described and simulations performed to comparatively demonstrate the advantages of the new protocol.

6561-64, Session 8

Performance evaluation of a 3D imaging system for vehicle safety

A. M. Lytle, S. M. Szabo, G. S. Cheok, National Institute of Standards and Technology

The NIST Construction Metrology and Automation Group (CMAG), in cooperation with the NIST Intelligent Systems Division (ISD), is developing performance metrics and standard tests for the evaluation of 3D imaging systems used in autonomous mobility applications. This work supports the broader effort to develop open, consensus-based performance evaluation standards for a wide range of 3D imaging systems and applications through the ASTM E57 Committee on 3D Imaging Systems. This report presents initial efforts to characterize the range performance of a 3D imaging sensor which will be used in a performance measurement system for crash prevention and safety systems. Factors examined include range, target reflectance, target angle of incidence, and sensor azimuth.

6561-66, Session 9

Terrain aware inversion of predictive models for high-performance UGVs

A. J. Kelly, Carnegie Mellon Univ.

The capacity to predict motion adequately over the time scale of a few seconds is fundamental to autonomous mobility. The quality of such predictions depends directly on the capacity to anticipate the consequences of the forces applied by the terrain to the vehicle. However, autonomy also requires a capacity to consider multiple alternatives and rate them based on utility, cost, risk, opportunity etc. in order to select a best one. Model predictive optimal control is a general formalism within which most approaches since the beginning of the field can be cast as special cases. Applications continue to grow in ambition to seek higher precision of motion and/or higher vehicle speeds. Predictions must therefore improve in fidelity and speed simultaneously. At the National Robotics Engineering Center we have recently been favoring a technique that we call parametric optimal control. This approach formulates the original optimal control problem as one of nonlinear programming - optimizing over a space of parameterized controls encoding all feasible motions. Using this technique, we have developed a core capacity to efficiently invert the solutions to the equations of motion for a ground vehicle. Such an inversion enables a computation of precisely the command signals necessary to drive the vehicle to goal position, heading, and curvature while following the contours of the terrain under arbitrary wheel terrain interactions.

Dynamics inversion is so fundamental that many other mobility behaviors can be constructed from it. Fielded applications include pallet acquisition controls for factory AGVs and high speed adaptive path following for military UGVs. We have also applied the technique successfully to the problem of compensation for wheel slip on the Mars Exploration Rovers and the problem of full configuration space planning in dense obstacle fields. We believe the technique may also advance the state of the art in high speed obstacle avoidance and slow speed obstacle negotiation.

6561-67, Session 9

Amphibious modular robot astrobiologist

M. Yim, Univ. of Pennsylvania

A modular robot system called CKBot is made up of a large number of identical modules and several specialized modules. These modules may be combined together in different configurations to form robots capable of different tasks. This paper presents the design and experimentation of one set of configurations for an amphibious robot applied to the astrobiolocal domain.

Astrobiologists study the origins of life. Part of this work involves field trips where a variety of tasks can be aided or replicated robotically. An astrobiologist on a field study will spend most of the time walking around and exploring the site looking for areas of interest which will be tested in situ or sampled for testing offsite. For a robot replicating these tasks, it must be able to locomote in that terrain, sense the interesting features (or provide sensing for teleoperation), and do a variety of manipulation tasks once an area of interest is reached.

The configurations for this robot include 10's modules and can achieve astrobiological tasks such as amphibious locomotion, digging, core sampling, probing, liquid sampling and exploration. This paper also presents results from the first experiments of this platform at Lake Tyrrell, a salt lake in Australia. Most tasks were successful on this first attempt.

6561-68, Session 9

Symbolic perception-based autonomous driving in dynamic environments using 4D/RCS

M. Foedisch, R. Madhavan, C. I. Schlenoff, National Institute of Standards and Technology

Our recent efforts have focused on the development of symbolic representations and their extraction from sensor data for on-road driving in dynamic environments. We contend that such rich symbolic representations can reduce the burden on sensory processing by dynamically directing it to look for particular features in expected locations and subsequently facilitating the vehicle to better react to potentially dangerous situations, such as the appearance of pedestrians in the road. We follow a knowledge-driven top-down approach to vehicle perception in order to overcome issues with classical bottom-up approaches, which can suffer from loss of information on the transition to higher levels and, therefore, cause failure in high-level scene interpretation through accumulation of locally insignificant inaccuracies on each level.

4D/RCS is a hierarchical architecture designed for the control of intelligent systems. One of the main areas that 4D/RCS has been applied to recently is the control of autonomous vehicles. To accomplish this, a hierarchical decomposition of on-road driving activities has been performed which has resulted in implementation of 4D/RCS tailored towards this application. This implementation has seven layers and ranges from a journey manager which determines the order of the places you wish to drive to, through a destination manager which provides turn-by-turn directions on how to get to a destination, through a route segment, drive behavior, elemental maneuver, goal path trajectory, and then finally to servo controllers.

In this paper, we show, within the 4D/RCS architecture, how knowledge-driven top-down symbolic representations combined with low-level bottom-up tasks can synergistically provide valuable information for on-road driving better than what is possible with either of them alone. We demonstrate these ideas using field data obtained from an Unmanned Ground Vehicle (UGV) traversing urban on-road environments. We also include a discussion on the performance limits of the proposed approaches as applied to the operational requirements imposed by on-road driving in addition to where the current research places us on the technology readiness level scale.

6561-69, Session 10

Mobile robots traversability awareness based on terrain visual sensory data fusion

A. H. Shirkhodaie, Tennessee State Univ.

Autonomous navigation in natural terrain is an emerging technology of interest to DoD for military surveillance, reconnaissance, and target tracking applications and, in particular, to NASA for robotic planetary space exploration. To operate autonomously and intelligently in unstructured terrain, a robot must possess many advanced navigational skills. In particular, it needs to have capability to perceive its surrounding environment, recognize hazardous circumstances, discriminate negotiable and non-negotiable obstacles, and select suitable routes compatible with its mobility capabilities without jeopardizing its safety and mission. In this paper, we have primarily discussed technical challenges and navigational skill requirements of mobile robots for traversability path planning in natural terrain environments similar to Mars surface terrains. We describe different methods for detection of salient terrain features based on imaging techniques. We also present three competing techniques for terrain traversability assessment of mobile robots navigating in unstructured natural terrain environments. These three techniques include: a rule-based terrain classifier, a neural network-based terrain classifier, and a fuzzy-logic terrain classifier. Each proposed terrain classifier divides a region of natural terrain into finite sub-terrain regions and classifies terrain condition exclusively within each sub-terrain region based on terrain visual clues. The Particle and Kalman filtering techniques are applied for aggregative fusion of sub-terrain assessment results. The last two terrain classifiers are shown to have remarkable capability for terrain traversability assessment of natural terrains. In the paper, we demonstrate a comparative performance evaluation of all three terrain classifiers.

6561-70, Session 10

Sensor fusion for intelligent behavior on small unmanned ground vehicles

G. T. Kogut, B. Sights, G. Ahuja, E. B. Pacis, F. Birchmore, H. R. Everett, Space and Naval Warfare Systems Ctr., San Diego

Sensors commonly mounted on small unmanned ground vehicles (UGVs) include visible light and thermal cameras, scanning LIDAR, and ranging sonar. The data provided by these sensors is vital to emerging autonomous robotic behaviors. However, sensor data from any individual sensor can become noisy or erroneous under a range of conditions, reducing the reliability of autonomous operations. We seek to increase this reliability through data fusion. Data fusion includes characterizing the strengths and weaknesses of each sensor modality, and combining their data a way such that the fused data is more accurate than each sensor's individual data contribution. We describe data fusion efforts in three autonomous behaviors: pursuit, object detection and recognition, and target-tracking. These behaviors are implemented and tested under a variety of realistic conditions, and their performance compared with that of single-sensor methods.

6561-71, Session 10

Utilizing simulation technologies in the development of autonomous platforms

O. Har, T. Shintel, HarTech Technologies Ltd. (Israel)

The modern combat theater is being populated by an increasing number of unmanned platforms that are operated in a wide variety of missions. These platforms, like manned platforms in joint operations, have to operate in concert as an integrated force. The operation of large numbers of unmanned platforms in a specific mission requires the use of autonomous platforms which can operate without a tight operator control. Such a paradigm enables a single operator (or a small group of operators) to control a large force of unmanned platforms conducting a mission similarly to the HQ command-support that a manned force will be receiving. The need to increase the autonomous capabilities of unmanned platforms operating in an integrated force promotes the development of Semi Automated Forces (SAF) and Fully Automated Forces (FAF).

The core technologies required in the development of operational of SAF and FAF are:

* Platform control

* Sensor control

* Multi sensor data fusion

* Mission management and mission control

* Learning and adaptive behavior

In a “Parallel Universe” Computer Generated Forces (CGF) are used in the Simulation domain to populate a synthetic environment. A current requirement from a synthetic environment is to have it populated with a large number of entities that behave in a sound and coherent manner. This causes a situation in which the number of trainees, exercise controllers and role players is not sufficient to run each entity/platform by a dedicated person and actually a high level of autonomous behavior is required from these CGFs. Therefore modern simulation and Scenario Generation and Animation Systems make use of CGF that are autonomous, which are guided by a Combat Doctrine, Mission Directives, and employ autonomous planning and mission management modules. These CGFs are reactive and responsive to the arena in which they operate and perform as SAF and FAF within the synthetic environment. In addition in simulation systems adaptive behavior and learning technologies are used to create realistic changing scenarios that present a more challenging environment for trainees in training systems.

The technology used for the development and operation of modern CGF highly resembles that of SAF and FAF. Decision making mechanism developed for CGF can be reused and embedded in Autonomous platforms, as well as learning and adaptive behavior technologies which will enable the SAF and FAF to optimally react to the changing conditions and the opponents' behavior in the real combat theater.

Importing technologies from the CGF domain for the development of SAF and FAF provides an advantage as these technologies are already tested and proven in the “actual” management of multiple collaborating entities as are expected to be in the future Battle Theater.

6561-73, Session 10

World representations for unmanned ground vehicles

G. S. Broten, S. P. Monckton, J. A. Collier, Defence Research and Development Canada (Canada)

Unmanned ground vehicles, traversing unstructured, outdoor, environments, require a world representation in order to safely avoid obstacles and hazards such as beams and ditches. This paper introduces a technique for creating such a world representation while traversing terrain at high speeds. The map represents the terrain around the vehicle through a uniform 2 1/2-D elevation grid. Each grid element that contains valid data encodes the terrain elevation, while grid elements with data are marked as unknown terrain. Range data, from various ranging sensors such as laser range finders and stereo vision cameras, is fused into the terrain map using a novel variance weighted statistical approach. This statistical approach ensures that all range data is optimally weighted by its associated variance. The map is implemented as a wrappable and scrollable patch of the global world that is always relative to the vehicle's front, centre bumper. An egocentric terrain map, which is the world viewed from the vehicle's perspective, is derived from the global terrain map. Defence Research and Development Canada has implemented this variance weighted, wrapping and scrolling, 2 1/2-D terrain map on its Raptor unmanned ground vehicle. Extensive field testing has shown that this implementation performs admirably. The terrain map accurately reflects the true terrain characteristics and smoothly scrolls and wraps with vehicular movement. Obstacles and slope hazards are reliably detected by a traversability analysis algorithm; thus allowing an obstacle avoidance algorithm to plan for safe corridors of travel.

6561-74, Session 10

Modeling aerodynamic co-efficients for autonomous trajectory planning of aerial vehicles using neural network approach

P. Xu, A. Verma, K. Vadakkeveedu, Knowledge Based Systems, Inc.

For autonomous and intelligent operations of aerial vehicles, online vehicle trajectory reshaping is highly desirable. For optimal performance, the aerial vehicles may operate at the edge of feasible regions of flight envelope, where the aerodynamics show non-linear behavior. Trajectory reshaping or trajectory determination algorithms solve two-point boundary value problem that requires a large number of iteration for the convergence of feasible solution. The standard approach of representing aerodynamic coefficients in tabular form is not suitable for real time trajectory generation. For online applications and faster convergence, it is desirable to represent aerodynamic coefficients in smooth functional forms that capture the non-linearity of aerodynamic coefficients sufficiently well by few parameters.

In recent work a weighted combination of piecewise smooth functions have been used for modeling aerodynamic coefficients. In this paper we present our research in modeling smooth functions using a Neural Network approach and compare with other approaches, such as weighted combination of piecewise smooth functions. The neural network models applied in this paper are multi-layer perceptrons (MLPs) trained with conjugate gradient algorithms. Each MLP consists of 14 input nodes representing the parameters governing aerodynamic coefficients. One key feature of our approach is the capability to model a vehicle at various damaged conditions. We have conducted experiments on modeling six aerodynamic coefficients generated by Missile Datcom, an aerodynamics design tool that is widely used in aerospace community. Our experimental results show that piecewise smooth function modeling can achieve very accurate approximation given well-selected control points. On the other hand, a MLP model is more efficient in training and can feasibly approximate aerodynamic coefficients at various geometric conditions and flying states.

6561-75, Session 10

Real-time prediction and diagnostics for unmanned ground vehicle (UGV) mobility

H. M. Jaenisch, J. Handley, M. P. Carroll, Tec-Masters, Inc.

This paper describes a novel capability for predicting and diagnosing current unmanned ground vehicle (UGV) system health and status. Prognostication is the results of a multi-step process consisting of successful novelty detection, fault detection, fault diagnosis, and failure prognosis. UGV mobility prediction requires the fusion of both external and internal situational awareness, resulting in a course of action that can be executed by the UGV and confirmed by its own sensors. Our algorithms are analytical and enable both prediction and diagnostics to be performed in real time and within the limited processor speed and memory constraints of the UGV. This paper summarizes these algorithms.

6561-65, Poster Session

Component-based open middleware architecture for autonomous navigation system

M. K. Ahn, Y. W. Park, T. Jee, Agency for Defense Development (South Korea)

There has been some skeptical aspects for the robot to be effective based on the currently available technology even though consensus of operational needs and some technological advancements.

One of the fundamental problems is difficulties in autonomous navigation technology applicable currently.

This technology is not sufficient to be applied for heavy combat operation, therefore, developer first makes open architecture, then, application software is implemented on the condition that new functions or technologies will be developed later.

It is also required to partition the function with common segments which are general to all platforms in order to operate together in the fields and to reduce the burden of development to each platform respectively.

In addition, Open System middleware is developed based on the reference architecture to accommodate the new technology evolution.

This paper introduces reference architecture and middleware applied in 3 XAV(eXperimental Autonomous Vehicle) developed in Agency for Defense Development(ADD) in South Korea.

In addition, the performance of autonomous navigation and system design characteristics are briefly introduced.

6561-76, Poster Session

Mobility analysis of differential torque steering vehicle

N. Huh, WIA Co., Ltd. (South Korea)

Differentially driven skid-steering vehicles are often considered for navigation in outdoor terrains.

However, the control of such vehicles is challenging because the wheels must skid laterally to follow a curved path, and motion stability can be lost as a result of excess skidding due to the position of the instantaneous center of rotation.

In this paper discussed mobility analysis of 6X6 differential torque steering vehicle from multi body dynamic analysis and driving experiment.

6561-77, Poster Session

Design of a skid steer-testing system of 4x4 wheeled-type vehicle

M. Kim, W. Yoo, T. Noh, H. Noh, H. Kim, Pusan National Univ. (South Korea)

In field robots, two types of suspensions, i.e., tracked type and wheeled type, had been widely used. Most of field robots have track type suspension, which is more suitable for the off-road. The wheeled type, however, has advantages in speed and fuel efficiency. The research of the wheeled type vehicle had been increased to obtain a better performance in off-road mobility.

The skid steering mechanism is useful in field robots without steering mechanisms, because it gives many advantages. In general, the skid steering requires smaller turning radius than steering linkage system. Thus, the need for the skid steering has been increased to provide more space for multi-wheeled type vehicles.

To investigate the skid steering mechanism of a multi-wheeled type vehicle, a skid steer measuring system was developed for one wheel model that uses an in-hub motor. It was applied to the design of the six wheeled vehicle, VGS-36(Variable Geometry Suspension 6x6), which is a field robot developed in CAE laboratory at the Pusan National University in Korea.

In this study, we expanded the one wheel model to a four wheeled vehicle, in which a skid steer measuring system was applied and tested. Then, changing the control signals of the in-hub motors, turning efficiency was tested in the system according to the torque distribution at each wheel. And positions of the wheels and center of gravity of the vehicle were also changed to see the turning effect. From the results of these experiments, more effective control signals and positions of the wheels are suggested. And these results will be applied to improve the controller design of the VGS-36.

6561-78, Poster Session

Design of a biologically inspired snake-like robot for all terrain use

R. Manayil John, National Institute of Technology/Tiruchirappalli (India)

The use of intelligent Unmanned Autonomous Robots in defense, civilian and planetary exploration is not something new. Most of these applications use Robots with wheels or tracks for locomotion with onboard camera and an arm with multiple degrees of freedom. Such a kind of locomotion becomes completely useless when the terrain is full of debris from a disaster or the inner side of a pipeline. In all these applications, a biologically inspired Robot with a snake like gait will be a better option. In this paper we are discussing the design of a Robot which is the result of a biologically inspired idea and has the motion gait similar to that of a snake. The snake Robot consists of eight aluminum segments which hold the electronics and actuators. Each segment has three degrees of freedom. The space between the segments is filled with a crude form of Magneto-Rheological (MR) Fluid. The whole structure is covered with flexible rubber based sheath, which acts as the skin. Each segment contains electronics, which contains a small microcomputer, wired to the main microcomputer in the first segment or head by means of a digital network. The first segment of the system contains sensors which are used for obstacle and sensing the terrain. We are on to the basic research of the system and in its very basic form, we hope that researchers around the world can modify the system and make it more successful and robust by adding more hardware features and software algorithms.

6561-79, Poster Session

Power PC-enabled rapid sensor prototype development platform for unmanned vehicles

J. N. Falasco, General Electric Co.

The proposed Poster Session reviews scalable embedded hardware and software solutions that allow for the Rapid Prototyping of new or modified sensor designs, mission payloads and functional sub assemblies for unmanned vehicle platforms. We are defining reconfigurable computing in the context of being able to place various PMC modules depending upon mission scenarios onto the base multiprocessor oriented SBC (Single Board Computer) p This SBC could be either a distributed or shared memory concept and have either two or four PPC7447/7448 processor clusters. In certain scenarios various combinations of boards could be combined in order to provide a heterogeneous computing environment. Applications addressed are image & signal processing centric.

6561-80, Poster Session

Integration of the Fido explosives detector onto the PackBot EOD UGV

P. Rudakevych, S. Clark, J. Wallace, iRobot Corp.

The digital architecture of the PackBot EOD has been exploited to integrate an explosives sniffer. This expands the usefulness of the UGV from its core EOD role to checkpoint vehicle inspections and facility clearing. It also expands the usefulness of the Fido sensor package from its core handheld role to a remote sensing device. From initial tests to deployment and training in Iraq and subsequent user feedback, we present the trials and tribulations of this effort from the perspective of the engineers that traveled to Baghdad.

6561-81, Poster Session

Framework for exploring issues in operator span of control: game interface lessons for developers of multi-robot systems

R. D. Ellis, Wayne State Univ.; G. Witus, Turing Associates, Inc.

The last decade has witnessed a dramatic growth in the use of unmanned aerial and ground vehicles (UAVs and UGVs). Most platforms in current use require one operator per vehicle. In order for new unmanned systems to become the force- multiplying tool they are envisioned to be, designers of these platforms will be required to develop new human-robot interaction schemes that take the best advantage of operator skills and semi-autonomous individual and team robot behaviors. In this paper, we explore issues related to the operator's span of control. First, we define the concept of span of control. We then propose a framework for evaluating requirements for the human- system interface at various spans of control, in the context of operator skill, the mobile robots' levels of autonomy and group control. Next, we offer observations on interaction modes and techniques at various levels of span of control using examples from the computer gaming industry. Finally, we propose a framework for empirical evaluation of future interaction modes based on multi-agent/multi-player gaming environments.

6561-82, Poster Session

Optimal steering of a mobile robot

G. Cook, George Mason Univ.

Robotic ground vehicles can be used in a variety of ways. In some circumstances it may be desirable for the robotic vehicle to travel from one point to another in minimum time and be oriented in a particular direction at the final state. Among other applications, this could apply to tasks such as remote sensing in a hazardous environment or to neutralization of a detected explosive. An interesting problem in the control of such a robotic ground vehicle is the steering. In this paper a mobile robot with front-wheel steering is treated. The problem of optimally steering the robot from its initial position and heading to the specified final position and heading is addressed. First a mathematical model for the mobile robot is required. For the purposes here a third-order kinematic model is formulated. This model does not contain the precision of a model based upon first principles; however, it is of sufficient fidelity to reveal some interesting and important features of the optimal trajectories. The performance measure is taken to be elapsed time. Assuming a fixed speed, this corresponds to a path of minimum distance. It is found that the optimal solution is a trajectory which consists of segments of maximum-curvature turns and segments of straight lines. The straight-line segments are singular arcs. The problem is shown to simplify when final heading is free. Examples is solved.

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6562-01, Session 1

The network: a revolutionary capability for the warfighter

J. A. Parmentola, U.S. Army

No abstract available

6562-02, Session 2

Passive ultrasonic method for human footsteps detection

A. E. Ekimov, J. M. Sabatier, The Univ. of Mississippi

Methods of human detection utilizing low-frequency seismic signals (typically below a few hundred Hertz) from footsteps are well known in the literature and in a practice. This frequency band is used for seismic detectors. Different walking styles (regular, soft and stealthy) result in different vibration signatures in the low-frequency range that determine the maximum ranges for this method of footstep detection. For example, the stealthy walking style was undetectable even a few meters from a seismic detector. Human footsteps generate broadband frequency vibrations in the ground/floor and sound in the air from a few Hertz up to ultrasonic frequencies. The dynamic forces from footsteps that are normal to the ground/floor are the primary cause of the low-frequency component in these signals. Striking and sliding contacts between a foot and the ground/floor produce the high-frequency responses. The physical mechanisms involved in the generation of high frequency signals and the possibility of their application for human footstep detection were investigated by the authors [A. Ekimov, and J. M. Sabatier "Vibration and sound signatures of human footsteps in buildings," J. Acoust. Soc. Am., 120 (2), 762-768 (2006)]. The present paper introduces an approach for human footstep detection using a passive ultrasonic method. The passive method employs an ultrasonic sensor that is sensitive to the sound from sliding contacts. Test results for the detection of a walking person indoors and outdoors are presented and discussed.

6562-03, Session 2

Automated target recognition of humans in infrared images

D. J. Bankman, T. M. Neighoff, Johns Hopkins Univ.

The ability to automatically detect humans in infrared images has important tactical value in military and civilian applications. Robots and unattended ground stations equipped with real-time human ATR capability can operate as scouts, perform reconnaissance for military units, and serve to locate humans in remote or hazardous sites. With the algorithm proposed in this study, human targets can be detected in infrared images based on the structure and radiance of the human head. The algorithm works in a three step process. First, the infrared image is segmented primarily based on edges and secondarily based on intensity of pixels. Once the regions of interest have been determined, the segments undergo feature extraction, in which they are characterized based on circularity and smoothness. The final step of the algorithm uses a kth Nearest Neighbor classifier to match the segment's features to a database, determining whether the segment is a head or not. This algorithm operates best in environments in which contrast between the human and the background is high, such as nighttime or indoors. Tests in a desert environment at nighttime show that the majority of test subjects are detected in the infrared images, with few false positives.

6562-05, Session 2

Personnel detection using ground sensors

T. R. Damarla, Army Research Lab.

In this paper we present a multi-modal multi sensor fusion algorithm for detection of personnel. The un-attended ground sensors employed consist of acoustic, seismic, passive infrared (IR) and video camera. The individual sensor data is processed and the probabilities of detection of a person are estimated which are then fused to estimate overall probability of detection of person. The confidence levels of each sensor modality are estimated based on a large set of data. The performance of algorithm is tested on a data collected in an un-occupied basement of a building with single and multiple present.

6562-06, Session 2

Magnetic tunnel junction technology for low-cost sensing

C. Nordman, P. Eames, R. Schneider, NVE Corp.; G. Lewis, Lewtech Co., Inc.

Unattended sensor systems capable of monitoring magnetic field perturbations can be used for a wide variety of applications including tracking, surveillance, counter-terrorism, border protection, and tamper-proofing. Newly emerging magnetic tunnel junction (MTJ) technology offers a low-cost, low-power, complement to the technologies of flux gates, SQUIDS, optically-pumped and other magnetic resonance devices. Recent thin-film and materials advances have shown exciting potential for high sensitivity, while the standard solid-state fabrication means production in volume for a low cost. The technology will be described and an example system, one which uses distributed MTJ sensor units for littoral water surveillance, will be detailed. The small, low-cost magnetic sensor units being developed for that application are suitable for other large unattended networks as well.

6562-07, Session 2

Joint processing of vector-magnetic and acoustic sensor data

R. J. Kozick, Bucknell Univ.; B. M. Sadler, Army Research Lab.

Multimodal sensor networks are being deployed in military and civilian scenarios where each node contains several sensor modalities, such as acoustic, magnetic, seismic, radar, electrostatic, infrared, optical, and others. The methods that are used to fuse the data from distinct modalities has a significant impact on the performance of the sensor network for detecting, localizing, tracking, and classifying sources. We focus on jointly processing two modalities, acoustic and magnetic, for the purpose of classifying civilian vehicles such as cars, SUVs, and trucks. In this work, the magnetic sensor is a vector magnetometer and the acoustic sensor is a single microphone, and we assume that the vehicle is moving along a road so that the range to the sensors is known approximately.

For a magnetic source moving with constant velocity, a model for the vector magnetometer output signal is available based on linear combinations of Anderson functions. We use this model to develop a novel estimator of the source speed and to reduce the vector magnetic data to 9 parameters. However, a corresponding parametric model is not available for the acoustic signal from civilian vehicles. In addition, models are not known for the joint statistical dependence between the magnetic and acoustic signals. We address this by using nonparametric probability density estimation to learn the joint statistics from training data, and then the magnetic-acoustic data is fused by extracting features for classification that maximize an information-theoretic criterion. The magnetic data model and the feature extraction

are described in detail in this paper. We apply the approach with measured magnetic-acoustic data from civilian vehicles. The results demonstrate that fusion of magnetic and acoustic data using the information-theoretic criterion improves the ability to discriminate between cars and SUVs. We also demonstrate that discrimination is improved when the features and classifier are combined with additional information about the vehicle's track.

6562-08, Session 2

Acoustic sensing from small-size UAVs

D. N. Robertson, T. Pham, Army Research Lab.; H. Edge, B. J. Porter, J. Shumaker, U.S. Army Research Lab.; D. Cline, Scientific Applications and Research Associates, Inc.

Acoustic sensing from small-size man-portable UAVs is being researched to find the sources of hostile fire. Data collected from microphones mounted on UAVs is being analyzed by ARL to localize transient signals of interest. Wind and platform noise are the primary technical issues that must be overcome to make acoustic sensors on moving platforms a viable technology. Algorithms are being developed to minimize the effects of platform and other noise. The effects of wind noise are being minimized by the use of uniquely designed windscreens from SARA, Inc. The acoustic sensor probes and the data collection hardware are described in detail in this paper, as are the small-size UAV platforms and the sensor mounting and placement. Data processing techniques are described and preliminary results from the data collected at Yuma are presented. Georegistration of moving sensors is another technical issue of critical importance. The need to continuously know the exact location and orientation of the sensor array is necessary, since they are constantly and rapidly changing during flight. This paper describes the approaches being used for handling this multi-faceted challenge.

6562-09, Session 2

A Gaussian approximation for acoustic range and speed estimation

V. Cevher, Univ. of Maryland/College Park

In this paper, we present a normal approximation for range and speed estimation by a passive acoustic microphone. We use the Laplacian approximation to demonstrate that the envelope of the microphone output is best modeled with a multiplicative Gaussian noise, when the source signal and the acoustic microphone noise have uncorrelated Gaussian distributions. We show that our normal approximation predicts the variance of the envelope measurements correctly and results in significantly smaller range estimation bias than the additive Gaussian model used in the literature. We also prove that the ignorance of the multiplicative noise is a reason for the negatively biased speed estimates that are commonly observed and noted in the literature. Using our multiplicative model, we analytically derive the receiver operating characteristics for acoustic target detection. We then present the Cramer-Rao bound for target localization in sensor networks. Estimation results are given using synthetic and field data.

6562-10, Session 2

Capabilities study of airborne acoustic sensor arrays

W. Prather, Miltec Corp.

Miltec Research & Technology along with the National Center for Physical Acoustics, Raspet Flight Research Laboratory, and Mississippi State University Aerospace Department have performed a detailed study of the benefits and issues associated with the implementation of an array of acoustic sensors on airborne platforms both moving and stationary. In order to facilitate this a platform has been developed for the testing of airborne acoustic arrays used in detection, tracking, and identification of objects of interest. The test bed has been selected such that it is optimized for this effort within reasonable limitations on complexity and costs. This approach allows for the determination of best case performance parameters for acoustic arrays on aerial platforms. Issues related to the design of the platform as well as measured results will be presented.

6562-11, Session 3

Real-time automated 3D sensing, imaging, and monitoring of dynamic microscopic biological events

B. Javidi, I. Moon, S. Yeom, Univ. of Connecticut; E. M. Carapezza, DARPA and DoD/DoJ Joint Program Committee Steering Group

No abstract available

6562-28, Session 3

TBD, The Boeing Co.

M. A. Kolodny, Army Research Lab.

No abstract available

6562-57, Session 4a

An intelligent video framework for homeland protection

P. Tu, G. Doretto, N. Krahnstoever, A. A. Perera, J. Rittscher, X. Liu, F. W. Wheeler, T. B. Sebastian, K. G. Harding, GE Global Research

This paper presents an overview of the Intelligent Video work that is currently being developed at the General Electric Global Research Center. Person detection from video cameras is the starting point for many surveillance applications. Variations in viewing conditions require a multi-pronged approach to person detection. A variety of approaches based on geometrical constraints, interest operators, part detection and machine learning methods are presented. Crowd segmentation methods enabling the tracking of individuals through dense environments such as retail and mass transit sites are discussed. It is shown how signature generation based on gross appearance and color constancy constraints can be used to reacquire targets as they leave and enter disjoint fields of view. Automatic camera calibration methods, which are used to infer the position, orientation and intrinsic camera parameters, are presented.

This information is used to further constrain the detection of people and to synthesize a top-view, which fuses all camera views into a composite representation. It is shown how site-wide tracking can be performed in this unified framework. Human faces are in important feature as both a biometric identifier and as a method for determining the focus of attention via head pose estimation. It is shown how automatic pan-tilt-zoom control; active shape/appearance models and super-resolution methods can be used to enhance the face capture and analysis problem. A discussion of additional features that can be used for inferring intent is given. These include articulated motion cues and physiological phenomena such as thermal images of the face.

6562-12, Session 4

Enabling technologies for force protection

J. Houser, L. Zong, T. Pham, J. Kovach, Army Research Lab.

The US Army Research Laboratory (ARL) has developed a number of sensing, communications, networking, and information technologies as a result of numerous research efforts. Although these disciplines are interrelated, they have historically been developed separately because of programmatic and organizational boundaries. The natural result is a collection of systems and enabling technologies that address the individual program goals but provide a limited situational awareness capability.

Although these technologies are often developed separately, ARL recognizes that a robust and effective sensing system requires a system level perspective of each component. As a result, we have begun the next logical step of integrating these capabilities to better understand their combined effectiveness as a system with a targeted application of force protection. As force protection is a broad topic, this effort is focused on high-value fixed sites such as military installations, government compounds, and strategic industrial facilities.

This paper describes an integrated sensor system and its application to the monitoring of high-value fixed sites. The system includes a variety of fixed and robotic sensors, data communication and distribution

components, as well as data fusion and display capabilities. We will present the system and provide early experimental results from fixed site monitoring.

6562-13, Session 4

Progress on the fabrication of integrated multi-parameter MEMS sensor

S. Rajic, W. Lawrence, P. Datskos, Univ. of Tennessee

We present the fabrication results of our work-in-progress integrated MEMS based multi-mode multi-parameter sensor. This type of orthogonal sensing platform can produce a very high confidence signal in a very low-cost and miniature package. An example of the parameters that are being simultaneously incorporated are acoustic, infrared, magnetic, and chemical. The readout of the individual MEMS devices is based on piezoresistive and optical beam/CCD. In one embodiment, over a million devices can be read essentially simultaneously providing substantial sensor element redundancy. In addition, this massively paralleled approach can form a system with both large dynamic range and high sensitivity.

6562-14, Session 4

Near Earth propagation: physics revealed

R. Wert, A. Goroch, E. Worthington, V. Wong, Naval Research Lab.

Both the military and consumer sectors are pursuing distributed networked systems and sensors. A major stumbling block to deployment of these sensors will be the radio frequency (RF) propagation environment within a few wavelengths of the earth. Increasing transmit power (battery consumption) is not a practical solution to the problem. This paper will discuss some of the physical phenomena related to the near earth propagation (NEP) problem. When radiating near the earth the communications link is subjected to a list of physical impairments. On the list are the expected Fresnel region encroachment and multipath reflections. Additionally, radiation pattern changes and near earth boundary layer perturbations exist. A significant amount of data has been collected on NEP. Disturbances in the NEP atmosphere have a time varying attenuation related to the time of day and these discoveries will be discussed. Solutions, or workarounds, to the near earth propagation problem hinge on dynamic adaptive RF elements. Adaptive RF elements will allow the distributed sensor to direct energy, beam form, impedance correct, increase communication efficiency, and decrease battery consumption. Small electrically controllable elements are under development to enable antenna impedance matching in a dynamic environment. Additionally, small dynamic beam forming antennas are under development to focus RF energy in the direction of need. By creating provisions for decreasing the output RF power to the level required, battery consumption can be reduced. With an increased understanding of the near earth propagation problem, distributed autonomous networked sensors can become a reality within a few centimeters of the earth.

6562-15, Session 4

Energy efficient joint acoustic-video target detection and tracking

S. Zhang, College of Staten Island/CUNY; M. Chen, Binghamton Univ.

Recently, joint acoustic and video processing has attracted much attention in target detection and tracking. Video sensors can provide accurate estimates but have limited field of view and require high power consumption. Acoustic sensors consume low power and can be omni-directional but have lower accuracy. Fusing data from both modalities has the potential to significantly improve tracking performance by exploiting the complementary information. However, it is not easy to efficiently fuse acoustic and video data due to the differences between the two modalities. Current research on joint acoustic-video detection and tracking has focused on the improvement of tracking performance by finding efficient fusion strategy. Since reducing the power consumption of video sensors is critical for unattended ground wireless sensor networks, this paper we focus on how to fuse acoustic and video information to save energy. A fusion strategy is proposed to help video sensors in reducing the power consumption by incorporating the acoustic tracking results. Simulation results are presented to demonstrate the effectiveness of the proposed method. The tradeoff of power-accuracy-communication is discussed.

6562-16, Session 4

Integrating pan/tilt/zoom and radar in unattended ground sensor systems

A. Kennedy, B. Jones, R. A. Knobler, R. D. Porter, McQ, Inc.

McQ's Omnisense family of unattended ground sensors utilizes a variety of passive detection methods to identify targets of interest, obtain imagery, and report this information to a central monitoring location. Integrating Pan/Tilt/Zoom capability along with the use of cueing sensors enables the user to better conceal the sensor at the detection location while maintaining the ability to capture good quality imagery of targets in the area. Integrating an active radar into the sensor enables the user to place the sensor in areas where passive detection methods experience reduced performance, while providing additional target information such as velocity and mutli-target tracking. This paper discusses the challenges involved in fusing the detection reports with existing sensor detection mechanisms. Command and control methods will also be discussed, particularly the ability to perform interactive pan/tilt/zoom operations without persistent communications connections between the backend systems and the sensor.

6562-17, Session 4

Self-assembled metal rubber(tm) interconnects for rugged ultra-lightweight unattended sensors and electronics

B. Davis, R. Claus, J. Lalli, NanoSonic, Inc.

This paper will present recent work in the development of self-assembled nanocomposite materials that may be used as ultra-lightweight electronic interconnects with integrated transducers for use in unattended ground sensors. An example of such materials is Metal Rubber(tm), a low mass density (1 gm/cc), highly elastic (modulus < 0.1 MPa), yet electrically conducting (107 S/m) material that may be patterned to create flexible, lightweight circuit interconnects. By varying the nanocluster constituents within the material during the self-assembly process, magnetic, dielectric, thermal, piezoelectric and other properties may also be controlled, enabling a variety of sensing functionalities. Examples of small conformal magnetic sensors for underwater applications, based on this technology, will be discussed.

6562-18, Session 5

Acoustic localization of ground vehicles using sparsely distributed nodes

M. R. Azimi-Sadjadi, G. P. Wichern, S. Srinivasan, Information System Technologies, Inc.

Unattended passive acoustic sensors are among the widely used sensors for remote battlefield surveillance, situation awareness and monitoring applications. These small and cost effective sensors can provide real-time information about different types of ground and airborne targets. They are rugged and reliable and can be left in the field for a relatively long period of time after deployment. Although the idea of deploying several baseline circular microphone arrays is found to be effective in detecting and localizing several isolated groups of vehicles, it cannot typically resolve the vehicles within a group when they are spatially very close together. This is due to limited spatial sampling resolution. Additionally, the number of sensors in the array typically limits the number of target groups or individual targets that can be resolved using these baseline arrays. Furthermore, these systems are not cost effective.

Distributed sensor networks using inexpensive Zigbee-based motes offer a new and promising paradigm for detection and localization of vehicles and for military surveillance in general. Randomly distributed motes with microphones attachments are used in this work to estimate the direction of arrival (DOA) of the sound sources. DOA's estimated from different clusters of sensor nodes allow us to localize the moving targets. Wideband geometric averaging Capon beamformer is used to estimate the DOA's at each cluster of nodes every one second. DOA's estimated from several clusters are subsequently used to estimate the vehicle location using a new maximum likelihood-based localization algorithm. Using this algorithm, erroneous DOA measurements are deemphasized and further outliers are identified and removed prior to ML-based localization. Results on the real data sets collected for several distributed acoustic sensing experiments involving moving light wheeled vehicles will be presented to show the usefulness of the developed algorithms. Important findings and observations on these results will also be outlined.

6562-19, Session 5

Capon beamspace beamforming for distributed acoustic arrays

M. R. Azimi-Sadjadi, N. J. Roseveare, Colorado State Univ.

This paper presents a beamspace implementation of a wideband Capon algorithm for distributed arrays. Distributed arrays have recently shown a decreased sensitivity to environmental and sensor configuration coherence losses. In an attempt to build upon this robustness, beamspace preprocessing is applied. Beamspace allows sector-focused beamforming and reduced computational complexity. A unique property of this implementation of beamspace, namely robustness to losses of entire channels of data, has been demonstrated. This implementation of beamspace to Capon beamforming also does not require beam orthogonalization, thus saving tremendous computational time, especially in not using the (.)^{-1/2} operator in whitening.

6562-21, Session 5

Underwater source localization based on energy measurement with randomly distributed sensor array

X. Chen, U. Tureli, Stevens Institute of Technology

In this paper, three underwater source location algorithms based on energy measurement using randomly distributed sensor array are proposed.

Compared to the methods based on DOA and TDOA, the energy-based underwater source localization method has several advantages:

1,the energy of the source varies slowly with respect to time, the acoustic energy time series can be sampled at a much lower rate . 2, the course time interval for computing energy reduces the burden of accurate time synchronization among sensors. 3,it is suitable for underwater wireless sensor network application due to relatively few computations and consumes little communication bandwidth and it is also suitable for the wideband and long duration sources localization. 4, the randomly distributed sensor array is more easily implemented in the underwater network which has severe bandwidth and energy limitations.

An acoustic signal energy attenuation model as a function of source-to-sensor distance is used and independent energy ratio is defined. First the closed form of least square (LS) and constraint LS(CLS) formulation for single source location are derived from the definition of energy ratio between different sensor readings. In two dimensions, we could use 4 sensors for LS and only 3 sensors for CLS and in three dimension, we require 5 sensors for LS and only 4 for CLS. CLS method reduces the minimum required number of sensors by one. Then, the maximum likelihood estimation for multiple sources based on energy measurement is presented and the alternating projection algorithm is applied to locate the multiple sources. The alternating projection transforms the multivariate nonlinear maximization problem into a sequence of much simple one-dimensional maximization problems. Simulation results based on underwater measurement show that our localization algorithms achieve good performance with computational efficiency and the performance of CLS is better than LS.

6562-22, Session 5

Analysis of the blind source separator's ability to perform direction of arrival estimations for multiple sources

C. Clark, Miltec Corp.

The Blind Source Separator (BSS) is an optimal non-linear least squares solution to Direction of Arrival (DOA) estimations for multiple acoustic sources. The details of the BSS are introduced; also, performance studies are conducted on all aspects of the algorithm. For instance, performance studies are conducted by varying parameters such as frequency bin selection, microphone spacing, number of sources present, signal-to noise ratio (SNR), and source separation distances. The BSS algorithm consists of many different factors that contribute towards producing reliable DOA estimations. Some of the most important factors are accurate modeling of the sound wave propagation near the array, the array configuration, and adequate stopping criteria for proper convergence. The influence of these factors has been analyzed and their inclusion in the algorithm has been optimized such that this solution has potential to be an optimal DOA estimator of multiple sources for real time systems.

6562-23, Session 6

Loud target suppression: an innovative approach to reduce excessive sensor collaboration in distributed UGS systems

C. A. Stelzig, G. Lipelt, General Dynamics Advanced Information Systems; S. Minor, U.S. Army Night Vision & Electronic Sensors Directorate

Effective management of sensor collaboration is crucial to the success of a distributed unattended ground sensor (UGS) systems. A successful management scheme must allow nodes to share enough information to form and maintain tracks while minimizing unnecessary or excessive collaboration. Systems developed with the traditional unidirectional or request/response models are typically susceptible to excessive collaboration in the presence of a persistent loud sound source. The work presented in this paper addresses the challenge of suppressing excessive sensor collaboration in the presence of loud targets. The Loud Target Suppression (LTS) algorithm utilizes Voronoi tessellation as a means to allow sensor nodes to autonomously determine alert regions that support track formation with neighboring nodes. By replying only with sensor measurements that fall within the alert regions, the LTS algorithm is able to significantly reduce message quantities without impacting track accuracy. This paper will demonstrate that an alert-based sensor collaboration scheme, employed by Distributed Cluster Management (DCM), greatly reduces sensor collaboration in the presence of loud targets which results in a more scalable system.

6562-24, Session 6

Layered mode selection logic control for border security

T. E. Born, A. B. Wright, Univ. of Arkansas/Little Rock; A. Wright, G. Ferrer, Hendrix College

Challenges in border security may be resolved through a team of autonomous mobile robots configured as a flexible sensor array. The robots will have a prearranged formation along a section of a border, and each robot will always attempt to maintain a uniform distance with its nearest neighbors. The robots will carry sensor packages which can detect a signature that is representative of a human (for instance, a thermal signature). When a robot detects a potential border crosser, it will move away from the crosser such that it attempts to maintain an constant distance from the crosser and moves away from the border (i.e. into its home territory). As the robot moves away from the border, its neighbors will move away from the border to maintain a uniform distance with the moving robot and with their fixed neighbors. The pattern of motion in the team of robots can be identified, either algorithmically by a computer or by a human monitor of a display. Unique patterns are indicative of animal movement, human movement, and mass human movement. To realize such a scheme, a new control architecture must be developed. This architecture must be fault tolerant to sensor and manipulator failures, scalable in number of agents, and adaptable to different robotic base platforms (for instance, a UGV may be appropriate at the southern border and a UAV may be appropriate at the northern border). The Central Arkansas Robotics Consortium has developed an architecture, called Layered Mode Selection Logic (LMSL), which addresses all of these concerns. The overall LMSL scheme as applied to a multi-agent flexible sensor array is described in this paper.

6562-25, Session 6

Role of quality of service metrics in visual target acquisition and tracking in resource-constrained environments

M. Anderson, Univ. of Minnesota; P. David, Army Research Lab.

Implementation of an intelligent, automated target acquisition and tracking systems alleviates the need for operators to monitor video continuously. This system could identify situations that fatigued operators could easily miss.

If an automated acquisition and tracking system plans motions to maximize a coverage metric, how does the performance of that system change when the user intervenes and manually moves the camera? How can the operator give input to the system about what is important and understand how that relates to the overall task balance between surveillance and coverage?

In this paper, we address these issues by introducing a new formulation of the average linear uncovered length (ALUL) metric, specially designed for use in surveilling urban environments. This metric coordinates the often competing goals of acquiring new targets and tracking existing targets. In addition, it provides current system performance feedback to system users in terms of the systems theoretical maximum and minimum performance. We show the successful integration of the algorithm via simulation.

6562-26, Session 6

Adaptive polarimetric sensing and processing

F. A. Sadjadi, Lockheed Martin Corp.

No abstract available

6562-27, Session 6

A temporal and spatial fusion-based decision support system for sparse undersea sensor network

B. Ling, Migma Systems, Inc.

In a sparse undersea sensor network, the sensor coverage areas are often non-overlapping. This type of surveillance network can achieve a reasonable target detection accuracy while minimizing the overall system cost. Although targets in the surveillance region may not always be detected, as they move, sensors can collectively detect, classify and track them. The traditional instantaneous target detection methods are less effective since, at certain sampling instances, targets may not be detected by any sensors at all! Therefore, operator must evaluate the sensor reports over a period of time. Since it is inevitable for sensors to generate false reports, over the entire evaluation period, both positive and false reports co-exist, making it difficult, if not impossible, for the operator visually or computer autonomously to identify the tracks. To overcome these problems, we have developed new temporal and spatial fusion methods for multiple targets detection and tracking. An optimization based fusion method has been developed to fuse spatially distributed sensor reports without making any assumptions of their underlying statistical distributions. The mathematical morphological operations are used to eliminate the isolated reports, thus, reducing the impact of random false detections. Our temporal fusion method further estimates the target tracks based on kinematic trajectories of moving targets. The synthetic target tracks are also estimated to provide the operator with a better view of the surveillance region. Simulation results have shown that our system can effectively detect multiple target tracks in a large surveillance region with false detections and sensor drifting.

6562-30, Session 7

Acoustic/seismic signal propagation and sensor performance modeling

D. K. Wilson, U.S. Army Engineer Research and Development Ctr.; D. H. Marlin, Army Research Lab.; S. Mackay, Atmospheric and Environmental Research, Inc.

Performance, optimal employment, and data processing methods for acoustic and seismic sensors depend strongly on the terrestrial environment in which they operate. Software tools for guiding non-expert users of these sensors are therefore much needed. However, accurate, meaningful predictions require that many individual components be constructed and correctly connected together. These components include the source signature and directionality, representation of the atmospheric and terrain environment, calculation of the signal propagation, characterization of the sensor response, and mimicking of the data processing at the sensor. Selection of an appropriate signal propagation model is particularly important, as there exist key trade-offs between fidelity and speed. Although most propagation modeling focuses on transmission loss (attenuation of signal energy), it is also important to consider the fading of the signal and, for array systems, variations in wavefront angle-of-arrival. Regarding the environmental characterization, the strong link is usually the availability of high-resolution terrain elevation data. Weak links in the environmental characterization are the temporal/spatial resolution of the atmospheric data, knowledge of the surface and subsurface properties, and data for the environmental background noise. Imperfect knowledge of the propagation environment is typically a primary source of uncertainty in the sensor predictions. We illustrate the design of software tools for acoustic/seismic sensors with two distinct examples: a detailed sensor-to-target calculation called the Sensor Performance Evaluator for Battlefield Environments (SPEBE), and a large-scale, polygon based calculation called Battlefield Terrain Reasoning and Analysis (BTRA).

6562-31, Session 7

ARL participation in C4ISR OTM experiment: integration and performance results

L. Zong, B. O’Brien, Army Research Lab.

The Army Research Laboratory (ARL) participated in the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) On-the-Move (OTM) experiment that was held at Fort Dix during the summer of 2006. This experiment was designed to examine the effectiveness that advanced C4ISR technologies have on an Army Future Combat Systems (FCS)-based Infantry Company and Reconnaissance Troop. The experiment included live soldier exercises conducting realistic scenarios, with each soldier being connected to a battlefield tactical network. Also connected to the tactical network was a suite of manned and unmanned sensor assets controlled via a cohesive command and control environment.

ARL’s objective in the exercise was to demonstrate system-level integration of developing technologies for small unit combat operations aimed at improving situational awareness. ARL brought expertise in unattended ground sensing technology, wireless mobile ad-hoc communication, and information fusion to the experiment. The ARL C4ISR system included a system of multimodal unattended ground sensors, a tripwire imager, multiple man-portable robotic vehicles (PackBots), and an unmanned scout/light-cargo carrying robotic vehicle (R-Gator). These disparate technologies were integrated into an overall C4ISR system using a combination of proprietary and COTS components, and communicated wirelessly using various methods. Users could control the system in a number of ways, via the Force XXI Battle Command, Brigade and Below (FBCB2) display suite mounted in tactical vehicles (HMMWV) or via Operator Control Units (OCUs) carried by dismounted soldiers.

This paper will describe in detail the ARL C4ISR system architecture, various components, and communication technologies. Further, the paper will describe some of the demonstration scenarios performed at the C4ISR OTM experiment and provide details on system performance analysis.

6562-32, Session 7

Modeling unmanned system collaborative target engagement

H. M. Jaenisch, dtech Systems Inc.; J. Handley, Licht Strahl Engineering Inc.; M. Hicklen, dtech Systems Inc.

This paper describes a novel algorithm for collaborative target engagement by unmanned systems (UMS) resulting in emergent behavior. We demonstrate UMS collaborative engagement using a simulation testbed model of a road, convoy vehicles traveling along the road, a squadron of unmanned aerial vehicles (UAVs), and multiple unmanned ground vehicles (UGVs) which are set to detonate when within close proximity to a convoy vehicle. No explicit artificial intelligence or swarming algorithms were used. Collision avoidance was an intrinsic phenomena. All entities acted independently throughout the simulation, but were given similar local instructions for possible courses of action (COAs) depending on current situations. Our algorithm and results are summarized in this paper.

6562-33, Session 7

Geometric considerations for optimally placing sensors in a field

T. Brown, City College/CUNY; D. Sarioz, The Graduate Ctr./CUNY; T. La Porta, The Pennsylvania State Univ.; D. C. Verma, IBM Thomas J. Watson Research Ctr.; A. Bar-Noy, M. P. Johnson, The Graduate Ctr./CUNY; H. Rowaihy, The Pennsylvania State Univ.

Resiliency of sensor monitoring infrastructure is a key requirement in the military context, since at any time one or more sensors may be unavailable. With enough sensors and careful deployment of sensors, one can provide a k-resilient area. A k-resilient, or k-covering sensor deployment is one in which each point within an area remains sensor observable even if up to k-1 of the sensors covering a point are unavailable.

One solution to the k-resiliency placement of sensors can be obtained by using geometric techniques. A geometric approach attempts to completely cover a sensor field so that every point is sensor-covered by k sensors using a regular pattern of placements (i.e. a grid). In this paper we explore a covering based on geometric ideas and also examine coverings when the grid locations are only approximated We show that these results can influence algorithms for self-locomoted sensors to move to better locations than the ones they currently occupy, to aid in proper placement of sensors when one has reasonable control on the placement, and to provide insights into how to place sensors under less than ideal conditions. Our current investigations have focused on geometric techniques where k equals 2. The regularity of our methodology to cover a square area with overlapping sensor coverage, allows these results to be extended for other geometric configurations and to different values of k.

6562-34, Session 7

Sensors that report by email: system concepts for keeping costs low

C. J. Brown, Brown Computer Co.

Military products are more often designed by engineers than by marketing people. When asked to optimize a design for cost, engineers tend to restrict their efforts to the parts they designed rather than looking at larger contexts. By focusing only on those components over which one has control, the engineer/designer will fail to see the largest opportunities for cost reduction. This paper presents several concepts for reducing the total cost of operating a geographically large network of autonomous sensors and argues that increasing the unit cost for a sensor can actually reduce the total cost of operating a sensor system.

6562-35, Session 8

Sustained unattended sensor networks: state-of-the-art challenges for future ocean and littoral systems

E. M. Carapezza, DARPA and DoD/DoJ Joint Program Committee Steering Group

No abstract available

6562-36, Session 8

Unattended ground sensors: the way ahead

M. A. Kolodny, Army Research Lab.

There are many applications, requirements and environments where Unattended Ground Sensors (UGS) are needed. However, a broad perspective reveals that a straigth path forward may exist for a common solution.

6562-37, Session 8

Real-time acoustic source localization with high performance sensor nodes

M. R. Azimi-Sadjadi, Information System Technologies, Inc.; G. Kiss, B. Fehér, Budapest Univ. of Technology and Economics (Hungary); Á. Lédeczi, Vanderbilt Univ.; S. Srinivasan, Information System Technologies, Inc.; P. Völgyesi, Vanderbilt Univ.

Distributed wireless sensor networks consisting of several single sensors with different sensing modalities offer numerous important benefits for a multitude of military applications including battlefield surveillance, situation awareness and monitoring, urban warfare and homeland security. Among these benefits are: simplicity and ease in deployment in battlefield or urban areas, larger coverage area, better spatial resolution for separating multiple closely spaced targets (i.e. vehicles), less hardware complexity and hence significantly lower costs, more flexibility in configuring different dynamic sensor array configurations, and potential widespread applications in urban warfare, homeland security, industrial monitoring, etc. However, the widespread application of the Zigbee-based sensor nodes is plagued by several technical challenges namely resource (e.g. bandwidth and battery power) constraints, reliability and health of sensors, and more importantly computational limitations of the nodes.

The computational capabilities of the inexpensive Zigbee-based distributed sensor nodes can be enhanced by COTS sensor boards. This gives the nodes the ability to preprocess the captured signals for sensor-level detection, feature extraction and direction of arrival (DOA) estimation and hence better utilize the limited resources e.g. battery power and bandwidth for long-term operations. This paper will present a custom design sensor board that can be interfaced with typical motes for multi-channel sensor-level data processing. The design is around FPGA supporting real-time data processing using five acoustic channels for numerous applications such as vehicle detection and tracking and acoustic transient (e.g. gunshots) localization. In this paper, the results on acoustic localization of various transient sources will be presented.

6562-38, Session 8

iScoutTM low-cost ad hoc networked sensor enhancements

M. A. Winston, McQ, Inc.

McQ has developed a family of state of the art miniaturized low cost unattended ground sensors (UGS). The iScoutTM sensors are designed for indoor and outdoor intrusion detection and battle damage assessment. McQ has developed a very advanced second version of this sensor that is a very flexible platform capable of performing in a variety of applications. This latest version has enhanced processing, added memory, and improved sensor transducers. Sensors are equipped with mesh radios, GPS, and integrated seismic, acoustic, infrared, and magnetic transducers. Typical sensor sizes are similar to

that of a deck of playing cards. Intended for high volume production, these are tactically useful sensors that can be manufactured in high volumes for a projected cost of less than $100 each. This paper will provide an overview of iScoutTM sensor systems, features, and performance.

6562-39, Session 8

Detection of the under-soil intruder activity

J. Cechak, Univ. of Defence (Czech Republic)

Submitted paper is directed to the area of the special devices - the Unattended Ground Sensors (UGS) for perimeter guarding use. It has been developed the sample of the new UGS conception. The main characteristics and digital signal processing principles are presented in this article. The proposal method how to detect under-soil intruder activity is presented too. It is currently more and more evident that passive means of intruder detection within a perimeter using most up-to-date technologies are going to be introduced in the most up-to-date military and security systems.

6562-40, Session 8

Know thy enemy's intent: the road ahead

M. A. Kolodny, Army Research Lab.

In urban warfare it is becoming more and more essential to be able to predict adverse events in order to preempt and avoid them. We need to develop a capability to "sense" enemy intent; to "read" his mind. This paper presents a vision of what needs to be done to achieve this objective.

6562-58, Session 8

Low-cost unattended ground sensors for continuous surveillance

S. Benda, General Atomics

The concept of sensor networks that can detect intrusions by hostile personnel and provide live, real time video of the intrusions to a central location has been circulated for over three decades. While there have been permanent installations of continuous surveillance monitors along small sections of the US border and such systems are routinely installed around high value facilities, these systems are not practical over large regions. The ideal sensor network would be covert, have self-contained power, be resistant to false alarms, be low cost, enable wireless data transfer, and require minimal personnel to operate/monitor. Unfortunately, the technical capability to produce such a sensor network has heretofore not existed. The advent of Ultra-Wideband (UWB) radiofrequency technology, digital cameras and night/day imaging technology developed during the telecom boom has changed this. By combining General Atomics' UWB communications and micro-impulse radar technology with commercially available micro-CCD or CMOS cameras, night illuminators, and lithium-ion batteries, an unattended sensor network capable of monitoring large (10 - 2000 km) class perimeters has been developed.

6562-04, Session 9

New seismic unattended small-size module for foot-step, and light and heavy vehicle detection and identification

E. T. Goldburt, A. Pakhomov, General Sensing Systems LLC

General Sensing Systems (GSS) has achieved outstanding and verifiable results in the design and performance of seismic unattended small size module with near zero false alarm rates for the detection of walking, running, and jumping persons. GSS has been developing a new seismic, unattended small size module that allows to detect and to identify not only footstep but also light and heavy vehicles. In addition, this module has extremely low power consumption that allows it to operate for up to a couple of months with the standard commercial batteries. This paper will describe our design for the module that has the capability to communicate with any radio transducer. We will also report on the preliminary lab and field-testing that was implemented in various environmental conditions.

6562-41, Session 9

Sniper detection using a helmet array: first tests in urban environment

S. Hengy, French-German Research Institute of Saint-Louis (France)

ISL started their work on sniper detection since years. First, it developped a high knowledge in small caliber shot acoustic propagation. Then, the studies for detection and localization of snipers lead to the development of an array prototype, mounted on a helmet.

This prototype has first been succesfully tested in free field propagation configurations (land) in 2005. Then, in November 2006, some tests on the Lehnin proving ground (Germany, in an urban environment) have been made.

The first results of this experiment are presented in this paper.

The helmet array has been positionned at distances varrying between 10cm and few meters away from walls. The estimation of the caliber and the distance between the shooter and the array is managed using the helmet array alone.

Different techniques have been tested and compared concerning the distance estimation. They are discussed in the paper.

6562-42, Session 9

Acoustic localization of mortar and rocket fires

T. Tran-Luu, L. Solomon, S. Tenney, Army Research Lab.

Acoustic sensors can provide a wealth of information for the Soldier. These devices accompanied by novel signal processing algorithms are useful in locating the point of origin and point of impact of mortars, rockets, and artillery as well as the location of IED (Improvised Explosive Devices) events. The signatures can also be classified to identify weapon type. Knowledge of this information increases overall situational awareness and allows triage in a timely manner and possibly return of fire. Impact locations can help damage assessment teams to get on site quickly.

ARL is developing a system of acoustic arrays for the purpose of acoustic events localization. This report examines the system's accuracy based on a live fire experiment in realistic conditions. The measured positional error is compared to the theoretical Cramer-Rao lower bound.

6562-43, Session 9

Quality of information trade-offs in the detection of transient phenomena

C. Bisdikian, IBM Thomas J. Watson Research Ctr.

Phenomenon (or event) detection is central element to a broad class of sensor-based applications in both civilian and military settings, for example in detecting the presence of aircrafts, hostile activities (e.g., explosions), studying threshold crossing (e.g., temperature), and so on. Upon determining the occurrence of a phenomenon, a decision maker may take corrective actions to remedy a situation, e.g., activate the fire-suppression sprinkler system, and/or trigger follow-on processes, e.g., sound the fire alarm. Thus, the quality of detection, and more generally the quality of information, supplied to a decision maker by a detection process is of high importance that directly influences the effectiveness of the decision making process.

The quality of information (QoI) achieved by detection processes is an objective of our on-going research where we investigate the trade-offs between the various attributes that influence QoI. Specifically, in this paper we present a set of attributes that are being proposed to characterize QoI in a domain-agnostic manner. We then focus on two important of these attributes, timeliness and data reliability, which capture the quality of detection processes with respect to how fast and how accurately a detection is made. With special emphasis on transient phenomena, i.e., phenomena of limited duration, using traditional Bayesian-based hypothesis testing techniques, we investigate the detection of these phenomena and we analytically derive relationships that capture the QoI of a phenomenon detector as a function of the duration of the observed phenomena and the rate with which observations of the phenomena are collected.

6562-44, Session 9

Acoustic classification of battlefield transient events using wavelet subband features

M. R. Azimi-Sadjadi, Colorado State Univ.; S. Srinivasan, Information System Technologies, Inc.

Collaborative distributed sensor networks offer a new and promising paradigm for military surveillance, reconnaissance and situation awareness for the military operations in urban terrain (MOUT). Generally, there can be wide variety of transient events in the battlefield depending on the specific mission like artillery fires, mortar fires, small arms fires, etc. The highly non-stationary nature of the transient signals makes the extraction of representative features a challenging task. This is compounded by the variations in the environmental and operating conditions and existence of a wide range of possible battlefield and MOUT transient events with perhaps overlapping features. The extraction of a salient feature set and the design of a robust classification system are the goals of this transient classification problem.

There are numerous acoustic sound sources on the battlefield and in MOUT environments that interfere with the transients of interest. First, the transient signal of interest is extracted using an ML-based transient signal estimation and restoration algorithm. The estimated transient signals are represented using wavelets, which provide an ideal framework to represent the transient signals because of its optimal multi-resolution time-scale properties. The multi-resolution property of the wavelet allows for capturing fine details or subtleties in the transient signals that can be used to successfully classify them. Wavelet sub-band higher order moment and energy-based features are used to characterize the transient signals. The discrimination ability and importance of each individual sub-band for transient signal classification is studied on several different gunshots and mortar fires. Important findings and observations on these results are outlined in this paper.

6562-45, Session 10

DARPA NetCentric radio demonstrations

L. B. Stotts, Defense Advanced Research Projects Agency

This paper describes a novel autonomously adaptive networked radio system that provides a broadband tactical mobile backbone to enable netcentric warfare. The system was successfully demonstrated to seamlessly interconnect multiple heterogeneous networked radio systems during the DARPA NetCentric (NC) demonstration at Ft. Benning, GA in January 2006, serving as the high availability terrestrial backbone link between dismount units that were otherwise beyond communications range. Real-time tactical voice, video, and situation awareness (SA) data were reliably delivered over the network to support the planning and execution of a simulated tactical mission with all radio network operation conducted by active duty US military personnel. Each NC node operated as a vehicular or airborne relay mobile ad-hoc router for the terrestrial backbone tactical network. Routing in each ground vehicle selected between this terrestrial backbone path and an alternate satellite backbone for assured line-of-sight (LoS) and beyond line-of-sight (BLoS) communications.

The broadband mobile ad-hoc radio system incorporates many innovative networking features to deliver breakthrough capabilities. Multiple discontiguous 1.2 MHz wide bandwidth segments are aggregated into a single RF waveform to ease frequency planning in crowded UHF spectrum bands. The system provides both high data rate and long range communications by autonomously adapting each link in the ad-hoc network topology to deliver the maximum possible throughput under dynamically changing link conditions. Prioritized delivery of time-sensitive and high value traffic is achieved through novel Quality of Service (QoS) mechanisms implemented in both the MAC and Network layers to ensure that the most important traffic is delivered during periods of network congestion. The reliable autonomous adaptation of the networked radio allows warfighters to focus on external events during tactical maneuvers without having to worry about communications connectivity.

6562-46, Session 11

Self-healing routing: a study in efficiency and resiliency of data delivery in wireless sensor networks

K. Wasilewski, J. W. Branch, M. W. Lisee, B. Szymanski, Rensselaer Polytechnic Institute

This paper presents the results of implementation of a novel protocol, Self-Healing Routing (SHR) for opportunistic multi-hop wireless communication, on Crossbow Motes. The protocol uses broadcast communication and a prioritized slotted transmission back-off delay scheme to empower a receiving node to use its hop distance from the destination to decide autonomously whether to forward a packet. This enables dynamic traversal of the shortest routes without requiring nodes to decide explicitly to which neighbors to forward packets. When severed routes are encountered, the protocol dynamically and locally re-routes packets so they traverse the surviving shortest route. This also makes SHR a natural complement for energy-efficient topology control algorithms that control radio power states.

We have implemented this protocol on a set of Crossbow Motes and conducted field testing with the motes placed at ground level (with limited radio range) and above ground (that gives them larger radio communication range and therefore increases the density of the motes placement over the same field of deployment). We also tested scenarios with the motes either turned off (modeling destroyed ones) or covered with a metal screen to prevent radio contact (modeling temporal unavailability). All these tests show the effects of a mote going off line temporarily and permanently.

The results, as shown by experimental measurement data reported in the paper, demonstrate that Self-Healing Routing is an efficient fault-tolerant protocol that performs well even with spontaneous network topology changes.

6562-47, Session 11

Simulation of sensor networks using message queue infrastructure

D. C. Verma, IBM Thomas J. Watson Research Ctr.

A simulation environment is very useful in analyzing sensor networks, but the development of a sensor simulation environment which can scale to a very large number of elements is hard to obtain using traditional simulation systems, or customized simulation environments. The desired level of scalability and high volumes are hard to achieve in customized simulation environments. One possible approach to obtain scalable simulation is by using commercially available messaging systems. Such messaging systems, e.g. IBM MQ system or OSMQ, are designed to operate at a very high bandwidth of message transfers rate and number of interacting message queue end-points. However, the communications abstractions offered by message queue systems are very different from the communications abstractions required by sensor networks.

In this paper, we describe an approach to map the communication abstractions of sensor network simulation systems to those of underlying message queue systems. We describe how issues related to message localization, prorogation delays and error rates can be effectively handled, and a highly scalable infrastructure for message simulation be deployed.

6562-48, Session 11

A survey of sensor selection schemes in wireless sensor networks

H. Rowaihy, S. Eswaran, The Pennsylvania State Univ.; M. P. Johnson, A. Bar-Noy, T. Brown, City College/CUNY; D. C. Verma, IBM Thomas J. Watson Research Ctr.; T. La Porta, The Pennsylvania State Univ.

The main goal of a sensor network is to provide accurate information to mission critical applications. This requires collecting measurement from as many sensors as possible to serve the requirements of one or multiple missions. However, to prolong the network lifetime the number of sensors activated to complete a mission must be kept to a minimum. To match sensors to mission a variety of selection schemes have been proposed. In this paper, we survey different schemes that are used to select sensors. We classify these schemes into (1) coverage schemes, (2) target tracking and localization schemes (3) single mission assignment schemes and (4) multiple mission assignment schemes. We also define the important open research problems in this field.

6562-49, Session 11

The color blue: an update on the ARL blue radio

R. Tobin, Army Research Lab.

ARL has developed a low cost, low power radio specifically designed for networked UGS applications. This paper will provide an update on the radio.

6562-50, Session 11

Secure communicating optical ultralight transponder (SCOUT) for low-power communication with remote sensors

S. Menn, P. A. Bierden, S. A. Cornelissen, Boston Micromachines Corp.; T. G. Bifano, Boston Univ.

With an ever-growing number of remote sensor applications in the defense industry and an emerging demand in the private sector, technology used to query and communicate with remote sensors must progress accordingly. Many remote sensing applications require secure, covert sensor communication and long battery operation times. Omni-directional sources such as RF transmitters are not viable given their high power consumption and low stealth level. Laser transmitters are an attractive solution but are limited in their tradeoff between communication range and power consumption. To meet both the needs of ultra-low power and secure communication, we are developing a new communication technology. The Secure Communicating Optical Ultralight Transponder (SCOUT) employs an unprecedented design that combines a deformable mirror made using microelectromechanical system (MEMS) processes with a conventional hollow glass retro-reflector. This device works by reflecting an illumination beam to its point of origin and modulating the incoming light to create a communication signal. The system benefits from two inherent characteristics: 1. No pointing or tracking subsystems are needed to establish a link to the source, and 2. no onboard laser transmission power is required. The strength of the return beam is directly proportional to the strength of the sending beam. Military applications include biological and chemical gas detection, laser remote sensing for surveillance, and land and air based situational awareness and force protection. This paper will describe the design and development of SCOUT, and will show initial performance results.

6562-51, Session 12

TBD, Army

No abstract available

6562-52, Session 12

TBD, Marines

No abstract available

6562-53, Session 12

TBD, Navy

No abstract available

6562-54, Session 12

TBD, INSCOM

No abstract available

6562-55, Session 12

TBD, INSCOM

No abstract available

6562-56, Session 12

TBD, DHS

No abstract available

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6563-01, Session 1

Biologically inspired models for swarming

E. W. Justh, V. Kowtha, Naval Research Lab.

“Understanding” the behavior of a biological system typically means formulating a sensible model, postulating a feedback law (incorporating biologically plausible sensory measurements), and experimentally verifying that the model and feedback law are consistent with nature. This approach is illustrated well in the work of K. Ghose, T. K. Horiuchi, P. S. Krishnaprasad, and C. F. Moss (and colleagues) on insect pursuit by echolocating bats. In work of F. Zhang, E. W. Justh, and P. S. Krishnaprasad, similar modeling principles and feedback laws have also been shown to play an important role in biologically-inspired formation-control and obstacle-avoidance laws. Building on this earlier work, we seek to identify a bio-inspired framework for cooperative swarming, in which the apparently complicated trajectories of individuals are explained by feedback laws which take a relatively simple form. The objectives of such swarming (e.g., for teams of unmanned vehicles) could include rendezvous, target capture (or destruction), and cooperative sensing.

6563-02, Session 1

Evolving behaviors in search and tracking problems

G. A. Vilches, A. S. Wu, Univ. of Central Florida; J. C. Sciortino, Jr., Naval Research Lab.; D. J. Pack, U.S. Air Force Academy; J. P. Ridder, Innovating Systems, Inc.

This work investigates the use of evolutionary computation in learning how to evolve goal priorities for a team of cooperating agents. Our goal priorities are trained to generate candidate parameter solutions for a search and tracking problem in an emitter/sensor scenario. We identify and isolate several behaviors that evolve to solve one or both task subsets. We also explore how quantity of emitters or sensors affect the capability to train for these behaviors and the performance outcome, isolate the types of goal vector parameters that contribute to them, and categorize the limitations from those parameters in these scenarios.

Studies indicate that social interaction can improve team performance in a variety of training simulations. We examine how the behaviors identified above are affected by distribution of limited, localized social interaction and hypothesize that the localized communications will improve the overall capability at solving the task.

6563-03, Session 1

Developing AEA system-of-systems mission plans with a multi-objective genetic algorithm

J. C. HandUber, Dynamic Analytics and Test, Inc.; J. P. Ridder, Innovating Systems, Inc.

The role of the airborne electronic attack (AEA) system-of-systems is to increase the survivability of friendly aircraft through jamming of hostile air defense radars. However, AEA systems are scarce, high-demand assets and have limited resources with which to engage a potentially large number of emitters. Given the limited resources, it is a significant challenge to plan their employment and to manage these in such a way as to achieve the desired result - the survival of friendly aircraft. Plans require specification of the geographic locations of jammer platforms, as well as the mix of wide- and narrow-band jamming assignments matched to particular radar targets. Further, the environment is uncertain as to the precise locations, numbers, and emissions behaviors of the radars. Therefore, we require plans that are not only capable, but also robust to the expected variability of the environment, and ultimately flexible for adaptation to larger variations. In this paper, we use a multi-objective genetic algorithm - the Dynamic Non-dominated Sorting GA (DNSGA) - to develop capable and robust AEA mission plans. The algorithm seeks to determine the Pareto-front of three objectives - maximize the operational objectives achieved by friendly aircraft, minimize the threat to friendly aircraft, and minimize the expenditure of AEA assets. The results show that this algorithm is able to provide planners with the quantitative information necessary to intelligently construct capable and robust mission plans for the AEA system-of-systems.

6563-04, Session 1

Genetic algorithms to find solutions to the minimum Voronoi classifier coverage problem

J. L. Overholt, G. R. Hudas, M. Skalny, G. Fiorani, U.S. Army Tank-Automotive Research, Development and Engineering Ctr.

No abstract available

6563-05, Session 2

Evolutionary optimization of cooperative heterogeneous teams

R. B. Heckendorn, T. Soule, Univ. of Idaho

There is considerable interest in developing teams of autonomous, unmanned vehicles that can function in hostile environments without endangering human lives. However, heterogeneous teams, teams of units with specialized roles and/or specialized capabilities, have received relatively little attention. Specialized roles and capabilities can significantly increase team effectiveness and efficiency. Unfortunately, developing effective cooperation mechanisms is much more difficult in heterogeneous teams. Units with specialized roles or capabilities require specialized software that take into account the role and capabilities of both itself and its neighbors. E.g. when a unit is lost, the other units must take into account the role of the lost unit and their own role and capabilities before deciding how to adjust their behavior.

Evolutionary algorithms, algorithms modeled on the principles of natural selection, have a proven track record in generating successful teams. However, using classification problems as a prototype, we have shown that typical evolutionary algorithms either generate highly effective teams members that cooperate poorly or poorly performing individuals that cooperate well. To overcome these weaknesses we have developed a novel class of evolutionary algorithms. In this paper we apply these algorithms to the problem of controlling simulated, heterogeneous teams (units are ‘scouts’ or ‘investigators’). Our test problem requires producing a map of an area and to further investigate ‘areas of interest’. Loss of units, either through hostile actions or mechanical failure, is possible, and only limited communication is allowed. We compare several evolutionary algorithms for their ability to generate individually effective members and high levels of cooperation.

6563-06, Session 2

Using a multi-objective evolutionary algorithm for the airman assignment problem

M. P. Kleeman, G. B. Lamont, Air Force Institute of Technology

The Air Force has been mandated to cut their military personnel drastically by 2009. With these forced cutbacks, many of the current processes need to be streamlined and become more efficient. In this paper, we present a multi-objective evolutionary algorithm (MOEA) that could be used by the Air Force Personnel Center (AFPC) to more efficiently determine military assignments. Specifically the paper focuses on maximizing two objectives - minimizing moving costs and minimizing any assignment penalties generated by the algorithm. The

complexity of the problem is increased due to the number of hard constraints that must be met before a solution is considered valid. The paper is divided into three sections.

The first section describes the problem domain and compares this assignment problem with others that have been previously researched. The assignment problem is categorized into the more general constrained assignment problem (CAP). The best practices of these common problems are discussed and applied to our problem.

After the problem is fully discussed, the second section describes the algorithm that is applied to the problem. The evolutionary operators are presented and the reason why these operators were implemented is discussed. Other algorithm parameters and settings, as well as the computing environment are discussed in this section.

The third section discusses the results. The paper uses standard MOEA metrics and uses timing information to show how quickly the algorithm generates valid solutions. Using Pareto analysis, the paper illustrates how the algorithm progresses toward the optimal solutions. A discussion of the results is presented and opportunities for future work are addressed.

6563-07, Session 2

Modeling and predicting abstract concept or idea introduction and propagation through geopolitical groups

H. M. Jaenisch, dtech Systems Inc.; J. Handley, Tec-Masters, Inc.; M. Hicklen, dtech Systems Inc.

This paper describes a novel capability for modeling known idea propagation transformations and predicting responses to new ideas from geopolitical groups. Ideas are captured using semantic words that are text based and bear cognitive definitions. We demonstrate a unique algorithm for converting these into analytical predictive equations. Using the illustrative idea of “proposing a gasoline price increase of $1 per gallon from $2” and its changing perceived impact throughout 5 demographic groups, we identify 13 cost of living Diplomatic, Information, Military, and Economic (DIME) features common across all 5 demographic groups. This enables the modeling and monitoring of Political, Military, Economic, Social, Information, and Infrastructure (PMESII) effects of each group to this idea and how their “perception” of this proposal changes. Our algorithm and results are summarized in this paper.

6563-08, Session 2

Modeling and predicting community responses to events using cultural demographics

H. M. Jaenisch, dtech Systems Inc.; J. Handley, M. P. Carroll, Tec-Masters, Inc.

This paper describes a novel capability for modeling and predicting community responses to events (specifically military operations) related to demographics. Demographics in the form of words and/or numbers are used. As an example, State of Alabama annual demographic data for retail sales, auto registration, wholesale trade, shopping goods, and population were used; from which we determined a ranked estimate of the sensitivity of the demographic parameters on the cultural group response. Our algorithm and results are summarized in this paper.

6563-09, Session 3

Exploring small UAV search strategies using a multi-objective genetic algorithm

J. P. Ridder, Innovating Systems, Inc.; J. C. Sciortino, Jr., Naval Research Lab.

Modern air defense systems include emitters that are characterized by their low peak power, low sidelobes, and short emission times. One approach to finding these is to employ multiple small UAV’s that actively search an area of interest. The target search environment may be partially known, but with a significant level of uncertainty as to specific emitters, their locations, and their emissions behavior. Therefore, the search effectiveness of the UAV’s is likely to be strongly influenced by the particular algorithms they employ. These algorithms can generally be characterized by the area they cover and their revisit rate to a particular point. In addition, intelligent algorithms will use environmental perception and interactions with other UAV’s to dynamically guide their search. In this paper we use a multi-objective genetic algorithm (MOGA) to explore the desirable characteristics of the search algorithms and numbers of UAV’s necessary to conduct a search for a set of air defense scenarios that vary in terms of numbers and location uncertainty of target emitters. This algorithm seeks to determine the Pareto-front of two objectives - maximize search performance (measured by the ratio of detections to detection opportunities) and minimize cost (measured by the number of UAVs). This work will help lay the foundation for development of intelligent search algorithms, and will also serve as the basis for a planning component that determines the initial search characteristics of small UAV’s for particular missions.

6563-10, Session 3

Optimizing a search strategy for multiple mobile agents

A. S. Wu, Univ. of Central Florida; P. Lima, U.S. Air Force Academy; J. C. Sciortino, Jr., Naval Research Lab.; D. J. Pack, U.S. Air Force Academy

In this paper, we propose a rule-based search method for multiple mobile distributed agents, seekers, to cooperatively search an area for mobile target detection. The collective goals of the seekers are (1) to maximize the coverage of a search area without explicit coordination among the members of the group, (2) to increase the unpredictability of the search pattern of individual seeker, and (3) to improve the average visit frequency rate for all locations within a search area. We assume that the search space contains multiple mobile targets and each seeker is equipped with a Global Positioning System (GPS) and a rudimentary sensor with a limited range. We also assume that each seeker has a limited communication range and can only communicate with nearby seekers. We envision the proposed search method to be applicable to cooperative mobile robots, Unmanned Aerial Vehicles (UAVs), and Unmanned Underwater Vehicles(UUVs). The final rules used by each seeker is developed by an evolutionary algorithm based process where the mobility decision of a seeker at each time incident is independently made as a function of the direction of the previous motion of the seeker, the known locations of other seekers, the distance of the agent to the boundaries of the search area, the agent’s knowledge of the area already covered by the group, and the desire to generate random search patterns. We demonstrate the effectiveness of the proposed search method in multiple scenarios with varying number of seekers and targets. We also show the generality and the scalability of the proposed method.

6563-11, Session 3

Swarming UAVs mission design strategy

K. Lin, Univ. of Central Florida

No abstract available

6563-12, Session 4

Cognitive algorithms for engineering applications: dynamic logic, neural fields, and the mind

L. I. Perlovsky, Air Force Research Lab.

Dynamic logic and neural fields are mathematical techniques describing aspects of the functionality of the mind: concepts, emotions, instincts, imaginations, intuitions. All of these are inseparable from perception and cognition. The talk first discusses combinatorial complexity often encountered in the past attempts at designing “intelligent systems.” Then a mathematical technique for reducing this complexity is described along with engineering applications (model-based pattern recognition, detection, tracking, fusion, financial predictions, Internet search engines). Results are presented suggesting orders of magnitude improvement in classical problems of detection and tracking in noise.

The last part of the talk moves to future research directions: evolution of languages and cultures, roles of beautiful, music, sublime in the mind, cognition, and evolution. We will argue that dynamic logic is related to the knowledge instinct, which drives the mind to understand the world, and argue that instinct is even more important than sex or food. A mathematical formulation of the knowledge instinct connects computers and the mind, the high and the mundane.

6563-13, Session 5

Bio-inspired large cellular neural networks

T. P. Jannson, T. C. Forrester, K. Chua, M. Reznikov, Physical Optics Corp.

In this paper, a new architecture of bio-inspired neural network is proposed, based on cellular neural network (called HYDRA), is based on virtual synaptic interconnects. These interconnects are either IR-wireless (for neural clusters), or RF-wireless (for interconnections between clusters). The cellular neuron consists of single, or a few neural transistors, based on low-cost (1 cent per transistor), silicon, or organic (transistor, FET or a biopolar one). In this paper, we discuss neural system issues as well as technologic issues, related to low-cost transistor fabrication.

6563-14, Session 5

Genetic programming techniques for thin-wire antennas

T. H. O'Donnell, Air Force Research Lab.

Simple genetic algorithm optimizations often utilize fixed-length chromosomes containing a predefined set of parameters to be optimized. While such algorithms have successfully created electrically-small narrow-band and large wide-band military antennas, they require the antenna designer to have a fairly concrete antenna representation apriori to the genetic algorithm. In this research, we investigate the use of genetic programming (GP) techniques to "program" the design of a simple thin-wire antennas. Genetic programming techniques offer the potential to create random, multi-arm, multi-dimension antennas from variable length, tree-like chromosomes. We compare and contrast several GP-designed thin-wire antennas to antennas created previous by simple genetic algorithms, discussing the pros and cons of these techniques.

6563-15, Session 5

Application of evolutionary algorithms and neural network concepts to the design of low-cost, wideband antenna arrays

S. Santarelli, R. J. Mailloux, T. Yu, T. M. Roberts, M. H. Champion, D. E. Goldberg, Air Force Research Lab.

No abstract available

6563-17, Session 6

Evolving military-grade image transforms using state-of-the-art variation operators

M. R. Peterson, Wright State Univ.; G. B. Lamont, Air Force Institute of Technology; F. W. Moore, Univ. of Alaska Anchorage

Military imaging systems often require the transmission of copious amounts of data in noisy or bandwidth-limited situations. High rates of lossy image compression may be achieved through the use of quantization at the expense of resulting image quality. We employ genetic algorithms (GAs) to evolve military-grade transforms capable of improving reconstruction of satellite reconnaissance images under conditions subject to quantization error. The resulting transforms outperform existing wavelet transforms at a given compression ratio allowing transmission of data at a lower bandwidth. Because GAs are notoriously difficult to tune, the selection of appropriate variation operators is critical when designing GAs for military-grade algorithm development. We test several state-of-the-art real-coded crossover and mutation operators to develop an evolutionary system capable of producing transforms providing robust performance over a set of fifty satellite images of military interest. The evolved filters consistently provide an average mean squared error (MSE) reduction greater than 15% over the original wavelet transform across all images. Application of a general pattern search (GPS) algorithm provides additional local refinement to evolved transforms. By improving image quality, evolved transforms increase the amount of intelligence that may be obtained reconstructed images.

6563-18, Session 6

Using a multi-agent evidential reasoning network as the objective function for an evolutionary algorithm

R. S. Woodley, C. M. Gore, E. R. Lindahl, 21st Century Systems, Inc.

Exhaustive search is often infeasible and many real world problems offer no objective measures of solution quality, preventing the discovery of solutions. We have combined evolutionary algorithms (EA) with the evidential reasoning network (ERN), a new concept in evidential reasoning that serves as the EA's objective function. This allows for a fusion of beliefs and opinions to guide the evolutionary force acting upon the possible solutions instead of a single quality metric, allowing us to approach problems that simultaneously require incomplete search methods and lack any single overall metric of solution quality.

ERN integrates the decisions of people and software using subjective logic, explicitly accounting for trust and pedigree. ERN provides a normalization layer for integrating evidence characterizers and classifiers with human opinions. ERN allows for fine-tuning of trust for disparate experts and tuning of classifiers, allowing for large-scale sensor and evidential fusion integration.

We apply our approach to battlefield stress calculations and identifying the optimal make-up of fighting units, a problem whose metrics are ill defined and subjective, further complicated by the human commanders who have unit preferences. Our approach can account for the disparate information and calculate a near-optimal troop make-up. We simplify the description of a good solution with ERN, which the EA explores to discover those good solutions. This approach is applicable to real-world problems where even defining a cost function is difficult, with the added feature that human intuition and subject expertise combine with the ability of computers to find good solutions.

6563-19, Session 6

Optimizing the usage of computer servers with a hybrid-genetic algorithm

D. Montana, Bolt, Beranek & Newman, Inc.

No abstract available

6563-20, Session 6

Object classifiction with recurrent loop networks

T. Achler, Univ. of Illinois at Urbana-Champaign

Recurrent connections associated with presynaptic inhibition can be found throughout the brain through cortical layers, antidromic activation and (thalamo, geniculate, olfactory bulb)-cortical loops. My work suggests that these connections implement dynamic networks where activation projects to the processing cells which then feeds back and inhibit the inputs. Multiple such circuits can be intermeshed to perform recognition.

Such circuits resolve combinatorial problems: the maximal number of connections demanded by the network depends only on the number of inputs a cell has. A cell does not require a connection to each cell it may potentially compete with, reducing computational complexity.

Within the feedback network, the degree of input feature overlap between a pair of representations defines the degree of competition between them. An increase in the similarity between two objects leads to the increase in the computational demand, resources needed, and time needed to distinguish between them. This correlates with human reaction time data.

Furthermore, when presented with multiple representations this network prefers the broadest representations with the least amount of inter-representation overlap, which elegantly addresses binding problems. Even though nonlinear, recurrent feedback networks are well suited for the search task, are combinatorially plausible, allow the best fit of multiple representations, touch on the binding problem, and are supported by brain neurophysiology and neuroanatomy.

6563-21, Session 6

Data mining approach for analysis of a co-evolutionary SASO simulation

L. Suantak, J. W. Rozenblit, F. Momen, The Univ. of Arizona

As modern military simulation systems develop in complexity and strive to incorporate greater numbers of fine-grained data sources, analysts are turning to databases to collect, organize and make sense of the large volumes of data that are generated. Decision support tools that use evolutionary algorithms to search very large solution spaces also benefit from the power and flexibility of analysis employing data mining techniques. This paper describes our approach to performing pattern analysis and trend discovery using databases on Sheherazade, a multi-sided genetic algorithm based course of action (COA) genereator that supports Stability and Support Operations (SASO). The Sheherazade system models the impact of the characteristic SASO parameters such as regional 'attitudes', population density etc., as well as conventionan and non-conventional forces such as military, terrorist, apolitical non-combatant, information operators etc. on the mission success of various factions (including the peacekeeping force). The COAs that are generated are visualized on a 3-dimensional platform supported by a range of analysis tools and displays. By populating a database with the output of many simulation runs, aggregate queries that yield statistical results becomes possible, providing insight into overall trends in the simulation that are difficult or impossible to observe by examining individual COAs. The results so far have allowed us to generate meaningful information about the simulation as well as the coevolution process that has been validated by domain experts in the field.

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6564-01, Session 1

Modeling stochastic phenomena in rocket exhaust signatures

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Fluctuations and rapid transients in rocket plume signatures have a significant affect on the performance of threat detection algorithms. Some of the phenomena, caused by: interaction of turbulent exhaust with the atmosphere, pressure fluctuations in the motor and inhomogeneity of atmosphere composition, for example in the distribution of ozone, can be modelled by solving the radiation transfer equations over ensembles of the composition. These ensembles are statistically equivalent to temporal Probability Density Functions (PDF) when the signature is at steady state. Slower transients can also be modelled when the average is orders of magnitude slower than the fluctuations. In this study, ensembles are derived from experimental data or calculated by solving a composition PDF transport equation. Preliminary results suggests that this approach can be useful in developing hybrid sensors for threat detection and missile guidance optics.

6564-02, Session 1

Modeling surveillance systems with meta-models

M. D. Barnell, Computer Science Corp.

The modeling and simulation for Radar Systems within the Air Force Research Lab (AFRL) Sensors Directorate (SN) are very complex. In order to develop, test, and analyze surveillance assets complex simulations (Physics driven Model {PM}) are run which accurately model a single state of the system. Using the information collected from several states of the PM the statistics are used to develop and create Meta-Models. The Meta-Model is then used in the Engagement driven Model (EM) to accurately model the radar system and signal processing. The EM models have missions that may run for hours and the Meta-Model is computationally efficient. The simulations can run in near real-time and still accurately model first, second and third order effects. This approach has been effectively used for the Space Radar (SR) program. The Integrated Space Based Radar (ISBR) simulation has Meta-Models that are used to emulate the radar system and associated signal processing for evaluation of system performance.

There is a need in the Air Force and the Air Force Research Lab (AFRL) to be able to evaluate, predict and analyze complex systems. The process of developing a comprehensive understanding and applying it in a Meta-Model is fundamental to building accurate simulations. Creating tools that allow researchers and analysts the ability to fully examine and predict the behavior of these systems with confidence, is critical to the mission's effectiveness.

6564-03, Session 1

Irma 5.2 multisensor signature prediction model

J. C. Savage, C. F. Coker, Air Force Research Lab.; B. Thai, O. Aboutalib, A. Chow, N. Yamaoka, Northrop Grumman Corp.

The Irma synthetic signature prediction code is being developed by the Munitions Directorate of the Air Force Research Laboratory (AFRL/MN) to facilitate the research and development of multi-sensor systems. There are over 130 users within the Department of Defense, NASA, Department of Transportation, academia, and industry. Irma began as a high-resolution, physics-based Infrared (IR) target and background signature model for tactical weapon applications and has grown to include: a laser (or active) channel (1990), improved scene generator to support correlated frame-to-frame imagery (1992), passive IR/millimeter wave (MMW) channel for a co-registered active/passive IR/MMW model (1994). Irma version 5.0 was released in 2000 and encompassed several upgrades to both the physical models and software, and it may be hosted on Windows, Linux, Solaris, or SGI Irix platforms. In 2005, version 5.1 was released after an extensive verification and validation of an upgraded and reengineered active channel. Since 2005, the reengineering effort has focused on the Irma passive channel. Field measurements for the validation effort include both unpolarized and polarized data collection. Irma 5.2 is scheduled for release in the summer of 2007. This paper will report the validation test results of the Irma passive models and discuss the new features in Irma 5.2

6564-04, Session 1

A conically scanning active/passive sensor simulation

P. Laupattarakasem, W. L. Jones, Univ. of Central Florida; R. S. Roeder, Raytheon Co.; S. O. Alweiss, Univ. of Central Florida

This paper presents the details of an advanced satellite radar scatterometer end-to-end simulation, known as the Conically Scanning Active/Passive Sensor Simulation (CAPSS) used for hardware development trade studies. This simulation is a collection of customized software tools that permits design engineers to vary the instrument parameters and configurations and to assess the resulting instrument performance under realistic on-orbit scenarios. Atmospheric and oceanic environment and satellite to earth geometry are used to simulate active and passive microwave measurements. Afterwards, these microwave observables are used in a geophysical retrieval algorithm to infer physical parameters such as ocean wind speed and direction. The simulation software provides an efficient method to perform engineering trade studies to optimize the scatterometer instrument design for a desired level of geophysical measurement performance.

The input parameters to the simulation include the satellite ephemeris, start/stop location and instrument antenna viewing geometry (e.g., conical scan rate & sampling interval) and other instrument parameters. The scatterometer radar measurements are simulated over a measurement swath determined by the satellite orbit and the instrument scan configuration and then inverted to retrieve the ocean conditions (wind speed and direction) that produced the measured backscatter and multi-polarization radiometric radiances. The output retrieved oceanic surface wind field is evaluated against input environmental data used for the simulation; and error statistics are presented.

6564-05, Session 2

Autonomous selection of nonlinear inpainting techniques versus stochastic inpainting techniques for high-resolution digital elevation models

M. D. Rahmes, J. H. Yates, J. D. Allen, Harris Corp.

High resolution Digital Elevation Models (DEMs) often have voids (missing data) due to the collection platforms that are used to obtain the DEM, inclement weather conditions, low returns, systems errors/malfunctions for the various collection platforms, or other factors. Inpainting accurately fills voids during bare earth processing where culture and vegetation have been extracted. The LiteSite Toolkit mitigates voids in DEMs via two novel techniques. The LiteSite Toolkit uses both a non-linear and stochastic based inpainting technique to accurately fill in voids. The non-linear technique has its origin in fluid dynamics and heat equations (partial differential equations). The stochastic technique has its origin in texture analysis and exemplar based processing. Each technique is optimally suited for different input conditions. The fluid dynamics based solution works better for areas requiring high accuracy where the area to be inpainted does not have disproportionately high frequency data in a neighborhood of the boundary of the void. The exemplar based technique is better suited for high frequency areas. Both are autonomous with respect to detecting and repairing void regions in disparate data sets. What we describe is a cohesive autonomous solution that selects the best technique as the void is being dynamically repaired.

6564-06, Session 2

On the criticality of parameter data transfer in avionic simulations

R. D. Teichgraeber, Lockheed Martin Corp.

In many PC-based simulations, message passing is commonly used for transfer of dynamic data between software models. Parameter definition and/or initialization are typically handled differently and may suffer because that data is not transferred to all the required models at any time during a simulation run. Instead multiple and often dissimilar initializations of the same parameters occur in various software modules, much to the chagrin of the configuration control personnel and test engineers. Results from using this approach can be particularly damaging for navigation sensor simulations such as a GPS-aided inertial mode and for flight program software evaluation and validation, where extreme accuracy of results is required.

The paper proposes solutions to prevent parameter data mismatch and/or compromise. These solutions are based upon doing a thorough job of critical parameter definition and initialization, given the simulation computer architecture. The solutions are discussed and explained. Included are descriptions of actual cases - examples of parameter mismatch within medium to large scale avionic simulations where accuracy was critical to performance evaluation. Parameter categories critical to accurate evaluations of avionic simulation performance are identified and discussed.

6564-07, Session 2

Limitations and uses of quick-turn analyses versus extensive integrated simulations

K. Schum, G. Boyarko, J. McCarty, Air Force Research Lab.

The Air Force Research Laboratory (AFRL) has an increasing reliance on Modeling and Simulation (M&S) to assess cost, risk, and performance of their space vehicle research. One of the most challenging aspects of modeling and simulation, especially for the military, is the time required to design, develop, and test a simulation. To further complicate the problem, military programs are typically operating under very tight timelines and limited resources. As a result, high fidelity, integrated simulations often are not given sufficient diligence to fully validate their results. Conversely, when the development teams do take the time to follow state-of-the-art software development practices, the end users have often already made their decisions based on rapidly developed quick-turn analyses. Because of the risk and associated cost of space flight experiments and the stringent timelines imposed by launch dates, the space community is steadily increasing their reliance on modeling and simulation. This brings the dilemma of large-scale integrated simulation vs. quick-turn analyses to the forefront of space vehicle program management. This paper will discuss the typical process most simulation teams use to develop and vet their tools, and compare the relative value of quick-turn analyses done with commercial off the shelf (COTS) and government off the shelf (GOTS) tools. Active research in this area includes simulation processes for linking but not integrating simulations of varying fidelities. The data supporting this paper will result from a series of analyses that range from short duration, mathematical analyses to engineering-level system simulations, and larger system-of-systems tools. A brief discussion will be presented explaining how managers of large, complex technical programs can benefit by using both quick-turn analyses and integrated system simulations.

6564-08, Session 2

Using ontology comparison methods for simulation composition

M. S. Patki, P. C. Benjamin, R. Mayer, Knowledge Based Systems, Inc.

Knowledge acquisition/discovery, ontology management, knowledge representation and knowledge sharing are key issues in ontology research. This paper focuses on the issue of ontology management and analysis to facilitate reusability of a simulation components based on ontology comparisons. This paper describes novel ontology comparison methods for component-based simulation composition. We describe four independent approaches for ontology comparison-terminology-based, feature-based, semantic, and topological. A data-fusion based approach is used to integrate the information from these four techniques into a single similarity score. The assignment of such similarity scores is demonstrated using ontology examples from various domains. In addition to assessing the similarity, simulation composability requires identification of potential mismatches before two component models can be integrated. We categorize mismatches into two primary types-language-level mismatch and ontology-level mismatch. Each of these are further categorized based on the nature of the mismatch. A comprehensive approach is developed for quantification of such mismatches. Finally, we outline simulation composition application scenarios that demonstrate the practical benefits of this research.

6564-09, Session 3

An adversary prediction environment based on DSAP capabilities

M. E. Valinski, N. Mia, R. M. McGraw, RAM Labs.

There is a need for anticipatory tools and techniques to assist command staff in Intelligently Preparing the Battlespace by predicting and assessing adversary and neutral courses-of-action in a manner that enable the rapid diffusion of undesirable military or socio-political situations.

This paper discusses the development of an Adversary Prediction Environment (APE) that will provide this capability by leveraging soft computing techniques and grid computing resources to provide an environment that allows for rapid exploration and analysis of enemy COAs for a given set of scenarios. The APE accomplishes these capabilities by utilizing prediction capabilities present in our DSAP (Dynamic Situation Awareness and Predictive (DSAP) environment to apply operationally focused simulation through Joint SemiAutomated Forces (JSAF) to evaluate plan effectiveness. The paper will discuss our current efforts to identify prospective scenarios and define a library of basic adversary and neutral force plans, actions, and adversary objectives that can be used to model adversary behavior for the identified scenario. The paper will also review candidate optimization, extrapolation, simulated annealing, and other techniques and heuristics that are being used to “tweak” adversary plans to maximize their effect at achieving both their primary objectives and key 2nd and higher order effects resulting from their actions. Additionally the paper will discuss our process for ranking plan effectiveness and the process for calibrating simulated plans with real-time C4I information.

6564-10, Session 3

An analysis of the effects of initial velocity errors on geometric pairing

B. C. Schricker, AT&T Government Solutions, Inc.; L. Ford, Icon Systems, Inc.

For a number of decades, among the most prevalent training media in the military has been Tactical Engagement Simulation (TES) training. TES has allowed troops to train for practical missions in highly realistic combat environments without the associated risks involved with live weaponry and munitions. This has been possible because current TES has relied largely upon the Multiple Integrated Laser Engagement System (MILES) and similar systems for a number of years for direct-fire weapons, using a laser to pair the shooter to the potential target(s). Emerging systems, on the other hand, will use a pairing method called geometric pairing (geo-pairing), which uses a set of data about both the shooter and target, such as locations, weapon orientations, velocities, and weapon projectile velocities, nearby terrain to resolve an engagement. A previous paper [1] introduces various potential sources of error for a geo-pairing solution. This paper goes into greater depth regarding the impact of errors that originate within initial velocity errors, beginning with a short introduction into the TES system (TESS). The next section will explain the modeling characteristics of the initial velocities of projectiles within a TESS followed by a mathematical analysis illustrating the impacts of errors related to those characteristics. A summary and conclusion containing recommendations will close this paper.

6564-11, Session 3

Real-time updates to the DSAP framework to improve calibration and dynamic situational awareness

R. M. McGraw, M. E. Valinski, RAM Labs.

RAM Laboratories is developing a more advanced real-time update capability for both the predictive and state-estimation features of its Dynamic Situational Awareness and Predictive Framework and its underlying Multiple Replication Framework in support of the Air Force Research Laboratory's Joint Synthetic Environment for Research and Development. The overall goal of the DSAP Infrastructure is to allow Commanders and their staff at Air Operations Centers the ability to perform "what-if" analysis of plans and alternatives "on-the-fly" while continually augmenting the real-time picture sensor inputs with simulated state-estimated assessments.

This paper will discuss design and implementation efforts to provide a Dynamic Situational Awareness capability utilizing embedded simulations calibrated by real-time C4I inputs to estimate the state of unobservable elements of an operational picture. Specifically this paper will discuss enhancements via a Calibrated Real-time Simulation component, a real-time simulation component along with the process for providing real-time updates to running simulations. The effort will also discuss the development of DSAP components that allow the infrastructure to connect to web-based data sources including T-Bone to extract track information. Additionally, this paper will discus steps being taken to host the DSAP environment in an exercise or live experimental environment.

6564-12, Session 3

Building and analyzing timed influence net models with internet-enabled pythia

P. W. Pachowicz, L. W. Wagenhals, J. Pham, A. H. Levis, George Mason Univ.

Timed influence nets have been used for course of action development, evaluation and selection in the context of effects based planning. A software implementation of this Bayesian Net modeling technique named Pythia has existed in stand alone mode and has been used in several case studies where the value of the tool and its underlying modeling and analysis technique has been demonstrated. As the software has matured, it became apparent that it will be more effective if it were to be used in a distributed testbed as part of a suit of tools for behavioral influence analysis. Consequently, the next version of the application, Pythia 1.5, was developed and brought into the state-of-the-art client-server computing environment. Pythia 1.5 is a server application for multi-user and multi-process computing. This server-centric application relies on the Citrix Presentation Server for integration, security and maintenance. Only the server computing power and the number of Citrix licenses limits the number of Pythia processes that can be open concurrently. While Pythia's process is run on a server, the input/output services are controlled and displayed through a client PC. Individual users need to obtain an account, install a free Citrix Presentation Server Client Component, and install a client-GUI. A web interface of the Citrix Presentation Server also allows users to login to the system and activate Pythia through any web browser. Current efforts on Pythia are focused on (1) a cross-application interfacing through model and data exchange mechanisms, and (2) its integration with an application suit of analyst tools. This version allows diverse users to develop models and maintain their own data bases while the developer can continue to enhance the capabilities of the tool.

The use of Pythia will be illustrated through its application to a specific problem concerning suppression of IED activity in an Iraqi province. The case study demonstrates how analysts can create executable (probabilistic) models that link potential actions to effects, based on knowledge about the cultural and social environment. Both the tool and the process for creating and analyzing the model are described as well as the benefits of using the new server based version of the tool.

6564-13, Session 4

Evolution of live training by the implementation of an electronic bullet

D. L. Fisher, J. Mann, T. Sherrill, M. Kraus, J. Lyons, A. York, Applied Research Associates, Inc.

In live force-on-force direct fire training, simulated munitions are used instead of live munitions. Simulated munitions are typically modeled using laser systems such as the Multiple Integrated Laser Engagement System (MILES). Replacing the laser with an electronic message (also known as an electronic bullet or e-bullet) sent over a network is becoming feasible due to advances in sensors, communications, and computing. The e-bullet engagement methodology uses weapon location, orientation, and adjudication algorithms. Technical challenges in implementation include having accurate weapon and target location and orientation, network bandwidth, and terrain database resolution. This paper discusses issues and challenges using an e-bullet and laser/e-bullet hybrids for delivery accuracy and damage assessment. We will also present an engagement methodology robust enough to evolve with advances in technology.

6564-14, Session 4

Architecture for an integrated real-time air combat and sensor network simulation

E. A. Criswell, J. A. Rushing, H. Lin, S. J. Graves, The Univ. of Alabama/Huntsville

An architecture for an integrated air combat and sensor network simulation is presented. The architecture ties together two components: a parallel real-time sensor fusion and target tracking simulation, and an air combat simulation. By integrating these two simulations, it becomes possible to experiment with scenarios in which one or both sides have very large numbers of primitive passive sensors, and to assess the likely effects of those sensors on the outcome of the battle. Modern Air Power is a real-time theater-level air combat simulation that is currently being used as a part of the USAF Air and Space Basic Course (ASBC). The simulation includes a variety of scenarios from the Vietnam war to the present day, and also includes several hypothetical future scenarios. Modern Air Power includes a scenario editor, an order of battle editor, and full AI customization features that make it possible to quickly construct scenarios for any conflict of interest. The scenario editor makes it possible to place a wide variety of sensors including both high fidelity sensors such as radars, and primitive passive sensors that provide only very limited information. The parallel real-time sensor network simulation is capable of handling very large numbers of sensors on a computing cluster of modest size. It can fuse information provided by disparate sensors to detect and track targets, and produce target tracks.

6564-15, Session 4

Applied cognition and training research to address emerging military requirements

D. M. Nicholson, L. Davis, C. M. Fidopiastis, Univ. of Central Florida

Modeling, Simulation and Training (MS&T) technologies have provided significant capabilities for Military training and mission rehearsal. However, most of the state-of-the-art MS&T systems used today are high fidelity, stand alone systems, routinely staffed by a team of support and instructional personnel. As the military becomes more reliant on these technologies to support ever changing concepts of operations, they are asking for numerous technological advancements including 1) automated instructional features to reduce the number of personnel required for exercises, 2) increased capability for adaptation of human computer interfaces to support individual differences and embedded performance support in operational settings, and 3) a continuum of low to high fidelity system components to provide embedded, deployable and transportable solutions. A multi-disciplinary team of researchers at the University of Central Florida's (UCF) Institute for Simulation and Training (IST) Applied Cognition and Training in Immersive Virtual Environments Lab (ACTIVE), lead by Dr. Denise Nicholson, is performing research and development to address these emerging requirements as part of on-going projects for Navy, Marine Corps and Army customers. In this paper we will discuss 1) designs for the use of agent technology to provide automated instructional support, 2) the use of our non-invasive, portable, Operational Neuroscience Sensing Suite (which includes eyetracking, EEG, fNIR and ECG/IBI) for advanced individualized performance measurement to drive future adaptive systems and 3) our prototype multi-fidelity MS&T tested which is being used to evaluate the effectiveness of laptop, portable and transportable systems to provide the "reality" required to train various Marine Corps skills.

6564-17, Session 5

Toward fully automated 3D scene reconstruction using decision-level fusion of remotely sensed data

M. C. Tarnowski, D. Warnaar, Applied Research Associates, Inc.

Improvements in remote sensing technology for the collection of high resolution aerial lidar and hyperspectal data of urban landscapes have lead to increasing interest in rapid scene reconstruction and environment inferencing. The data resolution required to accurately identify, extract, and reconstruct important features, which vary widely depending upon the application, emphasizes the need of an automated approach not relying on a human-in-the-loop. In recent years algorithmic strategies fusing aerial lidar with hyperspectral and orthorectified imagery have been proposed, taking advantage of inferencing capabilities of each sensor type and increased overall confidence in the data segmentation step. No technique exists today, however, that fully automates the end-to-end process - from the initial collection of the uncorrected data to the production of a finished, accurate and realistic urban scene. Notwithstanding, key milestones that minimize human intervention have been made, and notable high quality suites of semi-automated tools are available. In this paper, an end-to-end approach towards full automation of urban scene generation is presented. The paper discusses the advantages of decision-level fusion at each segmentation step after an initial hypothesis of the feature's classification has been made. The merit of such a strategy from the point of view of implementing it within a fully automated system supporting military planning and situational awareness is presented.

6564-18, Session 5

Experimental determination of key visibility modeling parameters for aircraft

S. R. Murrill, Army Research Lab.; B. S. Miller, T. Maurer, U.S. Army Night Vision & Electronic Sensors Directorate; W. K. Krebs, Office of Naval Research; G. Hewitt, U.S. Dept. of Transportation; R. G. Driggers, U.S. Army Night Vision & Electronic Sensors Directorate

The Federal Aviation Administration (FAA) is presently engaged in research to quantify the visibility of aircraft under two important scenarios: aircraft observed directly by human operators in air traffic control towers (ATCT's), and aircraft observed by human operators through unmanned aerial vehicle (UAV) sensors (cameras) viewed through ground-based display systems. In FY04 and FY05 an ATCT visibility analysis software tool (FAA Vis) was first developed and then enhanced by the U.S. Army Research Laboratory (ARL) in collaboration with the U.S. Army's Night Vision and Electronic Sensors Directorate (NVESD), and the FAA. In FY05, a baseline version of a UAV See-And-Avoid visibility analysis software tool was developed by the ARL, again in collaboration with NVESD and the FAA. As a first step toward validation of these models, experimental determination of key visibility calibration parameters such as the field-of-view (FOV) search-time equations, the target (aircraft) discrimination difficulty criteria (N50 for detection, recognition, and identification), and the proper characteristic dimension(s) for (high-aspect-ratio) targets (aircraft), is required. This paper will report on the results of a human perception (HP) experiment designed to measure both human response time and detection accuracy to displayed images containing variably-sized, scale-model, target (aircraft) images synthetically placed into real sky or terrain backgrounds at random locations within the FOV as a function of background clutter level. Determination of these critical parameters will serve to calibrate the UAV See-And-Avoid visibility analysis tool. A second HP experiment designed to calibrate the FAA Vis ATCT visibility analysis tool will be reported on at a later date. Both visibility analysis tools are currently available for preliminary use online \@ www.hf.faa.gov/visibility.

6564-19, Session 5

Automating ground-fixed target modeling with the smart target model generator

D. A. Verner, Applied Research Associates, Inc.; R. C. Dukes, Air Force Research Lab.

The Air Force Research Lab, Munitions Directorate, Lethality and Vulnerability Branch (AFRL/MNAL) is tasked with providing expeditious weapons effectiveness analyses of several weapons concepts against various types of buildings that may be potential target types. The building model must be generated before weapon effectiveness analysis can be performed against ground-fixed target sets. Existing target-modeling tools do not provide rapid target model generation necessary for the required quick turn-around lethality and vulnerability weapon effectiveness simulations.

In response to this need, AFRL/MNAL, under a small business innovative research phase II contract developed a 3-D modeling tool that will allow users to rapidly generate building models for weapon assessment analysis. This tool is called the Smart Target Model Generator (STMG). The STMG is a graphical tool that will allow users to quickly and automatically generate buildings that can be analyzed by various types of weapon effectiveness analysis tools. The STMG will provide the structural engineering data in addition to the geometry of the target that is required by various weapon effectiveness codes. This paper will present information on STMG and how it will assist the user to rapidly generate target models for lethality and vulnerability assessments.

6564-20, Session 6

Developing Markov chain models for road surface simulation

W. B. Israel, J. B. Ferris, Virginia Polytechnic Institute and State Univ.

Chassis loads and vehicle handling are primarily functions of the characteristics of the road surface over which a vehicle is traversing. By accurately measuring the geometries of road surfaces, one can generate computer models that will better predict the loads introduced to various vehicle components as well as have a more realistic model by which to determine vehicle response to the surface over which it is traveling. However, the logistics and computational power necessary to handle such large data files makes this problem a difficult one to resolve, especially when vehicle design deadlines are impending. We aim to improve this process by developing Markov Chain models by which all relevant characteristics of road surface geometries will be present in the model. This will reduce the logistical difficulties that are presented when attempting to collect data and run a simulation using physical data that was intentionally collected for a specific simulation. We will generate our models primarily by measuring road profiles of highways in the United States. Any synthetic road realized from a particular model is representative of all profiles in the set from which the model was derived. Realizations of any length can then be generated; allowing efficient simulation and timely information about chassis loads that can be used to make better informed design decisions, more quickly.

6564-21, Session 6

Development of a 3D terrain measurement system

J. V. Kern, Virginia Polytechnic Institute and State Univ.

The ability to measure road profiles accurately has progressed over the last four decades from response type systems to vehicle independent systems. General Motors Research developed direct measurement of road profiles in the 1960's using a road-following wheel extending below the body of a host vehicle to measure the relative distance between the body and the road surface and an accelerometer to calculate the absolute body motion. The Australian Road Research Board (ARRB) substituted a laser for the road-following wheel in 1987. Although a great deal of work has been done to refine these systems in the past 20 years, the work developed in this paper is the first to break from these established techniques. The system developed in this work establishes a new level of fidelity, resolution, and applications in terrain measurement. First, the system is developed for both highway applications and off-road terrain. Current road profiling systems are only suited for highway applications. Second, the system is capable of measuring terrain in three dimensions, on a grid of approximately 5mm in the horizontal plane, over a width of 4 meters. Third, the longitudinal distance traveled is now calculated with 2 cm accuracy, even over long trials of 10 km or more. It is only by increasing the fidelity and resolution of terrain topology data that application of these data can be advanced. This system is an enabling technology to pursue more advanced terrain modeling analyses and applications such as and 3-D tire models and terramechanics. Ultimately, the knowledge of how the data are acquired can lead to insights into advanced applications of the data.

6564-22, Session 6

Characterizing 2D road profiles using ARIMA modeling techniques

J. V. Kern, J. B. Ferris, Virginia Polytechnic Institute and State Univ.

Load data representing severe customer usage is needed throughout a chassis development program; the majority of these chassis loads originate with the excitation from the road. These chassis loads are increasingly derived from vehicle simulations, however simulating a vehicle traversing long roads is impractical and a method to produce short roads with given characteristics must be developed. There are many methods currently available to characterize roads when they are assumed to be homogeneous. This work develops a method of characterizing non-stationary road profile data using ARIMA (Autoregressive Integrated Moving Average) modeling techniques. The first step is to consider the road to be a realization of an underlying stochastic process. Next, non-stationary measured road profile data is transformed by differencing to create a stationary process. The order of the autoregressive model is then determined utilizing the sample autocorrelation and partial autocorrelation functions. The adequacy of the model is evaluated through statistical diagnostic checks performed on synthetic data generated by the autoregressive model parameters. Finally, the generated data is integrated to return a synthetic road profile. The use of the ARIMA model parameters in classifying road profiles is also discussed. By classifying various road profiles according to given model parameters, a tool is created in which a user can easily select a type of road to simulate. Any synthetic road realized from a given class of model parameters will represent all roads in that set, resulting in a timely and efficient simulation of a vehicle traversing any given type of road.

6564-23, Session 6

Analysis and estimation of vehicle position measurement in a 3D terrain scanning system

S. M. Wagner, J. B. Ferris, Virginia Polytechnic Institute and State Univ.

During the development of an automotive chassis, load data representing severe customer usage is needed to test the vehicle. The majority of these loads originate form the excitations of the vehicle from the road. Therefore, for modeling purposes, a well defined terrain profile is needed. Currently, terrain profiling technology includes the use of vehicle mounted lasers to acquire the topological data. In such systems, the profile data is measured relative to the laser's moving reference frame as the vehicle traverses the terrain. This necessitates the removal of the vehicle's body motion from the laser acquired data. This work examines one such 3-D terrain measurement system in which several sensors are used to approximate the vehicle's motion. Differential GPS and an inertial measurement unit (IMU) located at the vehicle's center of mass are typically combined using a Kalman filter. This technique is examined when additional accelerometers are placed at the location of the laser. This data is then used to cancel out the body motion of the vehicle using common mode rejection. This work examines the methodology of combining the GPS, IMU, and accelerometer solutions into a best estimate of the vehicle's true pitch and roll.

6564-24, Session 7

The development of an assessment tool for predicting the mobility of lightweight autonomous vehicles on coastal terrain

M. E. Worley, R. Ping, C. Sandu, D. W. Hong, Virginia Polytechnic Institute and State Univ.

The assessment of lightweight vehicles is hampered by the lack of analysis tools. Comparing the mobility of robotic vehicles with various means of locomotion is even more challenging due to specific vehicle-terrain interaction and mission goals. This study focuses on the development of an assessment tool for the performance prediction of lightweight autonomous vehicles with different locomotion platforms on coastal terrain. It consists of: (1) the development of a comparison matrix and indexing function, (2) modeling and development of novel forms of locomotion, (3) physical experimentation of lightweight tracked and wheeled vehicles on sand.

A statistical analysis based on the House of Quality is performed to identify the relationships between mission profile requirements, general performance measures, and vehicle configuration. This information, combined with known values for vehicle metrics, is used to obtain an index formula to quantitatively compare the mobility of a user-chosen set of vehicles, regardless of their methods of locomotion.

For experimental analysis, several new autonomous vehicles with novel forms of locomotion are under development. Dynamic models and prototypes provide the information needed to compare them with traditional wheeled and tracked vehicles.

To evaluate the applicability of current terramechanics models on light, robotic vehicles, a series of experimental tests has been designed. The running support for these tests is sand with different gradations, at various levels of moisture.

The statistical analysis, the design, and the experimental components of this study combine to provide useful insights in understanding and quantifying the mobility of lightweight vehicles operating on deformable terrain.

6564-25, Session 7

Using multibody simulation to evaluate armor impacts on military vehicle automotive performance

D. D. Gunter, U.S. Army Research, Development and Engineering Command

The ongoing effort in South West Asia has driven the Army to add armor to tactical and material handling vehicles that did not have an armor requirement when procured. This paper describes a Modeling and Simulation (M&S) effort undertaken at the US Army Research Development and Engineering Command's Tank Automotive Research, Development and Engineering Center (TARDEC) to investigate the impact adding armor has on these vehicles' automotive performance. We describe efforts to quantify performance degradation and identify safe operational limits, as well as experiments performed using the computer models to identify vehicle characteristics and suspension parameters that have the greatest impact on vehicle performance changes due to the addition of armor. Also design parameter trade-offs between lateral stability and ride quality influences, and efforts to balance these trade-offs to arrive at an optimum configuration are described.

6564-26, Session 7

Acoustic response modeling of energetics systems in confined spaces

D. R. Gonzalez, M. J. Sanford, Naval Surface Warfare Ctr.; W. Liou, Western Michigan Univ.; R. Hixon, Univ. of Toledo

Urban warfare presents many challenges to the warfighter. Among these is the fact that urban terrains add a degree of confinement in which the use of energetics systems like small, shoulder-mounted rocket launchers could pose as much hazard to the warfighter as the enemy. Currently, it is of interest to design a shoulder-mounted energetics system capable of being fired within the confines of a closed room with windows. The concern comes in the decibel levels the warfighter is exposed to while launching within such a room. These levels are well beyond those a human ear can withstand without causing severe hearing damage. Hence, the goal of the final design is to have a system that generates sound levels tolerable with minimal hearing protection.

To aid in the design of such a system, a computational aeroacoustics code's turbulence modeling capabilities have been modified to allow such a system to be modeled. In particular, the k-epsilon model implemented in the code had to be modified with an additional density term in order to compensate for the large-density gradients inherent in the launcher's exhaust jet. Additionally, an extensive database of actual rocket motor firings was used to develop realistic inflow profiles to the code. With these, the contributions to the perturbed pressure (acoustic) field from the gas exhaust and the projectile round were modeled separately. These results were then super-imposed to obtain an overall pressure-disturbance field which was post-processed with the use of a Fast-Fourier Transform to obtain pressure spectra to compare to actual test data.

6564-27, Session 7

Modeling of space shuttle SRB aft ends for inherent aerodynamic bias determination

D. R. Gonzalez, T. J. Gebhard, Naval Surface Warfare Ctr.; S. P. Stapf, U.S. Air Force

The Range Safety System (RSS) onboard the Space Transportation System provides the ability to partially destruct the solid rocket boosters (SRBs) during launch mishaps. This partial destruction brings about thrust termination, allowing the orbiter to separate from the thrusters and glide safely to an alternate landing field. The destruct action creates a large explosive debris footprint which may pose risks to the public and workers. The majority of this risk comes from the aft ends of the SRBs, which fall largely intact along with the remaining propellant. Historically, no data on such a scenario has been available and in support of the Space Shuttle Return-to-Flight schedule, aerodynamic and trajectory analyses were performed to characterize any pitch angle biases associated with the aft end's descent after initiating the linear shaped charges (LSCs) on the SRBs. It is important to note that this study makes no conclusions on the explosive yield characteristics of these aft ends as they impact ground. Further tests would be necessary to assess these characteristics. The study was conducted in three phases. First, a density-corrected, parametric solid model of the SRB aft ends was developed. For simplicity, several internal fixtures, such as the thrust vectoring assemblies, were lumped into a single, density-accurate part at the proper location to allow for the mass properties to be as accurate as possible. CFD wind tunnel runs were then performed at various angles of attack and Mach numbers to simulate the aft ends reaching apogee at different configurations. It was found that, at the subsonic speeds of interest, the aft ends were quite insensitive to Mach number. Finally, the findings from the initial phases were incorporated into a six-degree-of-freedom model. The model utilized classical dynamic equations and actual Space Shuttle trajectory data to simulate RSS initiation at different Mission Elapsed Times. Results show the aft end has a bias towards impacting at ±5, 70, or 175 degrees and takes an average of 10 seconds to stabilize into any one of these orientations after being separated from the SRB forward body.

6564-16, Session 8

Survey of contemporary aircraft flight dynamics models for use in airspace simulation

S. M. McGovern, John A. Volpe National Transportation Systems Ctr.

The U.S. DOT Volpe National Transportation Systems Center (Volpe Center) has been tasked with the development of a Government-owned, Monte Carlo-based computer simulation capability to enable rigorous analysis and certification of procedures, equipment, and airspace. Unique elements of this capability are the stochastic (i.e., random, but with known probability distributions) models of almost every component of the airpace - mechanical, electronic, and human - including navigation aids, surveillance systems (such as radar), pilots, aircraft, air traffic controllers, and weather; combined with known, discrete artifacts such as runway size and configuration, and obstacles. Due to the complexity, size, schedule, and aviation safety-critical nature of the simulation development effort, the Volpe Center has proposed a detailed survey of the current state-of-the-art in aircraft flight dynamic models for use in the simulation. This flight dynamics survey includes descriptions of basic 3-D performance envelopes of various aircraft (e.g., acceleration, deceleration, turn rate, climb rate), high-fidelity models (such as proprietary aircraft manufacturer models), commercial-off-the-shelf models (e.g., Laminar Research's "X-Plane" and Microsoft's "Flight Simulator"), Government models (i.e., NASA or FAA), and originally developed mathematical models (i.e., six degrees of freedom or 6DOF - providing x, y, and z (i.e., horizontal, vertical, and height), and pitch, roll, and yaw roll data - models using standard aircraft dynamics through implementation of the classical aircraft equations of motion, quaternion transformation methods, direct cosine Euler transformations, and non-dimensional aerodynamic coefficient implementation).

6564-28, Session 8

Modeling of microstructure evolution during LENS(TM) deposition

L. Wang, H. El-Kadiri, S. Felicelli, P. T. Wang, Mississippi State Univ.; B. R. Gady, U.S. Army Tank-automotive and Armaments Command

Laser Engineered Net Shaping (LENSTM) is a technology proven to be capable of repairing and fabricating complex components made from difficult-to-process materials without compromising the parent material properties. The LENS process is a direct metal deposition technology used to produce near net-shape metal parts directly from computer-generated designs. The thermomechanical properties of the as-deposited metal, however, are highly sensitive to the process parameters and can be unacceptable due to an inadequate understanding of the material behavior. To fully achieve the original one-step fabrication attribute of the LENS process, the process parameters must be optimized. Modeling and simulation methods have the potential to effectively optimize the LENS process. In this paper, a metallurgical model for microstructural evolution in low alloy steel laser deposits was developed by applying the coupled thermodynamics and kinetics approach, incorporated in the DICTRA program. The model predicts austenite grain size and volume fraction of the solid phases as a function of the material composition and heat input. For phase transformation, the model captures nucleation and growth mechanisms with physical distinction between displacive and reconstructive processes. A three-dimensional finite element thermal model based on the finite element software SYSWELD was developed to calculate the complex thermal history and as such map the microstructural transformations upon each overlaying deposition. The combined use of the thermal and metallurgical models provides useful information on how to control the process parameters and produce LENS deposits with improved qualities.

6564-29, Session 8

Design and modeling of prognostics and self-maintenance systems for military applications and future combat systems

J. Lee, M. Ghaffari, H. Wang, L. Yang, R. Allemang, T. C. Lim, Univ. of Cincinnati

The paper presents recent research advances on advanced prognostics and self-maintenance systems as well as its impacts to future combat vehicles systems. Technical approach used to evaluate and optimize prognostics tools to improve the predictability of reliability degradation of the critical components in the combat vehicles will be discussed. In addition, required infrastructure for implementation of intelligent network of combat vehicles will be examined.

A predictive maintenance network combined with a decision support system will provide critical maintenance information for decision making. The fleet readiness information, as well as maintenance priorities, will provide valuable information for logistic personnel and combat commanders. In a smart network system this information will be processed automatically, will be up-to-date, and remotely available. In addition to maintenance cost incentives, the smart network will play a critical role in success of combat units and saving lives of military personnel.

6564-30, Session 8

Modeling and simulation of a VTOL UAV for landing gear performance evaluation

B. J. Chan, C. Sandu, Virginia Polytechnic Institute and State Univ.; T. Streett, A. Ko, AVID LLC

A multibody dynamics model of a Vertical Take-off and Landing (VTOL) Unmanned Aerial Vehicle (UAV) is presented in this study. The scope of the project was to investigate a lightweight landing gear which has a stable and robust landing performance. Two original designs of the landing gear for the module of interest have been modeled and analyzed in this study. Two new designs have also been developed, modeled, and analyzed. A limited analysis of the forces that occur in the legs/struts has also been performed, to account for possible failure of the members due to buckling.

The model incorporates a sloped surface of deformable terrain for stability analysis of the landing scenarios, and unilateral constraints to model the ground reaction forces upon contact. The lift forces on the UAV are modeled as mathematical relations dependent on the speed of the ducted fan to enable the variation of the impact velocities and the different landing scenarios.

The simulations conducted illustrate that initial conditions at landing have a big impact on the stability of the module. The two new designs account for the worst possible scenario, and, for the material properties given, end with a larger weight than the one of the original design with three legs and a ring. Simulation data from several landing scenarios are presented in this paper, with analysis of the difference in performance among the different designs.

6564-31, Session 8

Emissive signature for HMMWV run flat insert modeling and simulation

W. W. Gardetto, Drive Dynamics LLC; D. J. Gorsich, A. Kurec, J. R. Mabesa, Jr., D. Murray, U.S. Army Tank-Automotive Research, Development and Engineering Ctr.

Analyzing thermodynamic patterns during product development can easily be characterized by various “Modeling and Simulation” software programs to observe and identify an Emissive Signature. An infrared spectrum distinguishes pattern profiles unique to the product for both thermodynamic performance and accurate verification on

selected materials. A collaborative CRADA effort has been established between the US Army RDECOM-TARDEC and Drive Dynamics LLC of Dallas, TX on the development of an advanced Run Flat Insert System for military wheeled vehicles. Mapping of measured infrared thermometer values help in locating and determining whether or not material temperatures are within design limits. Prior testing by the US Army Physical Simulation Team have established a baseline Emissive Signature for HMMWV wheel assemblies at specific loads and speeds. As advanced Run Flat Insert Systems are developed for increased load capacities using structurally engineered profiles the Emissive Signature can be used to compare and aid in establishing performance and product longevity.

6564-32, Session 9

Modeling and simulation for small system integration of military and homeland security applications

M. J. Bennahmias, V. Esterkin, K. Lee, R. Kogiol, A. A. Kostrzewski, T. P. Jannson, Physical Optics Corp.

For this paper, a highly productive approach to small system integration (SSI), and modeling and simulation (M&S), based on rapid/interactive prototyping is discussed that has been effectively used at Physical Optics Corporation (POC) to support small system development covering a broad range of electromagnetic spectra (x-ray, optical, IR, and microwave). In particular, how the implementation of an interactive prototyping environment produces effective engineering solutions for tackling difficult and complex technical issues for combining 3D mechanical design and microwave engineering will be discussed. Moreover, for this type of interactive engineering environment how collective input at the start of a development effort from a diverse range of areas like optics, mechanics, electronics, software, thermal modeling, electromagnetism, surface chemistry, and manufacturing plays an important role in the success of a project will also be discussed.

6564-33, Session 9

A mixed simulation and hardware-in-the-loop controller for autonomous sensing and navigation by unmanned air vehicles

G. E. Collins, P. E. Vegdahl, Toyon Research Corp.

This paper describes our recent work combining a high-fidelity battlefield simulator, a suite of autonomous sensor and navigation control algorithms for unmanned air vehicles (UAVs), and a hardware-in-the-loop control interface. The complete system supports multiple real and simulated UAVs that search for and track multiple real and simulated targets.

Targets communicate their real-time locations to the simulator through a wireless GPS link. Data for real target(s) is used to create target(s) in the simulation testbed that may exist alongside additional simulated targets. The navigation and video sensors onboard the UAVs are tasked (via another wireless link) by our control algorithm suite to search for and track targets that exist in the simulation. Video data is streamed to an image plane video tracker (IPVT), which produces detections that can be fed to a global tracker within the control suite. Routing and gimbal control algorithms use information from the global tracker to task the UAVs, thus completing an information feedback control loop. Additional sensors (such as the ground moving target indicator (GMTI) radar) can exist within the simulation and generate simulated detections to augment the tracking information obtained from the IPVT.

Our simulator is part of Toyon’s Simulation of the Locations and Attack of Mobile Enemy Missiles (SLAMEM?) tool. SLAMEM? contains detailed models for ground targets, surveillance platforms, sensors, attack aircraft, UAVs, data exploitation, multi-source fusion, sensor retasking, and attack nomination. SLAMEM models road networks, foliage cover, populated regions, and terrain, using the terrain elevation data (DTED).

6564-34, Session 9

Testbed for distributed scenario simulations with EW and its effects on C2

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The paper will present a simulation testbed in which a scenario can be setup, simulated and evaluated and where planning tools, electronic warfare (EW) components and command and control (C2) functionality can be integrated. The testbed is HLA (high level architecture) compliant, allows for a distributed simulation with dynamically configurable federates, and can also be used for testing actual equipment in a simulated scenario. One of the key components in the testbed is a set of planning tools that can be used to show ranges for sensors, jamming and communication systems. These tools can be used not only for planning the mission (e.g. best route) but can also be used during the mission to show the location of possible threats or the range of own equipment (sensor, jamming, communication) in different situations. During a mission these tools can be used to support the decisions of what actions to take in different situations. One goal with developing the planning tools in the testbed is to learn how to use planning tools in real life scenarios. Therefore, the planning tools are constantly developed and tested with respect to technical and tactical use. Also technical and tactical aspects of current and future EW and C2 equipment can be tested and developed in the testbed.

6564-35, Session 9

An integrated development environment for PMESII model authoring, integration, validation, and debugging

N. J. Pioch, C. L. Lofdahl, M. Sao Pedro, B. Krikeles, L. Morley, BAE Systems Advanced Information Technologies

To foster shared battlespace awareness in Air Operations Centers supporting the Joint Forces Commander and Joint Force Air Component Commander, BAE Systems is developing a Commander's Model Integration and Simulation Toolkit (CMIST), an Integrated Development Environment (IDE) for model authoring, integration, validation, and debugging. CMIST is built on the versatile Eclipse framework, a widely used open source Java IDE, and leverages software engineering standards and ontology-based tools for model representation and exchange. CMIST provides two distinct layers: 1) a Commander's IDE for supporting staff to author models spanning the Political, Military, Economic, Social, Infrastructure, Information (PMESII) taxonomy; integrate multiple native models; validate model interfaces and outputs; and debug the integrated models via intuitive controls and time series visualization, and 2) a PMESII IDE for modeling and simulation developers to rapidly incorporate new native simulation tools and models to make them available for use in the Commander's IDE. The PMESII IDE provides shared ontologies and repositories for world state, modeling concepts, and native tool characterization. CMIST includes extensible libraries for 1) reusable data transforms for semantic alignment of native data with the shared ontology, and 2) interaction patterns to synchronize multiple native simulations with disparate modeling paradigms, such as continuous-time system dynamics, agent-based discrete event simulation, and aggregate solution methods such as Monte Carlo sampling over dynamic Bayesian networks. This paper describes the CMIST system architecture, our technical approach to addressing these semantic alignment and synchronization problems, and initial results from integrating Political-Military-Economic models of post-war Iraq spanning several modeling paradigms.

6564-36, Session 9

Modeling multiple communities of interest for interactive simulation and gaming: the dynamic adversarial gaming algorithm project

Q. Zhao, E. Santos, Jr., Dartmouth College; F. Pratto, A. R. Pearson, Univ. of Connecticut; B. R. McQueary, A. Breeden, L. S. Krause, Securboration

Nowadays, there is an increasing demand for the military to conduct operations that are beyond traditional warfare. In these operations, analyzing and understanding who are involved in the situation, how they are going to behave, and why they behave in certain ways is critical for success. The challenge lies in that behavior does not simply follow universal/fixed doctrines; it is significantly influenced by soft factors (i.e. cultural factors, societal norms, etc.). In addition, there is rarely just one isolated enemy; the behaviors and responses of all groups in the region, and the dynamics of the interaction among them composes an important part of the whole picture. The Dynamic Adversarial Gaming Algorithm (DAGA) project aims to provide a wargaming environment for automation of simulating dynamics of geopolitical crisis and eventually be applied to military simulation and training domain, and/or commercial gaming arena. The focus of DAGA is on modeling communities of interest (COIs), where various individuals, groups, and organizations as well as their interactions are captured. The framework should provide a context for COIs to interact with each other and influence others' behaviors. These behaviors must incorporate soft factors by modeling cultural knowledge. We do so by representing cultural variables and their influence on behavior using probabilistic networks. In this paper, we describe our COI modeling, the development of cultural networks, the interaction architecture, and a prototype of DAGA. This effort is supported in part through the Air Force Office of Scientific Research project's on DAGA and cultural modeling of adversarial behavior.

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6565-01, Session 1

Hyperspectral anomaly detection beyond RX

A. P. Schaum, Naval Research Lab.

The basic multivariate anomaly detector ("the RX algorithm") of Kelly and Reed remains little altered after nearly 30 years and performs reasonably well with hyperspectral im-agery. Better performance can be achieved in spectral applications by recognizing a defi-ciency in the RX-generating hypothesis test. The problem is commonly ameliorated by deleting several high-variance clutter dimensions. However, there is a better way than removing the offending subspace. Differences between target and background signals in the clutter dimensions can be exploited to enhance discrimination. Two methods are dis-cussed for achieving detection gain using this principle. One evolves the RX algorithm to incorporate clutter-dependent weights, including "anti-RX" terms in the clutter subspace. The exact form of the detector can be derived from a simple modification of the common anomaly hypothesis test. The second involves the nonlinear suppression of false alarms caused by identifiable clutter detections. Both techniques rely ultimately on the incorpo-ration of simple spectral phenomenology into the detection process.

6565-02, Session 1

Beyond the adaptive matched filter: nonlinear detectors for weak signals in high-dimensional clutter

J. Theiler, B. Foy, A. M. Fraser, Los Alamos National Lab.

For known signals that are linearly superimposed on gaussian backgrounds, the linear adaptive matched filter (AMF) is well-known to be the optimal detector. The AMF has furthermore proved to be remarkably effective in a broad range of circumstances where it is not optimal, and for which the optimal detector is not linear. In these cases, nonlinear detectors are theoretically superior, but direct estimation of nonlinear detectors in high-dimensional spaces often leads to flagrant overfitting and poor out-of-sample performance. Despite this difficulty in the general case, we will describe several situations in which nonlinearity can be effectively incorporated into a weak signal detector. A unifying theme among these nonlinear detectors is that they can be described using the AMF as a first component. This allows improvement over AMF performance while avoiding the full force of dimensionality's curse.

6565-03, Session 1

A comparative study of linear and nonlinear anomaly detectors for hyperspectral imagery

N. M. Nasrabadi, Army Research Lab.; H. Goldberg, Univ. of Maryland/College Park

In this paper several linear and nonlinear anomaly detectors are implemented and their results are compared. At each pixel location we use a dual window to separate the local area into two regions — the inner-window region (IWR) and the outer-window region (OWR). The size of the dual window is set such that the inner window encloses a target-sized region and the outer window includes its neighboring background. We then exploit the differences of the statistical features between the IWR and OWR to check whether the inner materials (pixels) are substantially different than the neighboring materials. Based on the means and covariance matrixes of the IWR and OWR, a projection vector is generated in the original input domain as well as in a high dimensional feature space through the use of kernel-based learning algorithms. The spectral mean vectors in the IWR and OWR are then projected onto the linear projection operator as well as its nonlinear version so called kernel-based projection operator. The direction of the projection vector is determined such that the projected values of the IWR and OWR mean vectors are well separated. Anomalies are detected if the separation of the projected values is greater than a predefined threshold.

We have used four different methods to calculate the projection vector.

i) Eigen separation transform (EST) and Kernel EST:

A difference covariance matrix (DCOV) is calculated within the dual window by subtracting the covariance matrix of the OWR vectors from that of the IWR vectors. The eigenvector of DCOV associated with the largest positive eigenvalue is used as the projection vector.

ii) Principal component analysis (PCA) and Kernel PCA: The first eigenvector of either the IWR or the OWR vectors is used as the projection vector.

iii) Fisher linear discriminant (FLD) and Kernel FLD: The projection vector is the Fisher basis vector that maximizes the between-class scatter and minimizes the within-class scatter simultaneously.

iv) Reed-Xiaoli algorithm (RX) and Kernel RX: The mean-difference vector between the IWR and OWR is normalized by the covariance matrix of the background pixel vectors (OWR vectors) and then used as the projection vector.

The anomaly detectors based on the above methods have been applied to the HYDICE (HYperspectral Digital Imagery Collection Experiment) and mine images and detection performance for each method has been generated. Performance comparison (ROC curves) of the four methods will also be included in the full paper.

6565-04, Session 1

Adaptive constrained signal detectors for hyperspectral images

S. E. Johnson, Lockheed Martin Coherent Technologies; M. T. Eismann, Air Force Research Lab.; S. C. Cain, Air Force Institute of Technology

An algorithm called the constrained signal detector (CSD) was recently introduced for the purpose of target detection in hyperspectral images. The CSD assumes that hyperspectral pixels can be modeled as linear mixtures of material signatures and stochastic noise. It has been shown to be superior in theory than the orthogonal subspace projection (OSP) technique.

The CSD requires knowledge of the spectra of the background materials in the hyperspectral image. But in practice the background material spectra are often unknown and the CSD can not be implemented. In this paper, estimation techniques are used to create an adaptive version of the CSD. This adaptive algorithm uses training data to develop a description of the image background and adaptively implement the CSD. The adaptive CSD only requires knowledge of the target spectrum. It is shown through simulations that the adaptive CSD performs nearly as well as the CSD operating with complete knowledge of the background material spectra.

6565-05, Session 1

Anomaly detection in hyperspectral imagery: a comparison of methods using diurnal and seasonal data

P. C. Hytla, R. C. Hardie, Univ. of Dayton; M. T. Eismann, J. Meola, Air Force Research Lab.

The use of hyperspectral imaging (HSI) technology to support a variety of civilian, commercial, and military remote sensing applications, is growing. The rich spectral information present in HSI allows for more accurate ground cover identification and classification than with panchromatic or multispectral imagery. One class of problems where hyperspectral images can be exploited, even when no a priori information about a particular ground cover material is available, is anomaly detection. Here spectral outliers (anomalies) are detected based on how well each hyperpixel (spectral irradiance vector for a given pixel position) fits within some background statistical model. Spectral anomalies may correspond to areas of interest in a given scene. In this work, we compare several anomaly detectors found in the literature in novel experiments. In particular, we study the performance of the anomaly detectors in detecting several man-made painted panels in a natural background using visible/near-infrared hyperspectral imagery. The data have been collected over the course of a year, allowing us to test the robustness of the anomaly detectors with seasonal change. We also compare the performance of these detectors at various times of day, to study diurnal effects. The detectors considered include the simple Gaussian anomaly detector, a Gaussian mixture model (GMM) anomaly detector, and the cluster-based anomaly detector (CBAD). We examine the effect of the number of components for the GMM and the number of clusters for the CBAD. Our preliminary results suggest that the use of a GMM yields the best results for our data.

6565-06, Session 1

A theoretical framework for hyperspectral anomaly detection using spectral and spatial a priori information

B. Yver, R. Marion, Commissariat a l'Energie Atomique (France)

This study presents a new theoretical approach for anomaly detection using a priori information about the target. This a priori knowledge deals with the general spectral behavior and the spatial distribution of the target. This method is totally different to matched filters which suffer of a relative sensitivity to low errors in the target spectral signature. We incorporate the spectral a priori knowledge in a new detection distance and we propose a Bayesian approach with a markovian regularization to suppress potential targets that do not respect the spatial a priori. Gains of performances are illustrated on simulated data consisting in realistic anomalies superimposed on a real HyMap hyperspectral image.

6565-08, Session 2

The impact of initialization procedures on unsupervised unmixing of hyperspectral imagery using the constrained positive matrix factorization

Y. Masalmah, M. Vélez-Reyes, Univ. de Puerto Rico Mayagüez

The authors proposed in previous papers the use of the constrained Positive Matrix Factorization (cPMF) to perform unsupervised unmixing of hyperspectral imagery. Two iterative algorithms were proposed to compute the cPMF based on the Gauss-Seidel and penalty approaches to solve optimization problems. Results presented in previous papers have shown the potential of the proposed method to perform unsupervised unmixing in HYPERION and AVIRIS imagery. The performance of iterative methods is highly dependent on the initialization scheme. Good initialization schemes can improve convergence speed, whether or not a global minimum is found, and whether or not spectra with physical relevance are retrieved as endmembers. In this paper, different initializations using random selection, longest norm pixels, and standard endmembers selection routines are studied and compared using simulated and real data.

6565-10, Session 2

Hyperspectral target detection by using independent component analysis-based linear mixture model

E. Sarigul, M. S. Alam, Univ. of South Alabama

This paper presents Independent Component Analysis (ICA) based linear mixture unmixing for the purpose of a target detection application. ICA method has been relatively new method that attempts separate statistically independent sources from mixed dataset. The developed algorithm contains two steps - ICA based linear unmixing to discriminate statistically independent sources. This step determines both end-members in a given dataset as well as their corresponding abundance images. The second step performs analyzing unmixing results for target detection application to detect the abundance image that corresponds to target class. The performance of the developed algorithm has been evaluated with several hyperspectral image datasets and presented here. The preliminary results show that this method is promising new method for target detection.

6565-11, Session 3

A hyperspectral image projector for hyperspectral imagers

J. P. Rice, E. A. Dakin, S. W. Brown, R. R. Bousquet, J. E. Neira, M. Litorja, National Institute of Standards and Technology

We have developed and demonstrated a Hyperspectral Image Projector (HIP) intended for system-level validation testing of hyperspectral imagers, including the instrument and any associated spectral unmixing algorithms. HIP, based on the same digital micromirror arrays used in commercial digital light processing (DLP) displays, is capable of projecting any combination of many different arbitrarily programmable basis spectra into each image pixel at up to video frame rates. We use a scheme whereby one micromirror array is used to produce light having the spectra of endmembers (i.e. grass, water, minerals, etc), and a second micromirror array, optically in series with the first, projects any combination of these arbitrarily programmable spectra into the pixels of a 1024 x 768 element spatial image, thereby producing temporally-integrated images having spectrally mixed pixels. HIP goes beyond conventional DLP projectors in that each spatial pixel can have an arbitrary spectrum, not just arbitrary color. As such, the resulting spectral and spatial content of the projected image can simulate realistic scenes that a hyperspectral imager will measure during its use. Also, the spectral radiance of the projected scenes can be measured with a calibrated spectroradiometer, such that the spectral radiance projected into each pixel of the hyperspectral imager can be accurately known. Use of such projected scenes in a controlled laboratory setting would alleviate expensive field testing of instruments, allow better separation of environmental effects from instrument effects, and enable system-level performance testing and validation of hyperspectral imagers as used with analysis algorithms. For example, known mixtures of relevant endmember spectra could be projected into arbitrary spatial pixels in a hyperspectral imager, enabling tests of how well a full system, consisting of the instrument + calibration + analysis algorithm, performs in unmixing (i.e. de-convolving) the spectra in all pixels. We discuss here the performance of the HIP as applied to a laboratory hyperspectral imager working in the visible spectral range. The technology is readily extendable to the ultraviolet and infrared spectral ranges, and the scenes can be static or dynamic.

6565-12, Session 3

Sonification of hyperspectral image data

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There are many reconnaissance tasks which involve an image analyst viewing data from hyperspectral imaging systems and attempting to interpret it. Hyperspectral image data is intrinsically hard to understand, even when armed with mathematical knowledge and a range of current processing algorithms. This work is motivated by the search for new ways to convey information about the spectral content of imagery to people. In this work we have developed a tool for transforming different aspects of spectral imagery into sounds that an analyst can hear. Trials have been conducted that show that the use of these sonic mappings can assist a user in tasks such as rejecting false alarms generated by automatic detection algorithms. This paper describes some of the techniques used and reports on the results of user trials.

6565-13, Session 3

New developments and application of the UPRM MATLAB hyperspectral image analysis toolbox

S. Rosario-Torres, M. Vélez-Reyes, Univ. de Puerto Rico Mayagüez

The Hyperspectral Image Analysis Toolbox (HIAT) is a collection of algorithms that extend the capability of the MATLAB numerical computing environment for processing hyperspectral and multispectral imagery. HIAT provide information extraction algorithms such as as image enhancement, feature selection/extraction, abundance estimation, and classification, to users of hyperspectral and multispectral imagery in many domains. The toolbox is designed with a user friendly graphical user interface that enables ease of use by engineers, research and scientists from different domains. HIAT provides easy access from preprocessing routines to post processing routines algorithms developed at Laboratory of Applied Remote Sensing and Image Processing (LARSIP) over the last 10 years. This paper will give an update on the capabilities of the toolbox and its distribution capability. We will also present results of the application of the toolbox to hyperspectral information extraction in many domains.

6565-14, Session 3

A hyperspectral model for target detection

M. Bernhardt, Waterfall Solutions Ltd. (United Kingdom); P. E. Clare, Defence Science and Technology Lab. Farnborough (United Kingdom); C. E. West, M. I. Smith, Waterfall Solutions Ltd. (United Kingdom)

In this paper an end-to-end hyperspectral imaging system model is described. This model is able to predict the performance of hyperspectral imaging sensors in the visible through to the short-wave infrared regime for sub-pixel targets. The model represents all aspects of the system including the target signature and background, the atmosphere, the optical and electronic properties of the imaging spectrometer as well as details of the processing algorithms employed. It is efficient, allowing Monte-Carlo runs for sensitivity analysis or to sweep model parameters over a wide range. It is also capable of representing certain types of non-Gaussian hyperspectral clutter arising from heterogeneous backgrounds. The capabilities of the model are demonstrated in this paper by considering the effect that different levels of heavy-tailed non-Gaussian clutter have on both anomaly detection and spectral matched-filter algorithms in terms of Receiver Operating Characteristic curves. Finally, some results from a preliminary validation exercise are presented.

6565-15, Session 3

Hyperspectral data processing algorithm comparison software (HyperPACS)

D. Runnels, C. Leflore, Radiance Technologies, Inc.; J. J. Dirbas, PAR Government Systems Corp.

Radiance Technologies has developed and integrated a multispectral / hyperspectral data analysis toolbox into an easy to use operator interface. HyperPACS (Hyperspectral data Processing Algorithm Comparison Software) allows the data analyst to process spectral data in multiple input formats with many different spectral algorithms and/or different algorithm parameters and options. Results are compared to user supplied ground truth and Receiver Operating Characteristic (ROC) curves providing a direct comparison of algorithm performance are automatically generated. The HyperPACS GUI makes the software easy to use and the architecture readily allows for the integration of custom algorithms provided by the analyst. Radiance has used HyperPACS in the evaluation of hyperspectral and multispectral algorithms in support of an ongoing program. A description of HyperPACS, the GUI, and processing examples are given.

6565-16, Session 3

Visualization of hyperspectral imagery

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We developed and evaluated methods for visualizing hyper spectral data. The presentation techniques are of 3 types: i) movie type (displaying subsequent bands as a movie), ii) colour image (merging the data into three broadband channels and displaying these as a colour image) and iii) matching strength (displaying the similarity between the pixel signatures and a known target signature). The movie type (i) has the advantages that no assumptions about target signature are used and no information is lost. The colour scheme (ii) has the advantage that it can be displayed in a single image, so it can be used in real-time. Disadvantage is that some information is lost. A display of the match (iii) between pixels and a target can be interpreted easily and fast, but relies on precise knowledge of the target signature. Each scheme has its advantages and disadvantages and is more or less suited for real-time and post-hoc processing. The idea is that the final interpretation is best left to a human observer. In contrast to automatic target recognition systems the number of assumptions (signature of target and background, target shape etc.) can be small and the interpretation (by the human visual system) is robust to noise and image transformations, and takes target and background into account. When more knowledge about target and background (signature, shape etc.) is available this may be used to help the observer interpreting the data.

6565-17, Session 4

Spectral/spatial filter selection for illumination-invariant hyperspectral texture discrimination

N. Nejati, G. E. Healey, Univ. of California/Irvine

We propose a method for selecting an optimal spatial filter based on both spectral and spatial information to improve the discriminability of hyperspectral textures. The feature vector for each class contains the covariance matrix elements in filtered versions of the texture. The new method reduces the length of the representation by selecting an optimal subset of bands and also uses an optimized spatial filter to maximize the distance between feature vectors for the different texture classes. Band selection is performed based on the stepwise reduction of bands. We applied this method to a database of textures acquired under different illumination conditions and analyzed the classification results.

6565-18, Session 4

Applicability of ICA to hyperspectral imagery of various complexity levels

D. C. Koestler, P. J. Diute, D. W. Messinger, Rochester Institute of Technology

Several methods to characterize highly-dimensional reflective hyperspectral imagery have been developed and used for various applications. End-member selection schemes seek to define the “corners” of the assumed convex hull in which the data lie. Principle Components Analysis derives a rotation from the scene statistics to represent the data in a space in which the data are uncorrelated. Recently, Independent Components Analysis has been applied to hyperspectral imagery for several applications. We assume that the original source signals are independent but the data are linear combinations of these source signals. We investigate the viability of this approach to retrieve the original source signals. In this work, synthetic data of increasing levels of complexity are used to understand the applicability of ICA to hyperspectral imagery. Initial datasets use one and two classes of materials with in-class variability based on measured data. Further analysis is applied to multiple class datasets as well as data with varying levels of sub-pixel mixing. Results using one, two and multiple class datasets will be described.

6565-19, Session 4

From PCA and MNF to ICA: ERDAS IMAGINE incorporates next-generation remote sensing technology for improved spectral unmixing and target detection

C. A. Shah, Univ. of California/Los Angeles; I. Anderson, Z. Gou, S. Hao, A. Leason, Leica Geosystems, LLC

Analysis of multi/hyperspectral imagery necessitates a selection of an optimal subset of bands in order to avoid the Hughes phenomena and parameter estimation problems due to interband correlation. This can be achieved by employing feature extraction techniques for significant reduction of data dimensionality. From the perspective of statistical pattern recognition, feature extraction refers to a process, whereby a data space is transformed into a feature space, in which the original data is represented by a reduced number of effective features, retaining most of the intrinsic information content. Feature extraction from remote sensing imagery must also aim to enhance the discriminability of surface materials based on their spectral characteristics.

Conventional remote sensing feature extraction techniques such as Principal Component Analysis (PCA) and Minimum Noise Fraction (MNF) model the multi/hyperspectral image data with a multivariate Gaussian distribution. Inadequacy of such algorithms stems from the Gaussian distribution assumption, which is only an assumption rather than a demonstrable property of most remote sensing data. In order to overcome this fundamental limitation, we at Leica Geosystems have developed a feature extraction technique based on Independent Component Analysis (ICA) that exploits the higher order statistical characteristics of multi/hyperspectral imagery. ICA performs a linear transformation of the image data, such that the resulting transformed features are as statistically independent from each other as possible. A direct implication of making the features statistically independent is that they contain complementary information and thus enhance the discriminability of surface materials. Thus, compared to correlation based transformations such as PCA and MNF, ICA not only decorrelates the features but also reduces the higher order statistical dependencies between them.

In this paper, we will provide a theoretical formulation of ICA and prove its superiority over PCA and MNF in a mathematical framework. Our illustrations would also demonstrate the potential benefits of employing ICA in improving the performance of several multi/hyperspectral analysis techniques such as spectral unmixing, classification, and anomaly detection.

6565-20, Session 4

Integration of PCA and JPEG2000 for hypespectral image compression

Q. Du, W. Zhu, Mississippi State Univ.

In this paper, we report our recent investigation on principal components analysis (PCA) and JPEG2000 in hyperspectral image compression, where the PCA is for spectral coding and JPEG2000 is for spatial coding for principal component (PC) images (referred to as PCA+JPEG2000). We find out such an integrated scheme significantly outperforms the commonly used 3-dimensional (3D) JPEG2000 in rate distortion performance, where the wavelet transform is used for spectral coding. We also find out that the best rate distortion performance occurs when a subset of PCs is used instead of all the PCs. An empirical approach to estimate the sub-optimal number of PCs is presented.

In the AVIRIS and HYDICE experiments, PCA+JPEG2000 can bring about 5-10 dB increase in SNR compared to 3D-JEPG2000, whose SNR in turn is about 0.5dB greater than other popular wavelet based compression approaches, such as 3D-SPIHT and 3D-SPECK. The performance on detection and classification using the reconstructed data is also evaluated. We find out that using PCA for spectral decorrelation can provide better performance, in particular, in low bit rates. We will also present automatic algorithms to pre-remove noisy bands and pixels to further enhance the performance of PCA+JPEG2000.

6565-21, Session 5

New grating designs for a CTIS imaging spectrometer

N. A. Hagen, C. J. Vandervlugt, E. L. Dereniak, The Univ. of Arizona; D. T. Sass, U.S. Army Tank-automotive and Armaments Command

We present somenew grating designs for use in a computed tomographic imaging spectrometer (CTIS) and discuss their differences with previous gratings. One of the advantages of the new designs is that they provide added flexibility for a tunable CTIS instrument, and we show some preliminary data illustrating this advantage.

6565-22, Session 5

Reconfigurable liquid-crystal dispersing element for computed tomographic imaging spectrometer

C. J. Vandervlugt, The Univ. of Arizona; H. J. Masterson, Boulder Nonlinear Systems, Inc.; N. A. Hagen, E. L. Dereniak, The Univ. of Arizona

A Computed Tomographic Imaging Spectrometer (CTIS) is an imaging spectrometer which can acquire a multi-spectral data set in a single snapshot (one focal plane array integration time) with no moving parts. Currently, CTIS instruments use a specially designed computer generated hologram (CGH) to disperse the light from a given spectral band into a grid of diffraction orders. The capabilities of the CTIS instrument can be greatly improved by replacing the static CGH dispersing element with a reconfigurable liquid crystal spatial light modulator. The liquid crystal spatial light modulators are tuned electronically, enabling the CTIS to remain a non-scanning imaging spectrometer with no moving parts. The ability to rapidly reconfigure the dispersing element of the CTIS allows the spectral and spatial resolution to change by varying the number of diffraction orders, diffraction efficiency, etc. In this work, we present the initial results of using a fully addressable, 2-D liquid crystal spatial light modulator as the dispersing element in a CTIS instrument.

6565-23, Session 5

Affordable spectro-polarimetry with MANTIS-3T

J. J. Dirbas, A. Davies, PAR Government Systems Corp.; J. S. Schoonmaker, Advanced Coherent Technologies LLC; G. R. Gilbert, U.S. Army MRMC and TATRC; V. M. Contarino, Naval Air Systems Command

PAR Government Systems Corporation (PAR) with Advanced Coherent Technologies, LLC (ACT) has developed affordable, narrow-band polarimetry sensor hardware and software based upon the PAR Mission Adaptable Narrowband Tunable Imaging Sensor (MANTIS). The sensor has been deployed in multiple environments, polarimetric imagery of the clear blue sky and the sea surface has been collected. In addition, a significant amount of calibration data has been collected to correctly calibrate the sensor for Stokes Vector imaging. Data collected with the MANTIS polarization sensor has been compared to modeled data. The sensor hardware and software, collected calibration data, and comparison to the developed model are presented.

6565-24, Session 5

Narrowband polarization in maritime imaging

J. S. Schoonmaker, Advanced Coherent Technologies LLC; J. J. Dirbas, A. Davies, PAR Government Systems Corp.; Y. Podobna, I. Petrosuk, Advanced Coherent Technologies LLC; V. M. Contarino, Naval Air Systems Command; G. R. Gilbert, U.S. Army MRMC and TATRC

Narrow band simultaneous polarization imagery was collected over water from the Coronado Bay Bridge in San Diego, Ca. The objective of the test was to quantify the importance of polarization sensitivity in through water imaging systems, to determine the utility of an adaptive linear polarization analyzer in through water imaging and to demonstrate some of the capabilities of the PGSC/ACT MANTIS imaging system. The MANTIS (Multimission Adaptive Narrowband Imaging Sensor) system was configured to collect four simultaneous linear polarization each 45 degrees apart. All polarization channels were collected through a 550 nm interference filter with 40 nm band pass. Elevation scans from the 70 m bridge made at various azimuthal angles as well as azimuthal scans at various elevation angles. In addition elevation scans were made both up and down looking to calculate the sea water Mueller matrix.

6565-25, Session 5

Laser-based multispectral polarimetric imaging

Y. Wang, Y. Wang, B. Hu, H. Q. Le, Univ. of Houston

Laser-based multi-spectral imaging allows measuring target intrinsic optical scattering properties rather than just the scattered ambient light intensity from targets like passive imaging. The resulting image is a mapping of the target scattering optical response as a function of wavelength and polarization that may contain features for discrimination, classification, and identification that are not distinctive in scattered light intensity images. This paper describes a study of laser-based multi-spectral and polarimetric imaging using multi-spectral near- and mid-IR laser. There are fundamental issues and challenges with laser-based imaging that are different from passive imaging. This study focuses on the basic aspects of spectral and polarimetric scattering phenomena, as well as the system engineering issues. The near-IR study employed several wavelengths from 0.635-1.55 um, and demonstrated the complex behavior of wavelength- and polarization-dependence of diffuse scattering from various target surfaces. The multi-spectral polarimetric Stokes vector images reveal unique and distinctive features that are not evidenced in scattered intensity images. The mid-IR study employed 4 wavelengths from 3.3-9.6 um, and was also shown capable to resolve and distinguish small spectral differences that are not evidenced in the visible. System engineering is also important for laser-based imaging. The system architecture here employs wavelength-division-multiplexing for high spectral fidelity, and the scalable CDMA approach for multiple transmitters and receivers for distributed field-of-view. Although the experiments were done with low-power lasers, the results are applicable to high-power ladar system, and suggest that multi-spectral polarimetric laser imaging can be a unique and powerful technology for target discrimination.

6565-26, Session 5

High-performance Sagnac interferometers using cooled and uncooled detectors for infrared hyperspectral applications

P. G. Lucey, K. A. Horton, T. J. Williams, B. B. Wilcox, Univ. of Hawaii at Manoa

Imaging interferometry in the infrared has several potential advantages for hyperspectral imaging. The multiplex advantage enables higher sensitivity than dispersive systems when using uncooled detector arrays and the large throughput enables the use of uncooled optics when using using cryogenic detectors. We will present measurements and model results using Sagnac interferometers that demonstrate high performance hyperspectral imaging using cooled and uncooled detectors.

6565-27, Session 6

Explosives-generated plumes using AVHRR

M. B. Tayahi, Univ. of Nevada/Reno

Using satellite imagery to detect and track plumes caused by explosions is considerate a powerful tool for identfying and tracking of hazardous incidents involving nuclear, radiological, chemical or biological releases. The aim of this work is to combine the visible, the near infrared, and the thermal infrared channels in order to produce a two-dimensional feature space image in which explosive generated plumes can be detected and monitored. The first simulation was done using images collected by the Advanced Very High Resolution (AVHRR) on board the NOAA KLM satellites. A set of false color composites of Advanced Very High Resolution Radiometer (AVHRR) and Multichannel Visible and Infrared Scan Radiometer (MVISR) images was used to investigate the dispersion of the plumes, which may contain toxic substances, over wider areas, as well as to estimate plume spatial characteristics.

6565-28, Session 6

Hyperspectral image unmixing over Benthic habitats

M. Vélez-Reyes, E. M. Alvira-Concepción, S. Rosario-Torres, Univ. de Puerto Rico Mayagüez

Hyperspectral imagery (HSI) is an effective technology for quantitative monitoring of shallow water coastal environments. Hyperspectral sensors collect hundreds of narrow and contiguously spaced spectral bands of data organized in the so-called hyperspectral cube. However, the spatial resolution of most HSI flown nowadays is larger than the size of the objects being observed. Therefore, the measured spectral signature is a mixture of the signatures of the objects in the field of view of the sensor. The high spectral resolution can be used to decompose the measured spectra into its constituents. This is the so-called unmixing problem in HSI. Spectral unmixing is the process by which the measured spectrum is decomposed into a collection of constituent spectra, or endmembers, and a set of corresponding fractions or abundances. Unmixing allows us to detect and classify subpixel objects by their contribution to the measured spectral signal. Unmixing over benthic habitats is further complicated by the presence of the water column. Two approaches can be followed for unmixing over benthic habitats. In the first approach, the unmixing problem is treated in a similar fashion as an unmixing problem over land where the atmospherically corrected image is unmixed using one of several unmixing algorithms. In the second approach, the effects of the water column are removed before or jointly with the abundance estimation. In this paper, we compare the performance of the two approaches in unmixing HYPERION and AVIRIS imagery over a reef area in southwestern Puerto Rico.

6565-29, Session 6

Terrain categorization using LIDAR and multispectral data

A. M. Puetz, R. C. Olsen, M. F. Helt, Naval Postgraduate School

LIDAR data taken over the Elkhorn Slough region in central California were analyzed for terrain classification. Data were collected on April 12th, 2005 over a 10 km x 20 km region which is mixed use agriculture and wetlands. LIDAR temporal information (elevation values), intensity of returned light, and distribution of point returns (in both vertical and spatial dimensions), were used to distinguish land-cover types. Terrain classification was accomplished using LIDAR data alone, Multispectral QuickBird data alone, and a combination of the two data types. Results are compared to significant ground truth information.

6565-30, Session 6

Scintillometer network for calibration and validation of energy balance and soil moisture remote sensing algorithms

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Accurate estimation of sensible and latent heat fluxes as well as soil moisture from remotely sensed satellite images poses a great challenge. Yet, it is critical to face this challenge since the estimation of spatial and temporal distributions of these parameters over large areas is impossible using only ground measurements. A major difficulty for the calibration and validation of operational remote sensing methods such as SEBALNM, ALEXI, and DisALEXI is the ground measurement of sensible heat fluxes at a scale similar to the spatial resolution of the remote sensing image. While the spatial length scale of remote sensing images covers a range from 30 m (LandSat) to 1000 m (MODIS) direct methods to measure sensible heat fluxes such as eddy covariance (EC) only provide point measurements at a scale that may be considerably smaller than the estimate obtained from a remote sensing method. The Large Aperture scintillometer (LAS) flux footprint area is larger (up to 5000 m long) and its spatial extent better constraint than that of EC systems. Therefore, scintillometers offer the unique possibility of measuring the vertical flux of sensible heat averaged over areas comparable with several pixels of a satellite image (up to about 40 Landsat thermal pixels or about 5 MODIS thermal pixels). The objective of this paper is to present our experiences with an existing network of seven scintillometers in New Mexico and a planned network of three scintillometers in the humid tropics of Panama and Colombia.

6565-31, Session 7

A framework for polarized radiance signature prediction for natural scenes

C. Devaraj, S. D. Brown, D. W. Messinger, A. A. Goodenough, D. R. Pogorzala, Rochester Institute of Technology

As the interest in polarization sensitive imaging systems increases, the modeling tools used to perform instrument trade studies and to generate data for algorithm testing must be adapted to correctly predict polarization signatures. The incorporation of polarization into the image chain simulated by these tools must address the modeling of the natural illuminants (e.g. Sun, Moon, Sky), background sources (e.g. adjacent objects), the polarized Bi-directional Reflectance Distribution Function (pBRDF) of surfaces, atmospheric propagation (extinction, scattering and self-emission) and sensor effects (e.g. optics, filters). Although, each of these links in the image chain may utilize unique modeling approaches, they must be integrated under a framework that addresses important aspects such as a unified coordinate space and a common polarization state convention.

This paper will present a modeling framework for the prediction of polarized signatures within a natural scene. The proposed image chain will utilize community developed modeling tools including an experimental version of MODTRAN and BRDF models that have been either derived or extended for polarization (e.g. Beard-Maxwell, Priest-Germer, etc.). This description will include the theory utilized in the modeling tools incorporated into the image chain model and the numerical techniques utilized to integrate these links into a full signature prediction capability. Analytical and experimental lab and field studies will be presented that demonstrate the correct implementation and integration of the described image chain framework within the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model.

6565-32, Session 7

Recreation of a nominal polarimetric scene using synthetic modeling tools

D. R. Pogorzala, S. D. Brown, D. W. Messinger, C. Devaraj, Rochester Institute of Technology

Comparisons have been made showing that modeled multi and hyperspectral imagery can approach the complexity of real data and the use of modeled data to perform algorithm testing and sensor modeling is well established. With growing interest in the acquisition and exploitation of polarimetric imagery, there is a need to perform similar comparisons for this imaging modality.

This paper will describe the efforts to reproduce polarimetric imagery acquired of a real world scene using a synthetic image generation environment. Real data was collected with the Wildfire Airborne Sensor Program-Lite (WASP-Lite) imaging system using three separate cameras to acquire simultaneously three polarization orientations. Modeled data was created using the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. This model utilizes existing tools such as polarized bi-directional reflectance distribution functions (pBRDF), polarized atmospheric models, and polarization-sensitive sensor models to recreate polarized imagery. Results will show comparisons between the real and synthetic imagery, highlighting successes in the model as well as areas where improved fidelity is required.

6565-33, Session 7

Multiband texture synthesis using histogram and power spectral density matching

S. Sarkar, G. E. Healey, Univ. of California/Irvine

In this work, we develop a new method for multispectral and hyperspectral texture synthesis using the multiband distribution and power spectral densities.

Different approaches to this problem suggested in the literature are mostly case specific and include histogram explosion, equalization in the HSV or some other color space, equalization based on earth mover distance (EMD), etc.

For multiband images, the usual practice is to define the psds for each band separately. While this captures the in-band autocorrelations, the cross-band correlations are not captured. Sometimes cross-psds are defined if it is known that cross band correlations are important. However, as the number of bands increase, this method becomes computationally prohibitive. We propose a method that expresses psds for multiband images using 3D fourier transforms. An iterative scheme is used to equalize the histogram and psds for an input and target image.

Our experiments show that the iteration tends to converge after 5-10 steps.

The proposed method is computationally simple and yet yields satisfactory results.

We compare synthesized multispectral textures with real multispectral data.

6565-34, Session 7

Radiometric modeling of cavernous targets to assist in the determination of absolute temperature for input to process models

M. Montanaro, C. Salvaggio, D. W. Messinger, S. D. Brown, Rochester Institute of Technology; A. J. Garrett, Savannah River National Lab.

Determination of the temperature of an internal surface within cavernous targets, such as the interior wall of a mechanical draft cooling tower, from remotely sensed imagery is important for many surveillance applications. The surface leaving radiance of an observed surface is a combination of the self-emitted radiance and the reflected background radiance. The self-emitted radiance component is a function of the temperature-dependent blackbody radiation and the view-dependent directional emissivity. The reflected background radiance component depends on the bidirectional reflectance distribution function (BRDF) of the surface and the incident radiance from surrounding sources and the BRDF for each of these sources. Inside a cavity, the background radiance emanating from any of the multiple internal surfaces will be a combination of the self-emitted and reflected energy from the other internal surfaces as well as the downwelling sky radiance. This scenario provides for a complex radiometric inversion problem in order to arrive at the absolute temperature of any of these internal surfaces. The cavernous target has often been estimated as a blackbody, but in field experiments it has been determined that this is not always true. The Digital Imaging and Remote Sensing Image Generation (DIRSIG) modeling tool is being used to represent a cavity target. The model demonstrates the dependence of the radiance reaching the sensor on the emissivity of the internal surfaces and the multiple internal interactions between all the surfaces that make up the overall target. The cavity model is extended to a detailed model of a mechanical draft cooling tower. The predictions of derived temperature from this model are compared to those derived from actual infrared imagery collected with a helicopter-based broadband infrared imaging system collected over an operating tower located at the Savannah River National Laboratory site.

6565-35, Session 7

Modeling signatures from particle-laden rocket exhaust plumes and active transmission through battlefield smoke

J. L. Rapanotti, R. Farinaccio, P. Gosselin, R. Pimentel, A. Schäfke, Defence R&D Canada/Valcartier (Canada)

Particle-laden exhaust plumes radiate over the entire spectrum of interest from MMW to ultraviolet. Detection and the ability to guide the missile is also affected by battlefield smoke. The commercial fluid-dynamics solver, FLUENT, is being developed to model these rocket plume phenomena. Particles, produced by the motor, are represented by a discretized size distribution and are tracked as interaction with the plume occurs through energy and momentum transfer. The temperature and position of the particles are then used to determine the radiance image and the contribution to the total spectral intensity. Battlefield smoke surrounding the missile can vary from dust to metal flake in composition and is distributed unevenly by turbulent mixing with the atmosphere. This lack of homogeneity is modelled by solving the radiation transfer equations over ensembles of the composition. Once the plume flow field and the simulated battlefield environment are established, the performance of passive sensors and active sources, such as lasers and radar, is determined. The preliminary results presented in this study suggests that this approach can be useful in integrating the various area of expertise required to develop hybrid sensors for threat detection and missile guidance.

6565-36, Session 8

Fast multiscale smoothing and segmentation of hyperspectral imagery

J. M. Duarte-Carvajalino, Univ. de Puerto Rico Mayagüez; G. Sapiro, Univ. of Minnesota; M. Velez-Reyes, Univ. de Puerto Rico Mayagüez

An algorithm for anisotropic smoothing and segmenting hyperspectral imagery is presented. Anisotropic smoothing reduces the spatial and spectral variability within uniform regions in the image, preserving the sharp discontinuities, which in turn improves the segmentation by increasing the separability between the different regions in the image. The algorithm solves a discretized Partial Differential Equation (PDE) that generates a discrete scale-space, represented by an irregular pyramid of coarser versions of the image. As the image is coarsened, spectral-spatial statistics are gathered from the multi-scale representation of the image, increasing the separability of the different regions in the image. At the same time, representative pixels are selected at each image scale, enabling a multi-scale segmentation of the image. The segmentation is performed in a top-down process that uses the representative pixels as seeds and distance metrics, based on the accumulated statistics. The PDE is solved using Algebraic Multigrid (AMG), a numerical analysis technique useful for boundary value problems on highly unstructured grids, with greater accuracy and speed than more traditional relaxation techniques. The coarsening step in AMG is based on a modified version of the Iterated Weighted Aggregation method, tailored to better exploit the discrimination power of high dimensional spaces such as those represented by hyperspectral data.

6565-37, Session 8

Improving multispectral mapping by spectral modeling with hyperspectral signatures

F. A. Kruse, Horizon GeoImaging, LLC

Hyperspectral imaging (HSI) data in the 0.4 - 2.5 micrometer spectral range allow direct identification of materials using their fully resolved spectral signatures, however, spatial coverage is limited. Multispectral Imaging data (MSI) are spectrally undersampled and may not allow unique identification, but they do provide synoptic spatial coverage. Combining the two data types by modeling hyperspectral signatures to multispectral band passes allows extending HSI mapping results to regional scales and leads to improved multispectral mapping over larger areas.

Coincident hyperspectral Airborne Visible/Infrared (AVIRIS)/Hyperion and multispectral ASTER/MASTER data supported by field spectral measurements are used to allow modeling and extension of hyperspectral signatures to multispectral data. Full-scene mapping using the modeled signatures allows subsequent mapping of extended areas using the multispectral data. Both the hyperspectral and multispectral data are atmospherically corrected using commercial-off-the-shelf (COTS) atmospheric correction software. Hyperspectral data are then analyzed to determine spectral endmembers and their spatial distributions, and validated using the field spectral measurements. Spectral modeling is used to convert the hyperspectral spectral signatures to the multispectral data response. Reflectance calibrated multispectral data are then used to extend the hyperspectral mapping to the larger spatial coverage of the multispectral data. Field verification of mapping results is conducted and accuracy assessment performed. Additional sites are assessed with multispectral data using the modeling methodology based on scene-external HSI and/or field spectra (but without scene-specific a priori hyperspectral analysis or knowledge). These results are further compared to field measurements and subsequent hyperspectral analysis and mapping to validate the spectral modeling approach.

6565-38, Session 8

Affine invariant and T-robust image registration/ conflation algorithm

B. Kovalerchuk, Central Washington Univ.

The robust imagery conflation, co-registration and geo-referencing are critical in many applications such as analysis of multispectral data from multiple sensors. This paper proposes a new affine invariant and noise robust registration/conflation algorithm (EAD algorithm) based on algebraic structures of linear and area based features. An algorithm that matches linear features from two images can be very accurate because it produces many matched points, but the selection of such robust and invariant points is a long-standing challenge. There are known definitions of points that are either robust or invariant, but not both. The Equal Area Divider (EAD) point is a major new component of the EAD-based registration/conflation algorithm. This point is affine invariant and robust to noise (T-robust in a formal definition). It augments several known points such as MAL (midpoint along the line) and ES (equal shoulder) points that we have used in our structural algorithms previously. MAL and ES points (mapped to the second image using a general affine transform) differ from MAL and ES points in the second image in the same feature. However, if MAL and ES points are computed after affine transform of the first image to the second one using EAD points then MAL and ES points are the same (or in the T-robust vicinity) of MAL and ES points found in the matched feature in the second image. This statement is formalized as a theorem and is used in EAD algorithm design. Advantages of the EAD registration/ conflation algorithm are shown in the experiment.

6565-40, Session 8

Enhancing projection method of geometric correction of satellite image geometry with wavelet-based approximation

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Precise remote sensing and high resolution satellite images have made it necessary to revise the geometric correction techniques used for ortho-rectification. There have been improvements in algorithms from simple 2D polynomial models to rigorous mathematical models derived from digital photogrammetry. In such scenario, conventional methods of photogrametric modeling of remotely sensed images would be insufficient for mapping purposes and might need to be substituted with a more rigorous approach to get a true orthophoto. To correct geometric distortions in these, the process of geometric modeling becomes important.

Pixel projection method has been devised and used for geometric correction. Algorithm has been developed in C++ and used for

FORMOSAT-2 high resolution satellite images. It geo-references a satellite image while geo-locating vertices of the image with its geo-locations extracted from ancillary data. Accuracy and validity of the algorithm has already been tested on different types of satellite images. It takes a level-1A image and the output image is level-2 image. To increase the geometric accuracy, a set of ground control points with maximum accuracy can also be selected to determine the better knowledge of position, attitude and pixel alignment.

Previously, we had adopted different techniques of approximations and applied three possible methods of interpolation for transformations of image pixels to earth coordinate system. Results showed that cubic convolution based modeling gave best suitable output pixel values as compared to bilinear interpolation and nearest neighbor methods.

In this paper, we will apply certain other techniques of approximations. These will be mainly wavelet based. Their results on different satellite images will be tested and they will be compared with previously applied methods.

6565-84, Session 8

Hyperspectral detection in high clutter using elliptically contoured distributions

A. P. Schaum, E. C. Allman, Naval Research Lab.

A new class of hyperspectral detection algorithm based on elliptically contoured distributions (ECDs) is described. ECDs have been studied previously, but only for modeling the tails of background clutter distributions. Here ECDs are exploited to produce new target detection algorithms. The methods generate highly selective decision surfaces and produce performance comparable to the best prior methods. The principal advantage of the ECD model over older ones is the absence of free parameters needing optimization. A particularly simple version has been evaluated, whose detection surfaces are from the same quadric family as those associated with subspace models. Experiments also indicate that ECD-based change detection in urban clutter can succeed for targets with low spectral contrast, where standard signature-based methods fail.

6565-41, Session 9

Comparative study of state-of-the-art algorithms for hyperspectral image analysis

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This work studies the end-to-end performance of different hyperspectral classification systems. Specifically, it compares the most widely used current state of the art algorithms with those developed at the University of Puerto Rico. These include algorithms for image enhancement, band subset selection, feature extraction, supervised and unsupervised classification, and constrained and unconstrained abundance estimation. The end to end performance for different combinations of algorithms is evaluated. The classification algorithms are compared in terms of percent correct classification. This method, however, cannot be applied to abundance estimation, as the binary kind of evaluation used for supervised and unsupervised classification is not directly applicable for unmixing performance analysis. A procedure to evaluate unmixing performance is described in this paper and tested using coregistrated data acquired by various sensors at different spatial resolutions. Statistics to analyze the unmixing performance are studied for a revealing representation of the results. Performance results are generally specific to the image used. In an effort to try and generalize the results, a formal description of the complexity of the images used for the evaluations is required. Techniques for image complexity analysis currently available for automatic target recognizers are included and adapted to quantify the performance of the classifiers for different image classes.

6565-42, Session 9

Modeling subpixel orientation effects for hyperspectral image analysis

K. Chandra, Univ. of California/Irvine

The radiance spectrum corresponding to a single pixel in an airborne hyperspectral image is dependent on the reflectance and orientations of the surfaces within an area corresponding to the pixel. Additional factors include the environmental conditions and the viewing geometry. In this paper we adopt a physics-based model which includes all of these factors. The model is a nonlinear parametric model and is based on subspace models for the reflectance spectra , illumination spectra and the path-scattered radiance. The subspace model for the illumination spectra and path-scattered radiance is coupled to account for the common dependence on the environmental condition and viewing geometry. The nonlinear parametric model parameters are estimated using the Levenberg-Marquardt method. We quantitatively analyze the utility of this model for the problems of subpixel orientation and reflectance recovery and target detection using a set of simulated radiance spectra.

6565-43, Session 9

Gaussian smoothing of sparse spatial distributions as applied to spectral separation calculations by use of the informational difference

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The characterization of separation between measured spectral distributions of different objects, by the use of any divergence-evolved method such as the Informational Difference, is problematic due to the relative sparsity of these distributions in the channel intensity space. The existence of zero-probability regions in this space renders the calculation result irrelevant, since the separation measure becomes either infinite or undefined.

A method to surmount this problem using experimental data is proposed. We consider the statistical nature of measurements for all available visual data, e.g. pixel values, and model the full spectral distributions of these pixels as a congregate of normal distributions. The inherent infinite extent of normal Gaussian distributions smoothes the zero-probability regions of the original discrete distributions, thus solving the divergence problem. The parameters of the Gaussian smoothing can be determined experimentally, or derived from statistical considerations where such measurements are not available.

6565-44, Session 9

An orthogonal subspace projection-based for estimation of virtual dimensionality for hyperspectral data exploitation

W. Liu, C. Wu, C. Chang, Univ. of Maryland/Baltimore County

A recently introduced concept, Virtual Dimensionality (VD) has been shown promise in many applications of hyperspectral data exploitation. It was originally developed for estimating number of spectrally distinct signal sources. This paper explores the utility of the VD and develops a new versatile technique for estimating the VD. It is derived from orthogonal projection subspace (OSP)-based linear spectral mixture analysis where the assumed number of signatures or signal sources is used to generate a subspace space that embraces as many data sample vectors as mixed pixels. It is closely related and also determined by the algorithm used to generate the subspace projection. In other words, different used algorithms produce different values of the VD. This is a significant key feature that is not included in any other method used to estimate the VD in the literature. For example, if an algorithm used to generate the subspace is an endmember extraction algorithm, then the VD will represent the number of endmembers. On the other hand, if an algorithm used to generate the subspace is a target detection algorithm, then the VD will represent the number of spectral distinct targets. In order to evaluate the performance of the proposed OSP-based VD estimation technique, a comparative study and analysis is conducted via synthetic and real image.

6565-45, Session 9

Dimensionality expansion in hyperspectral imagery using real and imaginary complex transformations

A. Castrodad, E. H. Bosch, R. G. Resmini, National Geospatial-Intelligence Agency

Several studies have reported that the use of derived spectral features, in addition to the original hyperspectral data, can facilitate the separation of similar classes. Dimension expansion methods are employed to project data to a higher-dimensional space with the expectation the decision surface separating similar classes become well defined. Therefore, the problem of discerning between similar classes in expanded space becomes more tractable. Some of the most common dimension expansion methods include linear and nonlinear combinations of the original spectral data. Recent work presented by one of the authors discusses a hyperspectral image (HSI) dimension expansion technique based on generating real and imaginary complex features from the original spectral signatures. In turn, a complex spectral angle mapper was employed to classify the dimension-expanded data. In this paper, we extend this method to include other approaches of generating complex spectral features from the original data, such as the Fourier Transform (FT), complex exponentials, complex logarithms and possibly analytic (holomorphic) transformations. We also investigate supervised class separation methods such as the Euclidean Distance, and others that require the computation of higher order statistics (e.g. complex covariance matrix), such as the Mahalanobis or the Battacharrya Distance. Results will be presented with real HSI data.

6565-46, Session 10

Wavelength calibration of hyperspectral sensors with 2D detector arrays

E. Lo, Susquehanna Univ.; A. W. Fountain III, U.S. Army Research, Development and Engineering Command; J. Ingram, U.S. Military Academy

A readily automated procedure for testing and calibrating the wavelength scale of a scanning hyperspectral imaging camera is described. The procedure is a laboratory calibration method and it uses the absorbance features from a commercial didydium oxide filter as a wavelength standard. The procedure was used to accurately determine the pixel positions. An algorithm was developed to determine the center of the wavelength for any given abscissa and the accuracy of the estimated wavelength for a given calibration. During this investigation we determined that the sampled pixels show both trend and serial correlation as a function of the spatial dimensions. The trend is more significant than the serial correlation. In this paper, the trend will be filtered out by modeling the trend using an efficient global linear regression model of different order for different spectral band. The order is selected automatically and different criteria for selecting the order are discussed. Experimental results will be presented to show the improvement in the accuracy.

6565-47, Session 10

Processing misregistered hyperspectral data

J. T. Casey, J. P. Kerekes, Rochester Institute of Technology

Many hyperspectral sensors collect data using multiple spectrometers to provide broad spectral coverage. These spectrometers often have separate apertures defined by optical fibers leading to the multiple spectrometers. The airborne Modular Imaging Spectrometer Instrument (MISI), a 70 band line scanner built by the Rochester Institute of Technology (RIT), is configured in this manner. Visible and near infrared spectrometers are each fed by their own optical fiber at the primary focal plane. A spatial offset between the two fibers causes an inherent misregistration between the two sets of spectral bands. This configuration of MISI causes a relatively complicated misregistration which cannot be corrected with a simple shift, rotation or translation of the data. In MISI, incident light from the ground is first reflected off of a rotating scan mirror before an additional reflection from a fold mirror and into the optical fibers. This geometry leads to a scan angle dependent misregistration between the imagery in the two spectrometers. Coupled with roll, pitch, and yaw variations, and elevation changes in the ground surface, these effects make registration and geo-rectification of the imagery quite challenging. Also, the mismatch between spectral channels severely degrades the spectral purity of each pixel, and can particularly reduce performance in sub-pixel target detection applications. A geometric model of the sensor is being developed to solve for the misregistration and achieve image rectification. This paper will address the issues in dealing with the misregistration, and the techniques used to improve spectral purity on a per pixel basis. Data collected by the MISI sensor over RIT's campus are being used in research aimed at detecting and tracking potentially threatening civilian vehicles in an urban area based on their unique spectral characteristics. This paper will also report on our efforts to compare performance of existing target detection algorithms in this application, particularly in the context of the misregistration between spectrometers. Several algorithms have been studied to determine which perform well ,and which fail, under these conditions. Preliminary results indicate statistical algorithms such as the adaptive coherence estimator (ACE), and Constrained Energy Minimization (CEM) outperform signature-based or geometrical detection algorithms.

6565-48, Session 10

Median spectral-spatial bad pixel identification and replacement for hyperspectral SWIR sensors

A. D. Fischer, NovaSol; T. V. Downes, R. A. Leathers, Naval Research Lab.

Hyperspectral focal plane arrays typically contain many pixels that are excessively noisy, dead, or exhibit poor signal-to-noise performance in comparison to the majority. These bad pixels can significantly impair the performance of spectral target-detection algorithms. Even a single missed bad pixel can lead to false alarms. Because of this sensitivity to bad pixels, a completely automated approach for identifying and replacing bad pixels has remained elusive.

If the bad pixels are sparsely populated across the focal plane, the over-sampling in both spatial and spectral dimensions of the array can be capitalized upon to replace these pixels without significant loss of information. However, bad pixels are frequently localized in clusters, requiring a replacement strategy that rather than providing a good estimate of the missing data will instead minimize artifacts that may negatively affect the performance of spectral detection algorithms.

In this paper, we evaluate a robust method to automatically identify bad pixels for short-wavelength infrared (SWIR) hyperspectral sensors. In addition, we introduce a novel procedure for the replacement of these pixels, which we demonstrate provides a better estimate of the original pixel value compared to interpolation methods for bad pixels found as both isolated individuals and in clusters.

The advantages of our technique are discussed and demonstrated with data from several different airborne sensor systems.

6565-49, Session 10

Spatial misregistration detection for hyperspectral sensors using in-flight data

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Hyperspectral pushbroom sensors suffer from a number of artifacts which can prevent the accurate record of the total upwelling radiance for each ground-spot. We focus our attention mainly on spatial misregistration, also called keystone. Spatial misregistration is the sum of both optical aberrations, introduced by lens and mirrors, and misalignments, due to assembling procedures, between the optical parts of a sensor.

The physical causes of this artifact are presented, and it is shown how it does depend quadratically on the positions where the light rays hit the focal plane. An in-flight calibration method, able to identify spatial misregistration in hyperspectral cubes, has been implemented, and it will be used in the hyperspectral sensor Airborne Prism Experiment

(APEX). This procedure combines edge detection, and weighted summation to achieve subpixel precision. The main advantage of this processor is that it tries to give an absolute measure of spatial misregistration. The proposed in-flight method is also easy to be adapted to other sensors; in fact, it has been tested on large variety of hyperspectral instruments. We namely analyze pushbroom scanning system, either grating-based design (HYSPEX, PHILLS, AISA Eagle, HYPERION), or prism-based design (CASI-3, CHRIS) with AVIRIS as the only whiskbroom scanner, which has been used as a benchmark for the proposed in-flight detection method. The results confirm the quadratic dependence of spatial misregistration on the focal plane position, and basically how its distribution, along the CCD elements, is symmetrical within the focal plane itself. The influence of filtering in grating-based designs is also shown as well as identification of misalignments between the focal plane, and other optical components.

6565-50, Session 10

Coregistration of multispectral images for enhanced target recognition

F. Khaghani, Solid State Scientific Corp. and Tufts Univ.; R. J. Nelson, Solid State Scientific Corp.

Unlike straightforward registration problems encountered in broadband imaging, spectral imaging in fielded instruments often suffers from a combination of imaging aberrations that make spatial coregistration of the images a challenging problem. Depending on the sensor architecture, typical problems to be mitigated include differing focus, magnification, and warping between the images in the various spectral bands due to optics differences; scene shift between spectral images due to parallax; and scene shift due to temporal misregistration between the spectral images. However, typical spectral images sometimes contain scene commonalities that can be exploited in traditional ways. As a first step toward automatic scene coregistration for spectral images, we exploit manually-selected scene commonalities to produce transformation parameters in a four-channel spectral imager. The four bands consist of two mid-wave infrared channels and two short-wave infrared channels, and employ a common snapshot-mode focal plane array to mitigate scene shift problems due to temporal misregistration. Each of the four bands is blurred differently due to differing focal lengths of the imaging optics, magnified differently, warped differently, and translated differently due to parallax. Centroid location techniques are used on the scene commonalities in order to generate sub-pixel values for the fiducial markers used in the transformation polygons, and conclusions are drawn about the effectiveness of such techniques in spectral imaging applications.

6565-51, Session 11

Recent theoretical advances in analysis of AIRS/AMSU sounding data

J. Susskind, NASA Goddard Space Flight Ctr.

The AIRS Science Team Version 5.0 retrieval algorithm will become operational at the Goddard DAAC in early 2007 in the near real-time analysis of AIRS/AMSU sounding data. This algorithm contains many significant theoretical advances over the AIRS Science Team Version 4.0 retrieval algorithm used previously. Two very significant developments are: 1) the development and implementation of a very accurate Radiative Transfer Algorithm (RTA) which allows for accurate treatment of non-Local Thermodynamic Equilibrium (non-LTE) effects on shortwave sounding channels; and 2) the development of methodology to obtain very accurate case by case product error estimates which are in turn used for quality control. These theoretical improvements taken together enabled a new methodology to be developed which further improves soundings in partially cloudy conditions, without the use of microwave observations in the cloud clearing step as has been done previously. In this methodology, longwave CO2 channel observations in the spectral region 700 cm-1 to 750 cm-1 are used exclusively for cloud clearing purposes, while shortwave CO2 channels in the spectral region 2195 cm-1 to 2395 cm-1 are used for temperature sounding purposes.

The new methodology will be described briefly and results will be shown, including comparison with those using AIRS Version 4 , as well as a forecast impact experiment assimilating AIRS Version 5.0 retrieval products in the Goddard GEOS 5 Data Assimilation System.

6565-52, Session 11

Utility of AIRS retrievals for climate studies

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Satellites provide an ideal platform to study the Earth-atmosphere system on practically all spatial and temporal scales. Thus, one may expect that their rapidly growing datasets could provide crucial insights not only for short-term weather processes/predictions but into ongoing and future climate change processes as well. Though Earth-observing satellites have been around for decades, extracting climatically reliable information from their widely varying datasets faces rather formidable challenges. AIRS/AMSU is a state of the art infrared/microwave sounding system that was launched on the EOS Aqua platform on May 4, 2002, and has been providing operational quality measurements since September 2002. In addition to temperature and atmospheric constituent profiles, outgoing longwave radiation [OLR] and basic cloud parameters are also derived from the AIRS/AMSU observations [Susskind et al, 2003]. However, so far the AIRS products have not been rigorously evaluated/validated on a large scale. Here we present validation efforts of climatically important “Level3” (Monthly mean 1x1 Degrees Gridded) AIRS “Version-4.0” retrieved products (available to the public through the DAAC at NASA/GSFC) to assess their utility for climate studies. Though the current AIRS climatology covers only 4 years, it will hopefully extend much further into the future. On the other hand, we are also working on its backward extension, by integrating it with the other sounder-based climate dataset, namely the TOVS Pathfinder “Path-A” retrievals, available from 1979 through 2004.

First we present “internal consistency checks” by evaluating the 4-yr long time series of global and tropical means, as well as grid-scale variability and “trends” of the retrieved atmospheric parameters. Next, we present comparison studies with available independent climatologies. For example, cloud top pressures [Pc] and “effective” (the product of infrared emissivity at 11 microns and physical cloud cover) cloud fractions [Aeff], which are key parameters for influencing OLR, are compared with the MODIS-Aqua (i. e., it is on the same satellite as AIRS) and ISCCP (available since 1983 to June 2005 for now) climatologies, whilst clear-sky OLR variabilities are compared with the available state-of-the-art CERES measurements.

Finally, we also present preliminary results regarding interrelationships of some of the retrieved parameters, to assess whether they are consistent with known principles of climate variability.

6565-53, Session 11

The impact of atmospheric infrared sounder (AIRS) profiles on short-term weather forecasts

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The Atmospheric Infrared Sounder (AIRS), together with the Advanced Microwave Sounding Unit (AMSU), represents one of the most advanced space-based atmospheric sounding systems. Aside from monitoring changes in Earth’s climate, one of the objectives of AIRS is to provide sounding information with sufficient accuracy such that the assimilation of the new observations, especially in data sparse regions, will lead to an improvement in weather forecasts. The combined AIRS/AMSU system provides radiance measurements used as input to a sophisticated retrieval scheme which has been shown to produce temperature profiles with an accuracy of 1 K over 1 km layers and humidity profiles with accuracy of 15% in 2 km layers in both clear and partly cloudy conditions. The retrieval algorithm also provides estimates of the accuracy of the retrieved values at each pressure level, allowing the user to select profiles based on the required error tolerances of the application.

The purpose of this paper is to describe a procedure to optimally assimilate high-resolution AIRS profile data in a regional analysis/forecast model. The paper focuses on the impact of AIRS profiles on short-term forecasts for a 30-day period, simulating a quasi-operational environment. Temperature and moisture profiles—containing information about the quality of each temperature layer—are obtained from the prototype version 5.0 Earth Observing System (EOS) science team retrieval algorithm. The quality indicators are used to select the highest quality temperature and moisture data for each profile location and pressure level. AIRS data are assimilated into the Weather Research and Forecasting (WRF) numerical weather prediction model using the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS), to produce near-real-time regional weather forecasts over the eastern half of the continental U.S. The preliminary assessment of the impact of the AIRS profiles will focus on quality control issues associated with AIRS, intelligent use of the quality indicators, and forecast verification against gridded analyses and precipitation data.

6565-54, Session 11

Retrieval of atmospheric sulfur dioxide and nitric acid using the atmospheric infrared sounder (AIRS)

L. L. Strow, S. Hannon, Univ. of Maryland/Baltimore County

The Atmospheric Infrared Sounder (AIRS) has been operating on NASA'a AQUA satellite since Sept. 2002. AIRS is a grating spectrometer with a nominal resolving power of 1200, and was developed to retrieve atmospheric profiles of temperature and water vapor. However, since AIRS covers much of the infrared spectrum from 3.7 to 15 microns, information on the abundance of several minor gases is possible. We will present retrievals of sulfur dioxide and nitric acid using AIRS and discuss characteristics of the retrieval algorithm and cross-validation using the OMI and MLS sensors on the NASA AURA satellite. Observations of volcanic dust plumes with AIRS will also be discussed.

6565-55, Session 11

Analysis of SO2 point source emissions using NASA atmospheric infrared sounder data

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Determining the extent to which large power plant emission sources interacting with atmospheric constituents affect the environment will play a significant role in future U.S. energy production policy. The effects on the environment caused by the interaction between the power plant emissions and the atmospheric constituents has not been investigated in depth due to the lack of calibrated spectral data on a suitable temporal and spatial scale. The availability of NASA's space-based Atmospheric Infrared Sounder (AIRS) data makes it possible to explore, and begin the first steps toward establishing, a correlation between known emission sources and environmental indicators. For this study, a time series of 26 cloud-free AIRS data containing two coal-fired power plants in northern New Mexico were selected, acquired, and analyzed for SO2 emissions. A generic forward modeling process was also developed to derive an estimate of the expected AIRS pixel radiance containing the SO2 emissions from the two power plants based on published combustion analysis data for coal and available power plant documentation. Analysis of the AIRS NE∆R calculated in this study and subsequent comparison with the radiance values for SO2 calculated from the forward model provided essential information regarding the suitability and risk in the use of a modified AIRS configuration for monitoring anthropogenic point source emissions. This study along with its conclusions and recommendations in conjunction with additional research collaboration with the NASA AIRS Science Team in several specific topics will provide guidance for the development of the next generation infrared spectrometer system that NASA is considering building for environmental monitoring.

6565-56, Session 11

Advanced remote-sensing imaging emission spectrometer (ARIES): AIRS spectral resolution with MODIS spatial resolution

T. S. Pagano, Jet Propulsion Lab.

The Advanced Remote-sensing Imaging Emission Spectrometer (ARIES) will measure the primary earth quantities fundamental to the study of global climate change including atmospheric water vapor and temperature, atmospheric composition of key gases, and land and ocean productivity. It will build upon the success of the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Atmospheric Infrared Sounder (AIRS) instruments currently flying on the EOS Aqua Spacecraft. Both MODIS and AIRS are facility instruments for NASA providing data to thousands of users investigating land, ocean and atmospheric Earth System processes. ARIES will meet all the requirements of AIRS and MODIS in a single compact instrument, while providing the next-generation capability of improved spatial and spectral resolution for AIRS and improved spectral resolution for MODIS.

The NASA MODIS and AIRS key facility instruments on the EOS Aqua spacecraft have made significant advancements in Earth Science and weather forecasting. The ARIES instrument concept will not only assure the continued climate quality observations of MODIS and AIRS for science research, but offer hyperspectral resolution from the Vis through the LWIR at MODIS spatial resolution or better. This new capability will enable new scientific discovery by the broad community of existing users of AIRS and MODIS resulting in major contributions to Earth Science for the next decade. This paper presents the measurement requirements from ARIES and a concept for meeting the requirements.

6565-57, Session 11

Recent progress in neural network estimation of atmospheric profiles using microwave and hyperspectral infrared sounding data in the presence of clouds

W. J. Blackwell, F. W. Chen, MIT Lincoln Lab.

Recent work has demonstrated the feasibility of neural network estimation techniques for atmospheric profiling in partially cloudy atmospheres using combined microwave (MW) and hyperspectral infrared (IR) sounding data. In this paper, the retrieval performance in "problem areas" (over land, near the poles, elevated terrain, etc.) is examined. Simulated data generated for these conditions is used to supplement the data set used in previous experiments, which underrepresented the most difficult cases because of data sparsity in these regions.

A novel statistical method for the retrieval of atmospheric temperature and moisture (relative humidity) profiles has been developed and evaluated with sounding data from the Atmospheric InfraRed Sounder (AIRS) and the Advanced Microwave Sounding Unit (AMSU). The present work focuses on the cloud impact on the AIRS radiances and explores the use of stochastic cloud clearing mechanisms together with neural network estimation. A stand-alone statistical algorithm will be presented that operates directly on cloud-impacted AIRS/AMSU data, with no need for a physical cloud clearing process. The algorithm is implemented in three stages. First, the infrared radiance perturbations due to clouds are estimated and corrected by combined processing of the infrared and microwave data using a Stochastic Cloud Clearing (SCC) approach. The cloud clearing of the infrared radiances was performed using principal components analysis of infrared brightness temperature contrasts in adjacent fields of view and microwave-derived estimates of the infrared clear-column radiances to estimate and correct the radiance contamination introduced by clouds. Second, a Projected Principal Components (PPC) transform is used to reduce the dimensionality of and optimally extract geophysical profile information from the cloud-cleared infrared radiance data. Third, an artificial feedforward neural network (NN) is used to estimate the desired geophysical parameters from the projected principal components.

The performance of this method was evaluated using global (ascending and descending) EOS-Aqua orbits co-located with ECMWF fields for a variety of days throughout 2003 and 2004. Over 350,000 fields of

regard (3x3 arrays of footprints) over ocean and land were used in the study. Retrieval performance compares favorably with that obtained with simulated observations from the NOAA88b radiosonde set of approximately 7500 profiles. The method requires significantly less computation than traditional variational retrieval methods, while achieving comparable performance.

6565-58, Session 12

Using the MODTRAN(tm)5 radiative transfer algorithm for NASA satellite data analyses: AIRS and SORCE

G. P. Anderson, Air Force Research Lab.; A. Berk, Spectral Sciences, Inc; J. W. Harder, J. M. Fontenla, Univ. of Colorado/ Boulder; E. P. Shettle, Naval Reasearch Lab.; P. Pilewski, B. C. Kindel, Univ. of Colorado/Boulder; J. H. Chetwynd, Jr., J. A. Gardner, M. L. Hoke, G. W. Felde, R. B. Lockwood, Air Force Research Lab.; H. E. Snell, Atmospheric and Environmental Research, Inc.; P. K. Acharya, Spectral Sciences, Inc.

The opportunity to test MODTRAN(tm)5 (MOD5) capabilities against NASA's satellite state-of-the-art radiance and irradiance measurements has recently been undertaken with the newly cleared code. New solar data are from: (1) SORCE satellite measurements of solar variability over solar rotation cycle, and (2) ultra-narrow calculation of a new solar source irradiance, extending over the full MOD5 spectral range, from 0.2 um to far-IR. The AIRS data (presented at SPIE 2006) have been similarly revisited with appropriate channel response functions.

MODTRAN(tm)5, MODerate resolution radiance and TRANsmittance code, has been developed collaboratively by Air Force Research Laboratory and Spectral Sciences, Inc., with history dating back to LOWTRAN. It includes approximations for all local thermodynamic equilibrium terms associated with molecular, cloud, aerosol and surface components for emission, scattering, and reflectance, including multiple scattering, refraction and a statistical implementation of Correlated-k averaging. The band model is based on 0.1 cm-1 (also 1.0, 5.0 and 15.0 cm-1) statistical binning for line centers within the interval, captured through an exact formulation of the full Voigt line shape. Spectroscopic parameters are from HITRAN 2004 with user-defined options for additional gases. Recent validation studies show MOD5 replicates line-by-line brightness temperatures to within ~0.05ºK average and <1.0ºK RMS.

MOD5 can then serve as a surrogate for a variety of perturbation studies, including the two modes for the solar source function, Io. Additionally, MOD5 calculations, using the 'truth' data and satellite measurements supplied by the AIRS community, provide validation in the Long Wave Infrared (LWIR). All ~2400 instrument spectral response functions (ISRFs) are expected to be supplied with MODTRAN(tm)5.

6565-59, Session 12

Atmospheric correction of off-Nadir hyperspectral imagery

S. M. Adler-Golden, L. S. Bernstein, M. W. Matthew, M. J. Fox, R. L. Sundberg, Spectral Sciences, Inc.; A. J. Ratkowski, Air Force Research Lab.

Compared to nadir viewing, off-nadir viewing provides dramatic improvement in the collection geometries obtainable from a given remote-sensing platform. However, large off-nadir angles lead to unusually large atmospheric absorption and scattering, which can be very difficult to remove with standard atmospheric correction techniques. To gain insight into the challenges and capabilities of off-nadir atmospheric correction, we have recently studied a set of Hyperion hyperspectral images taken at an extreme off-nadir angle (9 * above the horizontal), performing atmospheric correction using both the first-principles FLAASH method and the empirical QUAC method. Results of this investigation and implications for less-extreme viewing geometries are discussed, and FLAASH upgrades for improved handling of off-nadir geometries and other stressing scenarios are described.

6565-60, Session 12

Error analysis for a temperature and emissivity retrieval algorithm for hyperspectral imaging data

C. C. Borel, Ball Aerospace & Technologies Corp.

In the hyperspectral thermal data analysis temperature-emissivity separation has the same function as reflectance retrieval in the visible and shortwave infrared. The problem however is more complicated since in the thermal the surface emits radiation as well which depends on the skin temperature. The measured radiance is a function of the materials' surface emissivity and temperature, reflected down welling radiance (clear sky, clouds environment) and the path radiance (temperature and gas (e.g. water vapor, ozone) profiles). The current implementation of the Automatic Retrieval of Temperature and EMIssivity using Spectral Smoothness (ARTEMISS) uses look-up-tables (LUT) to compute the best fitting atmosphere which results in the smallest residual. Over last few years we have developed an end-to-end simulation of the hyper spectral exploitation process by generating synthetic data to simulate datasets with "known" ground truth, modeling propagation through the atmosphere, adding sensor effects (telescope, detector, readout electronics), radiometric and spectral calibration, and test the temperature emissivity separation algorithm. We will present an error analysis where we shifted the band centers, varied the bandwidths (FWHM), changed the spectral resolution, added noise and varied the atmospheric model. We will also discuss a general method to retrieve the spectral smile as a function of wavelength and the FWHM from hyperspectral data with only approximate spectral calibration. We found that our algorithm has trouble finding a unique solution when the watervapor exceeds about 3 g/cm2 and will discuss remedies for this situation. To speedup the LUT generation we have developed fast and robust initial atmospheric parameter estimators (water vapor, ozone, near surface atmospheric layer temperature) based on channel ratios and brightness temperatures in atmospheric absorption regions for the LWIR.

6565-61, Session 12

Modeling and estimation of adjacency effects in aerial images

H. Chandra, Univ. of California/Irvine

This paper presents a physics based model to estimate the adjacency effect in aerial images. Radiations scattered by a ground surface out of the field of view (FOV), sometimes, get scattered by the atmosphere back into the FOV. The term "adjacency

effect" is used to describe this phenomenon. Adjacency effects can lead to image blurs and low contrast in aerial images. This can make the quantitative explanation of surface features difficult. Modeling and estimation of adjacency effects can facilitate improved airborne image analysis. A new scene-geometry invariant, physics based adjacency model based on "Radiative Transfer" (RT) theory is proposed.

The model is validated by comparing synthetic aerial image data generated using Digital Imaging and Remote Sensing Image Generation (DIRSIG) with the real HYperspectral Digital Imagery Collection Experiment (HYDICE) image data under various atmospheric and illumination conditions. We use an error measure, defined as the difference between the actual HYDICE radiance and the predicted HYDICE radiance, to quantitatively compare the two radiance measures, with and without the adjacency effects. For the test scenes, we consider grass background and calibrated reflectance panels as our target objects. When we do not consider the adjacency model, we show that the error measure is high near the target-background boundaries; whereas the error measure is very low with the inclusion of the proposed adjacency model.

6565-62, Session 12

Correlated-k-based fast accurate bandpass radiance and transmittance (kURT) calculations for scenes

P. K. Acharya, R. Panfili, A. Berk, S. M. Adler-Golden, Spectral Sciences, Inc.; A. Wetmore, R. C. Shirkey, Army Research Lab.

The ability to rapidly calculate at-sensor radiance over a large number of lines of sight (LOSs) is critical for scene simulations, which are increasingly

used for sensor design, performance evaluation, and data analysis. We have recently demonstrated a new radiation transport (RT) capability that combines an efficient multiple-LOS multiple scattering algorithm with a broad-bandpass correlated-k methodology called kURT-MS. The multiple-LOS capability is based on DISORT and exploits the existing MODTRAN-DISORT interface. kURT-MS is a new sensor-specific correlated-k (c-k) ultra-fast radiative transfer formalism for UV-visible to LWIR wavelengths that is derived from MODTRAN's correlated-k parameters. Scattering parameters, blackbody and solar functions are cast as compact k-dependent source terms and used in the radiance computations. Preliminary transmittance results are within 2% of MODTRAN with a two-orders-of-magnitude computational savings. Preliminary radiance computations in the visible spectrum are within a few percent of MODTRAN results, but with orders of magnitude speed up over comparable MODTRAN runs. This new RT capability has potential applications for hyperspectral scene simulations as well as target acquisition algorithms for near earth scenarios.

6565-63, Session 13

Analysis of hyperspectral change and target detection as affected by vegetation and illumination variations

J. Meola, Air Force Research Lab.

This paper covers the use of detection algorithms on hyperspectral data of a scene collected over several seasons. The effectiveness of specific target detection algorithms on scenes with different illumination conditions such as shadows, low sun angles, and seasonal vegetation changes is examined. Various algorithms are currently employed to detect anomalies within a scene. Specifically, a simple Mahalanobis distance measure and spectral matched filter algorithm are often employed on hyperspectral data to detect specific objects within a scene. These algorithms are limited to use on a single scene acquired at a specific time. When hyperspectral data from the same scene at different times is available, more sophisticated algorithms utilizing linear predictors such as chronochrome and covariance equalization are used for detection. These change detection algorithms attempt to suppress background in order to focus on more prominent alterations within the scene.

Using a push-broom style imaging spectrometer mounted on a pan and tilt, visible to near infrared data of a scene containing specific objects is gathered. Hyperspectral system characterization and calibration is performed to ensure viable data is produced. Data collection occurs from late August 2005 until May 2006 to obtain a wide range of illumination and vegetation conditions. After collecting and calibrating the scene data, the change detection algorithms are employed to assess background suppression for various conditions. These scene conditions can include daily illumination change, seasonal illumination change, and seasonal vegetation change. Often, the chronochrome and covariance equalization predictors work well for certain portions of the scene but struggle in others. This result demonstrates how areas of a scene may undergo different temporal transformations. In addition, comparing the change detection algorithms to single instance methods allows for the assessment of any advantages offered by a specific method. Using a signal to clutter ratio, the various algorithms are evaluated and conclusions are drawn.

6565-64, Session 13

Use of spectral clustering to enhance clutter suppression

M. T. Eismann, Air Force Research Lab.

Hyperspectral change detection has been shown to be promising approach for detecting subtle targets in complex backgrounds. Reported change detection methods are typically based on linear predictors that assume a space-invariant affine transformation between image pairs. Unfortunately, several physical mechanisms can lead to significant space variance in the spectral change associated with background clutter, including shadowing and other illumination variations as well as seasonal impacts on the spectral nature of vegetation, and this can lead to poor change detection performance. This paper outlines a methodology to deal with such space-variant change using spectral clustering and other related least-squares optimization techniques. Several specific algorithms are developed and applied to change imagery captured under controlled conditions, and the impacts on clutter suppression are quantified and compared. The results indicate that such techniques can provide markedly increased clutter suppression when the environmental conditions associated with the image pairs are substantially different.

6565-65, Session 13

Resampling approach for anomalous change detection

J. Theiler, S. J. Perkins, Los Alamos National Lab.

We investigate the problem of identifying pixels in pairs of co-registered images that correspond to real changes on the ground. Changes that are due to environmental differences (illumination, atmospheric distortion, etc.) or sensor differences (focus, contrast, etc.) will be widespread throughout the image, and the aim is to avoid these changes in favor of changes that occur in only one or a few pixels. Formal outlier detection schemes (such as the one-class support vector machine) can identify rare occurrences, but will be confounded by pixels that are "equally rare" in both images: they may be anomalous, but they are not changes. We describe a resampling scheme we have developed that formally addresses both of these issues, and reduces the problem to a binary classification, a problem for which a large variety of machine learning tools have been developed. In principle, the effects of misregistration will manifest themselves as pervasive changes, and our method will be robust against them — but in practice, misregistration is a serious issue, and we will describe efforts to ameliorate its effects.

6565-66, Session 13

An FPGA implementation of image space reconstruction algorithm for hyperspectral imaging analysis

J. Morales, N. G. Santiago, A. Fernandez, Univ. de Puerto Rico Mayagüez

The Image Space Reconstruction Algorithm (ISRA) has been used in hyperspectral imaging applications to monitor changes in the environment and specifically, changes in coral reef, mangrove, and sand in coastal areas. This algorithm is one of the set of iterative methods used in the hyperspectral imaging area to estimate abundance. However, ISRA is highly computational, making it difficult to obtain results in a timely manner. In this paper we present the use of specialized hardware in the implementation of this algorithm, specifically the use of VHDL and FPGAs. The implementation of ISRA algorithm has been divided into hardware and software units. The hardware units were implemented on a Xilinx Virtex II Pro XC2VP30 FPGA and the software was implemented on the Xilinx Microblaze soft processor. This case study illustrates the feasibility of this alternative design for iterative hyperspectral imaging algorithms. The main bottleneck found in this implementation was data transfer.

6565-67, Session 13

Maintaining CFAR operation in hyperspectral target detection

D. G. Manolakis, D. Zhang, MIT Lincoln Lab.

One of the primary motivations for statistical LWIR background characterization studies is to support the design, evaluation, and implementation of algorithms for the detection of various types of ground targets. Typically, detection is accomplished by comparing the detection statistic for each test pixel to a threshold. If the statistic exceeds the threshold, a potential target is declared. The threshold is usually selected to achieve a given probability of false alarm. In addition, in surveillance applications, it is almost always required that the system will maintain a constant false alarm rate (CFAR) as the background distribution changes. This objective is usually accomplished by adaptively estimating the background statistics and adjusting the threshold accordingly. In this paper we propose and study

CFAR threshold selection techniques, based on tail extrapolation, for a matched filter operating on hyperspectral imaging data. The basic idea is to obtain reliable estimates of the background statistics at low false alarm rates, and then extend these estimates beyond the range supported by the data to predict the thresholds at lower false alarm rates. The proposed techniques are based on the assumption that the distribution in the tail region of the matched filter statistics is accurately characterized by a member of the extreme value distributions. We focus on the generalized Pareto distribution. The evaluation of the proposed techniques will be done with both simulated data and real hyperspectral imaging data collected using the AVIRIS sensor and the Army Night Vision Laboratory COMPASS sensor.

6565-69, Session 14

Detecting changes in scenes using autonomous smart cameras

H. M. Jaenisch, dtech Systems Inc.; J. Handley, Licht Strahl Engineering Inc.; M. Hicklen, dtech Systems Inc.

This paper describes a novel smart camera algorithm capable of detecting important changes in scenes. These changes can take the form of observed crowd dynamics, group behavior, and mounted and unmounted traffic flow. Using webcam imagery of a football game and out a corner office window overlooking a street, these cameras successfully exhibited scene understanding and detected anomalies without prior training or examples. Our algorithm and results are summarized in this paper.

6565-70, Session 14

PM10 retrieval in urban area from space

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, Univ. Sains Malaysia (Malaysia)

This study determined the relationship between in situ and remote sensing observation to derive an algorithm for PM10 mapping. The main objective of this study was to test the feasibility of using Landsat TM imagery captured on 17 January 2002 for PM10 mapping over Penang Island, Malaysia. A new algorithm was developed based on the aerosol characteristic for air quality estimation. The corresponding PM10 data were measured simultaneously with the acquisition of satellite scene for algorithm regression analysis. Accuracy of the retrieved surface reflectance values is very importance to determine the atmospheric component from the remotely sensed data. In this study, we computed the surface component properties by using ACTOR2 in the PCI Geomatica 9.1 image processing software. The proposed algorithm produced high correlation coefficient (R) and low root-mean-square error (RMS) between the measured and estimated PM10 values. A PM10 map was generated using the proposed algorithm. Finally, the created PM10 map was geometrically corrected and colour-coded for visual interpretation. This study indicated the usefulness of remotely sensed data for air quality studies using the proposed algorithm.

6565-71, Session 14

PM10 retrieval over the water surface of Penang Straits

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, Univ. Sains Malaysia (Malaysia)

In this study, we used the Landsat TM data captured on 9 March 2006 for the retrieval of PM10 over the water surface of Penang Straits, Malaysia. PM10 measurements were collected using a handheld DustTrakTM meter simultaneously with the remotely sensed data acquisition. The PCI Geomatica version 9.1 digital image processing software was used in all image-processing analysis. An algorithm was developed based on the atmospheric optical characteristic. The digital numbers were extracted corresponding to the ground-truth locations for each band and then converted into radiance and reflectance values. The reflectance measured from the satellite [reflectance at the top of atmospheric, * (TOA)] was subtracted by the amount given by the surface reflectance to obtain the atmospheric reflectance. Then the atmospheric reflectance was related to the PM10 using regression analysis. These atmospheric reflectance values were used for calibration of the PM10 algorithm. The developed algorithm was used to correlate the digital signal and the PM10 concentration. The proposed algorithm produced a high correlation coefficient (R) and low root-mean-square error (RMS). The PM10 concentration was generated using this algorithm over the water surface of Penang straits.

6565-72, Session 15

Framework development for spectral libraries of natural hyperspectral backgrounds

M. A. Glennon, J. J. Cipar, Air Force Research Lab.; D. G. Manolakis, MIT Lincoln Lab.; R. B. Lockwood, Air Force Research Lab.; P. Grisgby, J. Jacobson, NASIC/DEKA

The reflectance spectra of natural backgrounds are often assumed to be drawn from a multivariate normal population, characterized by a mean spectrum and covariance matrix. Recent work has shown that even for background populations carefully screened using clustering algorithms, significant spectral outliers are present. These outliers suggest that the normal distribution model is not adequate and that more sophisticated distributions are required. In a prior study, statistical properties of natural hyperspectral backgrounds were modeled with distinct combinations of Gaussian body and t-elliptically contoured distributions, representing the heaviness of the tails. Moreover, intrinsic variability in hyperspectral backgrounds are required input to realistic modeling efforts. For example, performance evaluation of algorithms for hyperspectral imaging sensors depends on the characteristics of background distributions. The goal of this paper is to develop the framework for spectral libraries of natural backgrounds using a small number of parameters and to demonstrate that enough information has been captured to reproduce the full variability of the dataset.

We will present examples of background spectral libraries developed from low-altitude AVIRIS imagery along with required metadata. Next, the spectral statistics of the original reflectance spectra will be used to predict at-sensor radiance using the radiative transfer code, MODTRAN. The challenge will be to ensure that the observed variability in the imagery has been captured by the statistics and associated metadata.

6565-73, Session 15

Random sampling statistical analysis for adaptive target-scale-invariant hyperspectral anomaly detection

J. M. Romano, U.S. Army Armament Research, Development and Engineering Ctr.; D. S. Rosario, Army Research Lab.

The proposed paper focuses on the autonomous clutter background characterization (ACBC) achieved by a random sampling model and a parallel process to mitigate the inclusion of target samples by chance into clutter background classes during the process of randomly sampling the input imagery. This method handles underlying difficulties (e.g., target scale uncertainties) facing the development of autonomous anomaly detection algorithm. Suppose an N number of spectrum sets are randomly collected from the imagery, such that each set is tested against spectra from a window that moves across the imagery yielding N output surfaces from an anomaly detector. These N surfaces are fused by retaining the piecewise minimum at each pixel location, producing a single output surface (FMIN). In FMIN, blocks of data in the original imagery that are significantly different from the sampled N sets should be accentuated with respect to the spatial locations of the clutter background. To minimize the suppression probability of targets in the imagery by chance, a parallel process is introduced to repeat this sampling process M number of times and to yield a decision surface by adding these M FMIN surfaces. The rationale here is that the likelihood of suppressing the presence of targets in all M FMIN surfaces is small but real, and the motivation for proposing such scheme, rather than comparing blocks of data across the imagery against data surrounding these blocks, is that target scales are unknown and may vary in a short period of time for many Army Applications.

6565-74, Session 15

A comparative study and analysis between vertex component analysis and orthogonal subspace projection for endmember extraction

C. Wu, W. Liu, Univ. of Maryland/Baltimore County; H. Ren, National Central Univ. (Taiwan); C. Chang, Univ. of Maryland/Baltimore County

Endmember extraction has received considerable interest in recent years. Of particular interest is the Pixel Purity Index (PPI) because of its publicity and availability in ENVI software. There are also many variants of the PPI have been developed. Among them is an interesting endmember extraction algorithm (EEA), called vertex component analysis (VCA) developed by Dias and Nascimento who extend the PPI to a simplex-based EEA while using orthogonal subspace projection (OSP) as a projection criterion rather than simplex volume used by another well-known EEA, N-finder algorithm (N-FINDR) developed by Winter. Interestingly, this paper will show that the VCA is essentially the same algorithm, referred to as Automatic Target Generation Process (ATGP) recently developed for automatic target detection and classification by Ren and Chang except the use of the initial condition to initialize the algorithm. In order to substantiate our findings, experiments using synthetic and real images are conducted for a comparative study and analysis.

6565-75, Session 15

Impact of missing endmembers on the performance of the OSP detector for hyperspectral images

P. Bajorski, Rochester Institute of Technology

In evaluating the performance of the detectors such as the orthogonal subspace projection (OSP) detector, it is often assumed that the model under which the detector is constructed is the correct model. However, in practice, the ability to identify all background endmembers might be limited. Consequently, the OSP detector would use only a subset of all background endmembers. This clearly creates sub-optimality of such a detector. In this paper, we perform analytical calculations that allow us to assess how much of the detection power is lost due to the unidentified background endmembers. An analytical comparison is made between two OSP detectors-one using only the identified endmembers and the other one using even a smaller set of endmembers (in order to simulate the situation when only the smaller set of endmembers is identified).

6565-76, Session 15

Statistical models for LWIR hyperspectral backgrounds and their applications in chemical agent detection

D. G. Manolakis, D. Zhang, MIT Lincoln Lab.

Remote detection of chemical vapors in the atmosphere has a wide range of civilian and military applications. In the past few years there has been significant interest in the detection of effluent plumes using hyperspectral imaging spectroscopy in the 8-12- * m atmospheric window. A major obstacle in the full exploitation of this technology is the fact that everything in the infrared is a source of radiation. As a result, the emission from the gases of interest is always mixed with emission by the more abundant atmospheric constituents and by other objects in the sensor field of view. The radiance fluctuations in this background emission constitute an additional source of interference which is much stronger than the detector noise. In this paper we develop and evaluate parametric models for the statistical characterization of LWIR hyperspectral backgrounds. We consider models based on the theory of elliptically contoured distributions and the theory of extreme value distributions. Both models can handle heavy tails, which is a key feature of hyperspectral imaging backgrounds. The paper provides a concise description of the underlying models, the algorithms used to estimate their parameters from the background spectral measurements, evaluation of the goodness-of-fit, and the use of the developed models in the design and evaluation of chemical warfare agent detection algorithms.Remote detection of chemical vapors in the atmosphere has a wide range of civilian and military applications. In the past few years there has been significant interest in the detection of effluent plumes using hyperspectral imaging spectroscopy in the 8-12- * m atmospheric window. A major obstacle in the full exploitation of this technology is the fact that everything in the infrared is a source of radiation. As a result, the emission from the gases of interest is always mixed with emission by the more abundant atmospheric constituents and by other objects in the sensor field of view. The radiance fluctuations in this background emission constitute an additional source of interference which is much stronger than the detector noise. In this paper we develop and evaluate parametric models for the statistical characterization of LWIR hyperspectral backgrounds. We consider models based on the theory of elliptically contoured distributions and the theory of extreme value distributions. Both models can handle heavy tails, which is a key feature of hyperspectral imaging backgrounds. The paper provides a concise description of the underlying models, the algorithms used to estimate their parameters from the background spectral measurements, evaluation of the goodness-of-fit, and the use of the developed models in the design and evaluation of chemical warfare agent detection algorithms.

6565-77, Poster Session

Comparison among some anomaly detection approaches for hyperspectral imagery

S. R. Soofbaf, H. Fahimnejad, M. J. Valadan Zoej, B. Mojaradi, K.N. Toosi Univ. of Technology (Iran)

Nowadays the use of hyperspectral imagery specifically automatic target detection algorithms for these images is a relatively exciting area of research.

An important challenge of hyperspectral target detection is to detect small targets without any prior knowledge, particularly when the interested targets are insignificant with low probabilities of occurrence.The specific characteristic of anomaly detection is that it does not require atmospheric correction and signature libraries. Recently, several useful applications of anomaly detection approaches have been developed in remote sensing.

With this in mind, in this paper some anomaly detectors such as RX-based anomaly detectors, Gauss-Markov random field (GMRF) model,CFT model,as well as adaptive anomaly detectors,are compared. Finally the most efficient method is proposed for implementation in a planned software system.

6565-78, Poster Session

Fast implementation of N-FINDR algorithm for endmember determination in hyperspectral imagery

A. Chowdhury, M. S. Alam, Univ. of South Alabama

Hyperspectral image processing systems require the extraction of certain basis spectra, called endmembers, which are assumed to be pure signatures in the image data. N-FINDR algorithm is one of the most widely used endmember extraction algorithm. This algorithm is based on the fact that in L spectral dimensions, the L-dimensional volume contained by a simplex formed of the purest pixels is larger than any other volume formed from any other combination of pixels. Recently developed virtual dimensionality (VD) algorithm is used to determine the number of endmembers present in the dataset and an endmember initialization algorithm (EIA) is used to select an appropriate set of pixels for initialization of the N-FINDR technique, which improves the performance of the original algorithm. This paper proposes a fast algorithm to implement the N-FINDR technique using the VD algorithm to find the number of endmembers, N. Then we reduce the dimensionality of the hyperspectral dataset to N-1 by using maximum noise fraction (MNF) technique and then divide all the pixels into N number of classes by using spectral angle mapping. We extract N number of the most pure pixel from each group by classical N-FINDR algorithm but using an exhaustive searching method. Thus we get NÃ~N pixels that are most likely to be the endmembers. Classical N-FINDR algorithm is then again applied on these selected pixels to find

the final N endmembers. Grouping the pixels into several classes makes the computation very fast. Since we extract N number of pixels from each group by exhaustive search, there is no possibility to loose any endmember due to classification. The proposed algorithm has much better computational efficiency than all the existing N-FINDR algorithms.

6565-79, Poster Session

Improved forward floating selection algorithm for detection in hyperspectral imagery

S. Nakariyakul, D. P. Casasent, Carnegie Mellon Univ.

We consider selecting useful features or wavebands in hyperspectral data. Since optimal feature selection algorithms are not feasible in hyperspectral data that contains hundreds of features, we propose the new quasi-optimal improved forward floating selection (IFFS) algorithm, which is an improvement on the well-known sequential forward floating selection algorithm. Our IFFS algorithm is shown to give a higher performance rate than other sub-optimal feature selection algorithms. We test our IFFS algorithm to detect contamination on hyperspectral poultry imagery. Our initial results indicate that our method gives an excellent detection rate and performs better than other sub-optimal feature selection algorithms.

6565-80, Poster Session

Target detection in high-dimensional space using a stochastic expectation maximization algorithm

M. Karakaya, M. S. Alam, M. I. Elbakary, Univ. of South Alabama

This paper presents an object detection algorithm based on stochastic expectation-maximization (SEM) algorithm. SEM algorithm is based on the stochastic, expectation, and maximization steps to iteratively estimate the parameters of the classes in many applications including hyperspectral data cube (HDC). However, the application of SEM algorithm for classification of hyperspectral imagery becomes impractical because of the huge amount of data (e.g. 512 x 512 x 220).

To avoid this problem, we proposed a preprocessing step for SEM algorithm to fast classify the data cube formulating an Object Detection algorithm based on SEM for detecting small objects in hyperspectral imagery. In the proposed preprocessing step, we utilize the exponential of Euclidian Distance for rapidly separation of data cube into a potential object of interest class and a background class. Then, SEM algorithm is employed to classify the potential object of interest class further into classes to detect the object of interest class. In the conducted experiments using real hyperspectral imagery, the results of the proposed algorithm show comparatively low false alarm rate even with a challenging scenarios.

6565-81, Poster Session

Change detection for hyperspectral imagery

A. K. Shaw, K. Vongsy, S. Karimkhan, Wright State Univ.; D. Wicker, Air Force Research Lab.

Change Detection (CD) is the process of identifying and examining temporal or spectral changes in signals. Detection and analysis of change provide valuable information of possible transformations in a scene. Hyperspectral imaging (HSI) sensors are capable of collecting hundreds of narrow spectral bands of data. Such sensors provide high-resolution spatial and spectrally rich information that can be exploited for Change Detection. This paper develops and analyzes various HSI algorithms for the detection of changes using Hyperspectral images. For the validation and performance comparisons, changes obtained are compared with the conventional similarity correlation coefficient as well as traditional change detection algorithms, such as image differencing, image ratioing, and principle component analysis (PCA) methods. Another main objective is to incorporate Kernel based optimization by using a nonlinear mapping function. Development of nonlinear versions of linear algorithms allows exploiting nonlinear relationships present in the data. The nonlinear versions, however, become computationally intensive due to the high dimensionality of the feature space resulting in part from application of the nonlinear mapping function. This problem is overcome by implementing these nonlinear algorithms in the high-dimensional feature space in terms of kernels. Preliminary work on dismount tracking using change detection over successive HSI bands has shown promising results. We study the Kernelization of a similarity correlation coefficient algorithm via Hyperspectral change detection applications for possible improvement in performance.

6565-82, Poster Session

Automated recognition and detection of dismounts and vehicles using close-in urban hyperspectral images

A. K. Shaw, S. Karimkhan, K. Vongsy, Wright State Univ.; D. Wicker, Air Force Research Lab.

Recent advances in Hyperspectral imaging (HSI) sensor offer new avenues for precise detection, identification and characterization of materials or targets of military interest. HSI technologies are capable of exploiting 10s to 100s of images of a scene collected at contiguous or selective spectral bands to seek out mission-critical objects. In this paper, we develop and analyze novel HSI algorithms for detection, recognition and tracking of dismounts, vehicles and other man-made objects. Preliminary work on dismount/vehicle detection has been performed using Principal Component Analysis (PCA) of visible band HSI data and the results indicate improved performance with HSI when compared to traditional EO processing. We plan to incorporate kernel based optimization methods in order to improve detection and classification performance. This is done by using what is known as the kernel-trick, which converts a linear classifier algorithm into a non-linear one, by mapping the original observations into a higher-dimensional non-linear space so that linear classification in the new space is equivalent to non-linear classification in the original space. In addition to traditional HSI algorithms, such as PCA, Linear Discriminant Analysis method (LDA) and Independent Component Analysis (ICA), Spectral Information Measure (SIM), we study the Kernelization of these approaches for possible performance improvement.

6565-83, Poster Session

Evaluation of PCA dimensionality reduction techniques in imaging spectroscopy for foreign object detection

O. M. Conde, M. Amado, P. B. Garcia-Allende, A. Cobo, J. M. López-Higuera, Univ. de Cantabria (Spain)

Foreign object detection processes are improving thanks to imaging spectroscopy techniques through the employment of hyperspectral systems such as prism-grating-prism spectrographs. These devices offer a valuable but sometimes huge and redundant amount of spectral and spatial information that facilitates the classification and sorting procedures of materials in industrial production chains. Processing techniques whose aim is the reduction of the number of significant spectral features will be desirable to accelerate the automatic classification operations and to achieve real-time operation conditions. The spectral correlation that exists between the narrow spectral bands in the hyperspectral image enables this dimensionality reduction. In this work different algorithms of supervised and non-supervised Principal Components Analysis (PCA) are thoroughly applied on the experimentally acquired hyperspectral images. The evaluated PCA versions implement different statistical mechanisms to maximize the class separability. PCA alternatives (method-M, J-measure, Sepcor and Supervised PCA) are compared evaluating how the achieved spectral compression affects the classification performance in terms of accuracy and execution time. During the whole process, the classification stage is maintained and comprised by an Artificial Neural Network (ANN). The developed techniques have been probed and successfully checked in tobacco industry where detection of plastics, cords, cardboards, papers, textile threads, etc. must be done in order to enter only tobacco leaves in the industrial chain. Obviously, the developed technique could be applied to the classification and discrimination of other materials once their identification spectra will be properly characterized.

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6566-01, Session 1

Phenomenological modeling of surface roughness for predicting reflected and emitted polarization from targets

L. B. Wolf, Equinox Corp.

No abstract available

6566-02, Session 1

Minace IR ATR (classification and rejection) tests with aspect view, scale, depression angle, and thermal state variations

R. Patnaik, D. P. Casasent, Carnegie Mellon Univ.

In this paper, we examine the sensitivity of minimum noise and correlation energy (MINACE) filters to different types of variations (aspect view, scale, depression angle, and thermal state) that are typically present in IR imagery. Prior Minace ATR work has addressed at most two simultaneous variations - aspect view and depression angle variations for SAR data, and aspect view and thermal state variations for IR data. <i\>No prior Minace ATR work has addressed scale variations.</i\> In our tests, we consider up to three types of simultaneous variations, e.g. aspect view, scale and depression angle variations. Our goal is to determine if one Minace filter can handle all aspect view variations, and to determine the range of scales and depression angles that a Minace filter can handle before and after training on data at more than one scale and / or depression angle. We use our autoMinace algorithm that uses a training and a validation set to select the Minace filter parameter <i\>c</i\> (which selects emphasis on recognition or discrimination) and to select the training set images to be included in the filter, so that the filter can achieve both good recognition and good confuser and clutter rejection performance. No confuser, clutter, or test set data are present in the training or the validation set. We present test results using both real and CAD IR data; we address the recognition of variants and the rejection of confuser objects and clutter in our tests. We also present initial work on the use of multiple aspect view filters per object.

6566-04, Session 1

Automatic aerial target detection and tracking system in airborne FLIR images based on efficient target trajectory filtering

C. R. del Blanco-Adan, F. F. Jaureguizar, L. L. Salgado, N. N. García, Grupo de Tratamiento de Imagenes (Spain)

An automatic detection and tracking system for aerial moving targets in airborne forward-looking infrared images is presented. When clutter is absent, so the background is a clear sky, common strategies offer accurate results for the detection of aerial targets. On the other hand, when clouds and earth regions appear in the background, those strategies result in an over-detection which increases very significantly the false alarm probability. However, the clutter is mainly static and therefore it can be removed using a motion-based filtering strategy. Nevertheless, this procedure cannot be applied in airborne cameras where their movement yield a global motion in the sequences [1][2]. In this work, an innovative and efficient target trajectory filtering with global motion compensation strategy is proposed, allowing to detect accurately the aerial targets and remove the static clutter in images with ego-motion. Moreover, this strategy makes special emphasis in low complexity approaches to implement a real-time system. The global motion compensation is divided into three processing phases [1][2][3]. Firstly, a selection of the image regions optimum for the compensation is carried out. Secondly, the motion is estimated by a predictive diamond-pattern search block-matching technique [4], and the obtained motion vectors are filtered through adaptive thresholding based on the image noise estimation. Thirdly, a rigid transformation inferred from the motion vectors field is used to warp the image. After global motion compensation, potential aerial targets are detected through a combination of gradient and morphology based techniques. Finally, potential targets are tracked by template correlation techniques [5] and their trajectories are analysed: first filtering the data trajectory through a Kalman filter and then applying a curve fitting technique [6], discarding the objects with no motion o erratic trajectory. Tests using the proposed strategy on real air-to-air sequences show a dramatic reduction of the false alarm rate while maintaining the detection rate.

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6566-05, Session 1

Ground-target detection in a virtual battlefield

P. Gozard, DGA/DSP/Tour DGA (France)

To perform multi-sensors simulations, the French DGA/DET (Directorate for Technical Evaluation of the French Ministry of Defense) uses CHORALE (simulated Optronic Acoustic Radar battlefield). CHORALE enables the user to create virtual and realistic multi spectral 3D scenes, and generates the physical signal received by one or several sensors, typically an IR sensor or an acoustic sensor. This article presents how the expertise is made to evaluate smart ammunition to detect ground target with infrared sensor and shape detector in a virtual battlefield with the environment CHORALE and the workshop AMOCO. The scene includes background with trees, houses, roads, fields, targets, and the ammunition. Each tool is explained to understand the physics phenomena in the scene to take into account atmospheric transmission, radiative parameters of objects and counter-measure devices. Then numeric models are described as the 6 DOF ballistics models, sensor model according precise positions inside the ammunition as well as the different steps of calculation between industrial model and technical model to obtain the global simulation. Finally, this paper explains some results of the evaluation compared with the true behavior after tests on proving ground. Then future evolutions are presented to perform similar evaluation with other kind of intelligent ammunition in a real-time model.

6566-06, Session 1

Efficient feature selection for real-time object detection

C. Yu, Z. Yue, P. Topiwala, FastVDO LLC

AdaBoost may be the most successful method for real-time object detection. However, its training procedure is very time consuming. Previous AdaBoost training methods use forward or floating search to select the best several hundreds features out of millions of rectangle-like Haar feature candidates. The typical training time will be up to several weeks. Current greedy selection or float search method didn't exploit the huge redundancy among the extracted features. Some

researcher use post-processing method to remove the redundancy of the selected features after training. However, this won't decrease the training time. If most of redundant features can be removed by pre-processing feature selection without training, then the training time will be greatly reduced. Due to the high dimension of the feature space, general wrapper approaches for feature selection will be extremely slow. In this paper, we propose a hybrid feature selection method for AdaBoost object detection. First, the feature pool is clustered into subsets based on the feature similarity. After that, using filter approach with Fisher discriminant analysis, only partial of each cluster will be selected for training. During training, floating search will be integrated to avoid the nesting effect of forward search. The experimental results will validate the feasibility of the proposed feature selection method. Performance comparison will be done with FloatBoost and post-processing feature selection using SVM.

6566-07, Session 1

Low-complexity motion analysis and segmentation for target detection using portable computing platforms

P. Topiwala, A. V. Nehemiah, FastVDO LLC

A low complexity motion analysis and segmentation system to perform target detection using low-power portable computing hardware is presented. We present a hierarchical block-matching algorithm that estimates the optical flow vectors (motion vectors) for each pixel with sub-pixel accuracy. These motion vectors are used to perform motion analysis and geometric correction of the images (motion compensation). An algorithm is presented to detect motion of objects in the scene using local motion estimation and segmentation. Input images are geometrically mapped to a reference image from the image stream to provide image stabilization. The algorithm presented in this paper is implemented on a portable computing hardware to perform motion based target detection in real time.

6566-09, Session 1

Wavelet-based target detection using multiscale directional analysis

B. J. Chambers, W. Reynolds, Jr., ITT Visual Information Solutions; D. Campbell, ITT Industries; R. Ansari, Univ. of Illinois/Chicago

Research into methods that efficiently process imagery derived from remote sensing systems has become exceedingly important due to increasing data sizes, rates, and bit depths. Wavelets have been studied for compression for a number of years to address this need; however, advanced processing that exploits the hierarchical, statistical, structural, and directional properties of advanced wavelets to facilitate target recognition has only recently begun to be explored. This paper describes an algorithm that uses edge information derived from directional wavelet decompositions to detect targets of known dimension in electro-optical imagery. The decomposition is carried out using a bank of filters with narrow wedge-shaped passbands that help extract denoised edges of different orientations in the images. The edge information is refined with the use of morphological operations after which potential target regions are identified and features compared with available reference target information. The approach highlights many of the benefits of working with advanced wavelet analysis, versus traditional Fourier and spatial domain processing, for image denoising, detection, and recognition.

6566-09, Session 2

Three-dimensional passive sensing photon counting for object classification

B. Javidi, S. Yeom, Univ. of Connecticut; E. A. Watson, Air Force Research Lab.

No abstract available

6566-10, Session 2

Real-time adaptive classification environment using rules (RACER)

R. S. Eaton, M. S. Snorrason, Charles River Analytics, Inc.

Automatic Target Recognition (ATR) algorithms are extremely sensitive to differences between the operating conditions under which they are trained and the extended operating conditions (EOCs) in which the fielded algorithms operate. These EOCs can cause a target's signature to differ drastically from training exemplars, causing an ATR algorithm that was specifically trained under one set of conditions to perform sub-optimally under novel conditions. Rather than trying to create an ATR to handle all EOCs, we can significantly improve recognition accuracy by decomposing target recognition into solvable sub-problems. By subdividing the training data and training a number of classifiers, each expert in a specific operating condition, we can leverage the power of classifiers to learn specifics about a dataset while limiting the amount of generalization required from any one classifier.

We have developed an ATR system, called Real-time Adaptive Classification Environment using Rules (RACER), which subdivides training data based on characteristics of the data itself. Each subset of training samples is used to train an individual classifier, which is an expert in the conditions represented by that training set. Each classifier adaptively selects the best features for classifying targets under its specific conditions. At runtime, RACER uses the same data characteristics to determine which conditions are represented in the test sample. The expert classifier appropriate for the detected conditions then uses its best features to classify the target. We demonstrate performance improvements for this method of adaptive classifier selection and discuss a number of design considerations for adaptive ATR systems.

6566-11, Session 2

Evaluation of the VIVID confirmatory identification module

K. J. Erickson, Jacobs Engineering

The DARPA Video Verification of Identity (VIVID) program has as its goal the development of the best tracker ever. This goal is reached through a philosophy of on-the-fly target modeling and the use of three distinct modules: a multiple-target tracker, a confirmatory identification module, and a collateral damage avoidance/moving target detection module. Over the two years of VIVID Phase I, progress appraisal of the ATR-like confirmatory identification module was provided to DARPA by the Air Force Research Laboratory COMPASE Center through regular evaluations. This document begins with an overview of the VIVID system and its approach to solving the tracking problem. A survey of the data collected under VIVID auspices and its use in the evaluation are then described, along with the operating conditions relevant to confirmatory identification. Finally, the evaluation structure is presented in detail, including metrics, techniques, support tools, and experiment design.

6566-12, Session 2

High-performance polarization-enhanced wavelet joint-transform correlation for automated multiple target recognition system

A. M. El-Saba, M. S. Alam, H. Nalluri, Univ. of South Alabama

An efficient multiple target recognition technique which combines the inherited enhancement of the optical polarization field with the feature enhancement of the wavelet filter is proposed in this paper. The wavelet filter is superimposed on the joint power spectrum before the correlation output is produced. It is shown that the proposed technique yields cumulative target discrimination capabilities for automatic single/multiple target recognition applications.

6566-13, Session 2

Development of a long-wave infrared polarimetric imaging system

F. A. Sadjadi, C. Holden, Jr., Lockheed Martin Corp.; C. S. L. Chun, Physics Innovations, Inc.; W. T. Yenisch, Lockheed Martin Corp.; R. J. Johnson, Lockheed Martin Co.

Polarimetric diversity is an area of growing interest in computer vision, remote sensing, surveillance and reconnaissance. This interest has generated a need for development of fully polarimetric sensors in all areas of electromagnetic spectrum.

In this paper we provide a summary of our work in developing a long-wave infrared, 8-14 microns, polarimetric imaging sensor. The sensor is capable of capturing in real-time Stokes vector parameters at each pixel in the imagery without loss in resolution or need for registration. Result of using this system in number of applications will be provided.

6566-14, Session 3

Application of interferoceiver for battleship self defense

M. Li, Consultant

The ability of interferoceiver [1] to reveal micro Doppler signatures from a single radar pulse opens a new era in automatic target recognition. The present talk considers a real scenario to illustrate the power of such ability. In July 3, 1988, a United States Navy battleship in the Persian Gulf shot down an Iranian passenger plane. The Navy said it mistook it for a jet fighter. The incident killed all 290 people on board the passenger plane. The tragedy arose from battleship self defense to eliminate any perceived hostile aircraft within the guarded zone.

This is a classical case of misidentification. Micro Doppler signatures of a jet fighter are completely different from those of a passenger plane. Conventional Doppler radar receivers, which are based on super heterodyne, cannot distinguish between those differences to avoid the above tragedy. It will be shown in the present talk that the differentiation can be easily accomplished through interferoceiver. Hence, the tragedy could have been avoided and the safety of the battleship assured.

1. M. C. Li, “Interferoceiver, ISAR, and Passive Identification,” in “Automatic Target Recognition XVI, edited by Firooz A. Sadjadi, Proceedings of SPIE Vol. 6234 (SPIE, Bellingham, WA, 2006) 62340T

6566-15, Session 3

Radar classification of landmines by time-frequency analysis

D. C. Wong, L. H. Nguyen, G. C. Gaunaurd, Army Research Lab.

A flying platform illuminates a land mine field containing mixtures of various types of landmines (i.e., plastic or metallic, buried or on the surface, etc) and some ‘confusers’, with an ultra-wideband (UWB) radar. The polarimetric echoes returned by the mine field, mapped into a synthetic aperture radar (SAR) image, are then analyzed pixel-by-pixel by modern time-frequency (t-f) techniques. The echoes of any of the scatterers in the field can be (and have been) analyzed by a number of t-f distributions, which in turn generate two-dimensional plots of each scatterer in t-f space. These plots are richer in information than those in the original SAR image. Some t-f distributions are better than others for the present purpose of target classification. We find that the pseudo-Wigner-Ville and the Choi-Williams distributions provide the best discrimination results. Larger mines such as those here denoted ‘type-1’ are easiest to identify. Using the above distributions, the distinction between actual mines and clutter objects (or ‘confusers’) becomes clearer, particularly for metallic objects. Numerous images obtained here in t-f space from realistic battlefield environments confirm the above conclusions.

6566-17, Session 3

Feature extraction for classification of signals propagating in channels with dispersion and dissipation

G. Okopal, P. J. Loughlin, Univ. of Pittsburgh

In active sonar or radar, if the channel is spatially-varying (e.g., shallow water channels), then the received target echo will change with propagation distance, such that identical target echoes may not be identified as such if they propagated over different distances. Two common propagation effects that induce changes in the signal are dispersion and dissipation (or damping), which give rise to frequency-dependent velocity of propagation and frequency-dependent attenuation, respectively. We have previously developed a feature extraction process for target echoes in dispersive channels, to obtain moment-like features that are invariant to dispersion, per mode. Accordingly, even though the target echo changes with propagation in a dispersive channel, the “dispersion-invariant moment” features do not. However, these moment features are affected by damping. In this presentation, we consider the case of a channel with dispersion and damping, and present methods to obtain features that are (approximately) invariant to both phenomena. Results are presented from classification simulations to demonstrate the utility of these features.

6566-18, Session 3

Time-varying spectral moments and distributions

L. Cohen, Hunter College/CUNY; K. L. Davidson, Office of Naval Research; P. J. Loughlin, Univ. of Pittsburgh

A distribution is uniquely determined by its moments, except for pathological cases. For time-varying signals many time-frequency distributions have been defined and applied. Although these distributions do not have all of the properties of legitimate distributions (and hence are often called quasi-distributions), they do satisfy many of these properties. One important property they satisfy is that their moments determine the distribution. However, as is the case with standard probability distributions, a finite set of moments does not determine a particular distribution: many distributions have the same moments up to a fixed (finite) order. We examine the issue of time-varying spectral moments of signals, and address the following questions:

1. For a finite set of moments, how can one characterize the time-frequency distributions having these moments?

2. From all the possible distributions, which are the most effective in estimating important parameters such as the instantaneous frequency and group delay, given a finite set of moments?

3. Which moments are robust to noise?

4. For the case of random processes, one defines a time-varying power spectrum (in contrast to a distribution). How can one use moments of random signals to characterize the time-varying spectrum?

5. What are the conditions for a set of time-varying moments to be consistent with each other (the answer is known for the Wigner distribution but not for other distributions)?

6566-19, Session 4

Pattern recognition in hyperspectral imagery using one-dimensional maximum average correlation height filter and Mahalanobis distance

M. F. Islam, M. S. Alam, Univ. of South Alabama

Target detection in hyperspectral imagery is a challenging task as the targets occupy only a few pixels. The presence of noise makes the detection process more complicated by changing the spectral signature of pixels. This paper proposes a novel technique for target detection in hyperspectral imagery using one dimensional maximum average correlation height (MACH) filter. MACH filter is a type of matched spatial filter which has widely been used for spatial aperture radar, laser radar, forward looking infrared and other classes of two-dimensional images to train and detect objects. We developed a modified one-dimensional MACH filter which is trained using likely variations of the target spectral signatures by adding Gaussian noise to a given signature. Each pixels of the input scene is then compared with the detection filter using the Mahalanobis distance. Based on the distance between the trained filter and the pixels of the imagery, two classes are formed, named, the background class which does not contain a desired object, and the object class which contains the desired object. By applying a threshold boundary, a decision is then made whether a given pixel belongs to the background class or to the object class. The simulation results using real life hyperspectral imagery show that the proposed technique can detect and classify the desired objects with a high degree of efficiency even for very small and scattered targets.

6566-21, Session 4

Nonlinear unmixing of hypespectral data using BDRF and maximum likelihood algorithm

M. T. Rahman, M. S. Alam, Univ. of South Alabama

In this paper, we proposed a non linear unmixing matching algorithm using Bidirectional reflectance function (BDRF) and Maximum liklihood estimation (MLE). Spectral unmixing algorithms are used to determine the contribution of multiple substances in a single pixel of a hyperspectral image. For any kind of unmixing model basic approach is to describe how different substances are combined in a composite spectrum. When a linear reationship exists between the fractional abundance of the substances, linear unmixing algorithms can determine the endmembers present in that particular pixel. When the relationship is not linear rather each substance is randomly distributed in a homogeneous way the mixing is called nonlinear. Though there are plenty of unmixing algorithms based on linear mixing models (LMM) but very few algorithms have developed to to unmix nonlinear data. We proposed a nonlinear unmixing technique using BDRF and MLE and tested our algorithm using both synthetic and real hyperspectral data.

6566-22, Session 4

An automated method for pattern recognition using linear mixing model and vertex component analysis

N. Haq, M. S. Alam, E. Sarigul, Univ. of South Alabama

Now a days detection of man made or natural object using hyperspectral imagery is a great interest of both civilian and military application. With compared to other method, hyperspectral image processing can detect both full pixel and subpixel object by analyzing the fine details of both target and background signatures. There are lots of algorithms to detect hyperspectral full pixel targets. There are also methods to detect subpixel target.

In this paper we have presented an automated method to detect hyperspectral targets using Linear Mixing Model (LMM). In our method we estimated the background endmember signatures Vertex Component Analysis which is a fast algorithm to unmix hyperspectral data after removing target like pixels. Sensor noise is modeled as a Gaussian random vector with uncorrelated components of equal variance. This paper provides a complete and self-contained theoretical derivation of a subpixel target detector using the Generalized Likelihood Ratio Test (GLRT) approach and the LMM.

6566-23, Session 5

Probabilistic graphical models and their application in data fusion and monitoring and control

S. Bottone, C. J. Stanek, DataPath, Inc.

Probabilistic graphical models, in particular Bayesian networks, provide a consistent framework in which to address problems containing uncertainty and complexity. Probabilistic inference in high-dimensional problems only becomes tractable when the system can be made modular by imposing meaningful conditional independence assumptions. Bayesian networks provide a natural way to accomplish this. As a combination of probability theory and graph theory, the probabilistic aspects of a graphical model provide a consistent way of connecting data to models, while graph theory provides an intuitively appealing interface to express independence assumptions as well as efficient computation algorithms. There are three main problems associated with Bayesian networks: 1) Inference: given a model, to compute marginal probabilities on unobserved nodes, given evidence on some subset of other nodes. 2) Learning probabilities: given a model and some data, to estimate the unknown parameters for the local conditional probabilities. 3) Learning structure: given data, to estimate the unknown structure of the graph as well as the underlying local probabilities. Various aspects of Bayesian networks will be demonstrated with examples taken from sensor data fusion and monitoring and control of satellite network systems.

6566-24, Session 5

Target identification using multiradar fusion

I. I. Jouny, Lafayette College

The problem of target recognition using signatures collected by a multi-radar system is investigated in this paper. A comparison between the performance of target recognition systems that fuse the observed signatures with those that fuse the identification decision is established. Multi-radar systems interrogating the same target provide multi-aspect signatures that can enhance, when fused properly, the recognition performance. This paper proposes a signatures fusion scheme as well as a decision fusion mechanism. The recognition performance assuming a target with unknown azimuth is assessed using both systems, and a comparison is established. The performance is assessed using real radar signatures recorded in a compact range setting. The paper highlights scenarios where a multi-radar system provides little advantage for target recognition purposes, and when it can significantly improve the recognition performance. The same approach can be used when dealing with other types of networked sensors.

6566-25, Session 5

Tracking moving targets in complex environment by fusing active and passive sensors

B. G. Fitzpatrick, Z. Cheng, L. Liu, Y. Wang, Tempest Technologies LLC

We present a novel algorithm for tracking with ladar sensors to aid in navigation, guidance and control systems, suitable for applications to unmanned air vehicles. The methods we employ are based on Bayesian segmentation, optical flow, active contour and Bayesian particle tracking.

The algorithm herein holds several significant advantages over traditional tracking methods. The first step in the process is the optimal segmentation of images to enhance the targets and extract them from background clutter and noise. The Bayesian approach to segmentation allows the use of intensity (passive) and range (active) imagery to find targets. Optical flow generalizes and improves correlation techniques for locating objects within a frame, allowing for aspect angle and range changes. With optical flow, we may infer relative velocities on a pixel-by-pixel basis. Active contours are ideally suited to both target-sparse and target-rich environments. The energy approach to determining contours allows the merging and separating of potential targets in an automatic manner. Bayesian particle tracking techniques are used to track the contours over time.

The algorithm is tested successfully on experimental and simulated ladar data (using both intensity and range data) as well as sequences of video imageries. The streamed-lined processing, from getting the image data (of size 805x148 pixels) to detecting the moving target to wrapping an active contour on the target, takes less than one seconds clock time and provides very accurate predictions of the target location in future frames.

6566-26, Session 5

An ensemble approach to data fusion and its application to ATR

C. Barbu, Tulane Univ.; J. Peng, Montclair State Univ.; S. R. F. Sims, U.S. Army Aviation and Missile Research, Development and Engineering Ctr.

Ensemble methods provide a principled framework in which to build high performance classifiers and represent many types of data. As a result, these methods can be useful for ATR and making inferences about potential targets. We introduce an ensemble method for combining multiple representations (or views). The method is a multiple view generalization of AdaBoost. Similar to AdaBoost, weak classifiers are independently built from each represetation (view). However, all data types share the same sampling distribution computed from the type of data having the smallest error rate. As such, the most consistent data type dominates over time, thereby significantly reducing sensitivity to noise. The method is applied to the problem of facial and gender prediction based on biometric traits. The new method outperforms several competing techniques including kernel-based data fusion, and is provably better than AdaBoost trained on any single type of data.

6566-27, Session 6

Sense and avoid technology for unmanned aircraft systems

J. F. McCalmont, M. J. Taylor, Air Force Research Lab.; J. M. Utt, M. A. Deschenes, Defense Research Associates Inc.

Federal Aviation Administration (FAA) Regulation 7610.4 states remotely operated aircraft (aka unmanned aircraft systems or UAS) must provide "...an equivalent level of safety, comparable to see-and-avoid requirements for manned aircraft" in order to operate like manned aircraft in the National Air Space (NAS). The capability must be effective against all air traffic, with or without active, transponder-based collision avoidance systems. Currently, no operational "see and avoid" (SAA) capability exists. The Air Force Research Laboratory is developing a sensing capability for UAS that will allow UAS such as Global Hawk and Predator to sense the presence of other aircraft in its local airspace and either autonomously maneuver the aircraft or alert the remote pilot to avoid a collision. Using affordable commercially available sensors, innovative detection and tracking algorithms, and high performance data processors, AFRL is developing systems that have the potential to satisfy the FAA requirement. AFRL has a robust integrated program that includes research and development of the basic SAA technology; risk reduction and demonstration programs aboard UAS, and transition programs to transition this technology into military and commercial UAS in the near future.

6566-28, Session 6

Signal-to-noise behavior of gradient direction models for corner detection in images

D. W. Paglieroni, Lawrence Livermore National Lab.

A novel technique for corner detection in images that uses an FFT-based algorithm to match corners modeled as gradient direction fields to image gradient direction fields is described. The signal strength of a corner is discussed in terms of the number of pixels along the edges of a corner in an image, while noise is characterized by variance in gradient directions along those edges. The detection-false alarm rate behavior of our corner detector is evaluated empirically by manually constructing maps of corner locations in typical overhead images, and then generating different ROC curves for models of corners with different leg lengths and thicknesses. We demonstrate how corners found with our algorithm can be used to quickly extract prescribed polygonal shapes of arbitrary position, size and orientation from images.

6566-29, Session 6

Multiple target vehicles detection and classification based on low-rank decomposition

T. Viangteeravat, A. H. Shirkhodaie, H. Rababaah, Tennessee State Univ.

Considerable interest has arisen in the recent years utilizing inexpensive acoustic sensors in the battlefield to perform targets of interest identification and classification. There are many advantages of using acoustic sensor arrays. They are low cost and have relatively low power consumption. They require no line of sight and provide many capabilities for target detection, bearing estimation, target tracking, classification and identification. Furthermore, they can provide cueing for other sensors and multiple acoustic sensors responses can be combined and triangulated to localize an energy source target in the field. In practice, however, many environment noise, time-varying, and uncertainties factors affect their performance in detecting targets of interest reliably and accurate. In this paper, we have proposed a novel feature extraction approach for robust classification and identification of moving target vehicles to reduce those factors. The approach is based on Low Rank Decomposition based norm. Using Low Rank Decomposition based norm, dominant features of vehicle acoustic signatures are extracted efficiently with respect to vehicle operational responses. Then, these feature vectors are employed for robust identification and classification of target vehicles. The performance of the proposed approach was evaluated based on a set of experimental acoustic data from multiple vehicle test-runs. It is demonstrated that the approach yields very promising results to detect, identify and classify target vehicles in the field.

6566-31, Session 6

Shape prior active contour model based on curve similarity

P. Cheng, H. Cao, Huazhong Univ. of Science and Technology (China)

This paper present a shape prior active contour model designed for extracting irregular-shaped object which does not accurately correspond to the shape prior knowledge. Its main idea is to allow shape prior template deforms to a similar shape space, thus can fit the variance of the object. We propose curve similarity function based on Vector Field analysis to judge the likelihood between a contour and a shape space and embed it to our novel energy function, which makes the contour prone to approach both the boundary and the shape space but not rigidly limited to them, makes it balances between flexibility and shape-invariance. Experimental results show that the model is able to sustain heavy noise, cluttering background and concave boundary, which exceed the original model, and is easier to focus on deformed and distorted object than most contemporary shape prior active contours.

6566-32, Session 6

Toward a sensor-based threat warning system for patrols in MOUT scenarios

J. Metzler, D. N. Willersinn, Fraunhofer Institute for Information and Dataprocessing (Germany)

Military operations in urban terrain require the capability to perceive and to analyse the situation around a patrol in order to recognize potential threats. Human operators can only observe a limited field of regard. Sensors can enhance the field of regard up to 360°, but then the amount of data cannot be fully exploited by a human operator any more. For this reason an intelligent assistance system is required that monitors the circumference of a moving platform and warns the driver of a threatening situation. One first processing step of such a system is the recognition of humans and their behavior from a sequence of video images. There are numerous approaches to the analysis of human action, mainly from stationary cameras. Moving cameras play a role in the field of pedestrian protection from a moving road vehicle. There are two principal differences to this latter application domain. Firstly, the

threat in a MOUT scenario potentially stems from humans in the scene. Secondly, not only the trajectories of individual pedestrians are relevant, but also the motion and the behavior of groups of pedestrians. As a first step towards an assistance system that automatically warns drivers in a MOUT scenario, we implemented approaches to the detection of humans in video images and applied them to a relevant set of images sequences taken in a MOUT scenario. In the paper we assess the obtained results and outline further research activities.

6566-48, Session 6

Point target detection using superresolution reconstruction

J. Dijk, K. Schutte, D. J. de Lange, TNO-FEL (Netherlands)

Surveillance applications are primarily concerned with detection of targets. In electro-optical surveillance systems, missiles or other weapons coming towards you are observed as moving points. Typically, such moving targets need to be detected in a very short time. One of the problems is that the targets will have a low signal-to-noise ratio with respect to the background, and that the background can be severely cluttered like in an air-to-ground scenario.

The first step in detection of point targets is to suppress the background. The novelty of this work is that a super-resolution reconstruction algorithm is used in the background suppression step. It is well-known that super resolution reconstruction reduces the aliasing in the image. This anti-aliasing is used to model the specific aliasing contribution in the camera image, which results in a better estimate of the clutter in the background. Using super-resolution reconstruction also reduces the temporal noise, thus providing a better signal-to-noise ratio than the camera images. After the background suppression step common detection algorithms such as thresholding or track-before-detect can be used.

Experimental results will be given which show that the use of super-resolution significantly increases the sensitivity of the point target detection.

6566-33, Session 7

Vehicle ATR with separable correlation filters cued by pose estimates

F. E. McFadden, General Dynamics Advanced Information Systems

Synthetic discriminant functions (SDFs) were developed to recognize targets subject to moderate pose variations, but control of false alarms has been problematic. This work uses a precise pose estimator in order to narrow the range of poses that must be handled by the SDF, and thus to improve false alarm rates. It is also shown that acceptable classification performance can be achieved when the precise pose estimator is followed by a separable version of the MACH filter. In this way more pose-specific filters can be used while conserving memory requirements. The pose estimation algorithm is relatively robust to scale variations, and significantly more precise than previously published results. The two-step ATR system is demonstrated for MSTAR data, and recommendations are made for the number of components that can be used in a separable version of the MACH filters, without significant loss of performance.

6566-34, Session 7

An efficient quadratic correlation filter for automatic target recognition

W. Mikhael, P. Ragothaman, Univ. of Central Florida; R. R. Muise, A. Mahalanobis, Lockheed Martin Missiles and Fire Control

Quadratic Correlation Filters have recently been used for Automatic Target Recognition (ATR). Among these, the Rayleigh Quotient Quadratic Correlation Filter (RQQCF) was found to give excellent performance when tested extensively with Infrared imagery. In the RQQCF method, the filter coefficients are obtained, from a set of training images, such that the response to the filter is large when the input is a target and small when the input is clutter. The method explicitly maximizes a class separation metric to obtain optimal performance. In this paper, a novel transform domain approach is presented for ATR using the RQQCF. The proposed approach, called the Transform Domain RQQCF (TDRQQCF) has several advantages. It considerably reduces the computational complexity and storage requirements, by compressing the target and clutter data used in designing the QCF. Since the dimensionality of the data points is reduced, this method also overcomes the common problem of dealing with low rank matrices arising from the lack of large training sets in practice. Finally, this approach also leads to improved recognition performance over the original algorithm. The proposed method is tested using IR imagery, and sample results are presented which confirm its excellent properties.

6566-35, Session 7

Data driven training image set selection for composite correlation filter banks

D. W. Carlson, A. Ramirez, Raytheon Missile Systems

Composite correlation filters have been demonstrated in many automatic target recognition (ATR) applications because of their ability for class discrimination and distortion-tolerance with shift invariance. By combining a subset of the training images into each filter, the filter bank can recognize a target class across distortions such as target aspect (azimuth). However, the selection of training images for each filter in the bank is usually a simple approach resulting in variable performance across filters. We investigate different methods of data-driven grouping of target variation which allows for unique combinations of training images into a filter. We introduce a new use of Isometric Mapping (ISOMAP) manifold extraction and spanning trees to group the training images for use in composite correlation filter approaches to ATR. ISOMAP is a non-linear method that reduces the high dimensionality of data such as images. Other methods of selecting the training sets within a filter bank including equally-spaced assignment and k-means clustering are compared in their impact on target classification. Test results using the publicly released MSTAR database are shown.

6566-36, Session 7

Efficient directional filter bank structures for image decomposition

R. Ansari, Univ. of Illinois/Chicago; D. Fennell, ITT Space Systems LLC; A. M. Bagci, Univ. of Illinois/Chicago; B. J. Chambers, W. Reynolds, Jr., ITT Visual Information Solutions

In an effort to discover and extract highly directional cues in airborne surveillance images, we have developed efficient filtering methods for directional decomposition of images to aid in target detection. Since images of interest are very large and the filtered images are not downsampled in the application of interest, conventional filtering can be computationally extremely demanding and there is a need to explore alternative procedures to make the filtering efficient. In this paper a novel filter bank structure for directional filtering of images is proposed and its design described. The design is carried out by imposing structural constraints on the filters, which are implemented using a generalized notion of separable filtering. The structure uses one-dimensional (1-D) filters as building blocks, which are employed in novel configurations to obtain filters with narrow wedge-shaped passbands. In the implementation, 1-D filtering is performed along directions determined by the passband orientations of the directional filters. If downsampling is desired then the tree-structured decomposition lends itself to a lifting-based implementation. The structures exploit polyphase representations of 1-D and 2-D filters in combination with horizontal and vertical upsampling and downsampling to obtain wedge-shaped passband support. The filters are applicable in pyramidal decompositions and lifting-based wavelet decompositions. Design procedures have been developed for constructing 16-band, 32-band, and 64-band partitions starting with either built-in or user-specified 1-D prototypes. Filters generated by the proposed method have been applied to airborne surveillance images. Implementations of filters using the proposed method show significant improvement compared with conventional implementation, often more by an order of magnitude, which is also supported by a theoretical analysis of the filter complexity.

6566-37, Session 7

Autonomous spacecraft docking using optical correlation techniques

G. J. Outerbridge II, D. A. Gregory, The Univ. of Alabama/Huntsville

The six degree of freedom pose estimation for the identification and autonomous rendezvous and docking (AR&D) of spacecraft is being explored using optical correlation techniques. This method will utilize three existing technologies: Optical correlation using high speed spatial light modulators (SLM's), 3D animation and modeling software and nonlinear estimation methods utilizing neural networks. The SLM's provide rapid optical correlations obtainable at up to 4 KHz. The 3D animation software enables the rapid rendering of the 2D filter images of the modeled target craft for the neural network training sets. An added advantage of the 3D software is the ability to generate and analyze multiple docking scenarios. The performance of the optical correlator for a docking application as well as an analysis of the identification methods chosen will be discussed.

6566-38, Session 8

A novel ROC approach for performance evaluation of target detection algorithms

P. Ganapathy, J. A. Skipper, Wright State Univ.

Receiver operator characteristic (ROC) analysis is an emerging automated target recognition system performance assessment tool. The ROC metric, area under the curve (AUC), is a universally accepted measure of classifying accuracy. The detection algorithm output, i.e., a response plane (RP), must consist of grayscale values wherein a maximum value (e.g. 255) corresponds to highest probability of target locations. AUC computation involves the comparison of the RP and ground truth to classify RP pixels as either true negatives (TN), false positives (FP), true positives (TP) or false negatives (FN). Ideally, the background and all objects other than targets are TN. Historically, evaluation methods have excluded the background, and only a few spoof objects likely to be considered as a hit by detection algorithms were a priori demarcated as TN. This can potentially exaggerate the algorithm's performance. Here, a new ROC approach has been developed that divides the entire image into mutually exclusive target (TP) and background (TN) grid squares with adjustable size. Based on the overlap of the thresholded RP with the TP and TN grids, the FN and FP fractions are computed. Variation of the grid size can bias the ROC results by artificially altering specificity, so assessment of relative performance under a constant grid size is adopted in our approach. A pilot study was performed to assess the method's ability to capture RP changes under three different detection algorithm parameter settings on ten images with different backgrounds and target orientations. An ANOVA-based comparison of the AUCs for the three settings showed a significant difference ($p<0.001$) at 95% confidence interval.

6566-39, Session 8

Evaluation testbed for ATD performance prediction (ETAPP)

S. K. Ralph, Charles River Analytics, Inc.; J. M. Irvine, Science Applications International Corp.; M. S. Snorrason, Charles River Analytics, Inc.

Automatic target detection (ATD) systems process imagery to detect and locate targets in imagery in support of intelligence, surveillance, reconnaissance, and strike missions. Accurate prediction of ATD performance would assist in system design and trade studies, collection management, and mission planning. A need exists for ATD performance prediction based exclusively on information available from the imagery and its associated metadata. The modeling effort consists of two phases: a learning phase, where image measures are computed for a set of test images, the ATD performance is measured, and a prediction model is developed; and a second phase to test and validate performance prediction. The learning phase produces a mapping, valid across various ATR algorithms, which is even applicable when no image truth is available (e.g., when evaluating denied area imagery). Ongoing efforts to develop such a prediction model have met with some success. In particular, we have extended previous modeling work to characterize the relationship between the current image set and the training imagery used to develop the ATD. Inclusion of this information significantly improves prediction performance. The image measures employed in the model include: statistics derived from a constant false alarm rate (CFAR) processor, the Power Spectrum Signature, and others. We present a performance predictor using a trained classifier ATD that was constructed using GENIE, a tool developed at Los Alamos National Laboratory. The paper concludes with a discussion of future research.

6566-40, Session 8

EO ATR performance modeling to support fusion experimentation

E. P. Blasch, Air Force Research Lab.; B. Kahler, Veridian Inc.; D. Pikas, Univ. of Dayton

The identification of a target from an electro-optical sensor requires accurate sensor registration, quality sensor data, and an exploitation algorithm. Combining the sensor data and exploitation, we are concerned with developed an EO performance model. To combat the registration issue, we need a detailed list of operating conditions (i.e. collection position) so that the sensor exploitation results can be evaluated with sensitivities to these operating conditions or collection parameters. The focus of this paper will build on the NVSED EO AQUIRE model (detailed in Drigger's SPIE 2005) and incorporate additions of day/night operations and 3D looks. More importantly, we are concerned with developing an EO model that affords comparable operating condition parameters in a synthetic aperture radar (SAR) performance model. The choice of EO modeling additions are focused on areas were a Fusion Gain might be realized through an experiment tradeoff between multiple EO looks for ATR exploitation fusion. The three additions to known EO models discussed in the paper will include (1) adjacency, (2) shadow effects, and (3) image quality.

6566-41, Session 8

Phenomenological fireball model for remote identification of high explosives

K. C. Gross, Air Force Institute of Technology; J. A. Wayman II, The Ohio State Univ.; G. P. Perram, Air Force Institute of Technology

Many aspects of detonation phenomena have been well studied over the last century. However, the transient infrared and visible emissions from detonation fireballs have been poorly understood and hampered the robust identification of explosives via remote sensing techniques. Recently, time-resolved infrared spectra (1800-7000/cm, 4-16/cm resolution, 8-20 Hz) of various high-explosive (HE) detonation fireballs have been collected during several field experiments. The observed spectra are driven by many factors including the explosive's chemistry and weight, the method of detonation, interactions with the environment, and the casing used to enclose the explosive. Fireballs from conventional munitions, which are comprised of HEs such as TNT or HMX and encased in an iron shell, are optically thick and well-described as a greybody with a temperature that decays from ~1800 K to ambient within 3-5 s. A small amount of selective emission is also present and attributable to hot CO_2.

Detonation of uncased, raw charges of TNT and three types of enhanced novel explosives (ENEs) of various weights (10, 50, 100, and 1000 kg) produce fireballs with more interesting spectral characteristics. A simple model for fireball emissions has been developed which accurately describes the observed spectra in terms of the fireball radius, temperature, water and carbon dioxide concentrations, and grey particulate absorption coefficient. The model affords high-fidelity dimensionality reduction and provides physical features which can be used to distinguish the uncased explosives. For example, the observed H_2O:CO_2 concentration ratio is sensitive to the relative amounts of hydrogen and carbon in the HE. With absolutely calibrated spectra, the total number of observed water and carbon dioxide molecules can be used to infer the weight of the explosive material.

6566-42, Session 8

Evaluation of object level change detection techniques

J. M. Irvine, S. M. Bergeron, Science Applications International Corp.; D. W. Hugo, M. A. O'Brien, National Geospatial-Intelligence Agency

A variety of change detection (CD) methods have been developed and employed to support imagery analysis for applications including environmental monitoring, mapping, and support to military operations. Evaluation of these methods is necessary to assess technology maturity, identify areas for improvement, and support transition to operations. This paper presents a methodology for conducting this type of evaluation, discusses the challenges, and illustrates the techniques. The evaluation of object-level change detection methods is more complicated than for automated techniques for processing a single image. We explore algorithm performance assessments, emphasizing the definition of the operating conditions (sensor, target, and environmental factors) and the development of measures of performance. Specific challenges include image registration; occlusion due to foliage, cultural clutter and terrain masking; diurnal differences; and differences in viewing geometry. Careful planning, sound experimental design, and access to suitable imagery with image truth and metadata are critical.

6566-43, Session 8

Construction and correction of probability densities

L. Cohen, Hunter College/CUNY

Of fundamental importance in automatic target recognition is the establishment of probability densities for decision making. The construction and correction of probability densities is an old subject and numerous methods have been developed over the years. Two classical results of Edgeworth and Gram-Charlier series where corrections are be made to Gaussian distribuions. We have devised a generalization of the Gram-Charlier and Edgeworth series which makes these methods much more flexible. Our generalization is two fold. First one does not only transform from Gaussian distribution but one can transform from an arbitrary distribution and secondly an arbitrary Hermitian operator may be used rather then just the differential operator of the standard methods. This opens up possibilities for new and more effective methods for construction of probability densities that fits a given set of data. A number of concrete examples will be given to show that the generalization works much better then the standard methods.

6566-44, Session 9

Human motion tracking using mean shift clustering and discrete cosine transform

M. F. Islam, M. S. Alam, Univ. of South Alabama

Human motion tracking is an active area of research in computer vision and machine intelligence. Several motion tracking algorithms have been proposed for applications to video surveillance and human-computer interface systems. However, most of the techniques can only track more than one person in a given image. This paper proposes a novel detection algorithm for tracking a specific person from a crowded environment. Here mean shift clustering procedure is employed in the difference image to obtain the candidate cluster, which converges within little iteration. The number of clusters and cluster centers are automatically derived by mode seeking with mean shift procedure. Discrete cosine transform is then applied to each cluster and also to the known target for extracting the features of the cluster and the target. Finally, the Mahalanobis distance is measured between each transformed candidate cluster and the target. The cluster with the minimum distance is then considered as the desired target. Tracking is carried out by updating the cluster parameters over time using the mean shift procedure. Computer simulation is carried out with real life images where an excellent tracking performance is observed.

6566-45, Session 9

Vision-based vehicle tracking using image alignment with symmetrical function

L. Cheung, Y. Moon, The Chinese Univ. of Hong Kong (Hong Kong China)

The large number of rear end collisions due to driver inattention has been identified as a major automotive safety issue. Even a short advance warning can significantly reduce the number and severity of the collisions. In this paper, we describe an image alignment based vehicle detection methodology with a single camera as input for use in detecting vehicles approaching the blind spot of a car on highways and city streets with relative distance and time to contact information.

We have developed a methodology optimized for detecting vehicles in the blind spot of an intelligent vehicle. Generally, the blind spot becomes only viewable when the driver turns his head. Unfortunately, a lot of drivers are often lazy to turn their heads when driving. If a real-time rear vehicle detection system can give an advance warning to a driver when the relative distance or the contact time between a rear vehicle and the camera on the driver's car is too small, significant number of automobile collisions can be greatly prevented.

Our very first task is to identify the rear vehicles. Many active methods of obstacle detection such as laser and radar cannot be possible in the highway due to interference among vehicles. Therefore, it is worthwhile to investigate completely passive approaches, such as vision, for vehicle detection. With the aid of symmetrical function, the region of interest in the image can be greatly reduced. It makes the methodology becomes relatively simple to implement using embedded system technology in the automobile environment.

6566-46, Session 9

Facial feature tracking with the super image vector inner product

L. G. Hassebrook, W. Su, B. Hao, D. L. Lau, Univ. of Kentucky

We demonstrate a new and efficient distortion-invariant "super image vector inner product" tracker and pose estimator based on linear phase coefficient composite filter. The super image consists of a weighted sum of training images. These images span the distortion ranges of rotation, scale, and translation. The superimage vector inner product is mathematically related to composite filter design but, unlike correlation filters, the super image is implemented using a complex vector inner product operation. A super image vector inner product is implemented by element-wise multiplying a super image template by a window of interest in the input scene and then summing the element-wise operations. The resulting amplitude indicates target detection and the resulting phase indicates the value of scale, orientation or movement of the target object. The design and implementation of the super image vector inner product are presented and its applications to whole face and facial feature biometric tracking, such as earlobes, eyes with nose and lower jaw are demonstrated.

6566-47, Session 9

Rapid automatic target recognition using generic 3D sensor and shape-from-motion data

C. E. English, M. Labrie, G. Bouchette, P. Iles, B. Powaschuk, P. M. Church, Neptec Design Group Ltd. (Canada); J. Maheux, Defence Research and Development Canada (Canada)

Automatic Target Recognition using 3D sensor data has been proven to be very successful in experimental platforms. One of the factors limiting the implementation of these approaches is lag in operational hardware to provide the type of data required.

Neptec has addressed this sensor concern in its 3D ATR software. The previously reported ATR software has been expanded from proof-of-concept ground-to-ground to include air-to-ground capabilities. The system uses a generic 3D model of the target, such as from CAD or scanned from a scale or full sized model which does not need to be a perfect representation. The rapid recognition approach simultaneously

provides target pose estimation. The need for specific operational 3D sensing hardware is avoided by using a generic range image format. This capability has been demonstrated using ground-based imaging lidar, airborne pushbroom lidar, scannerless AMcw lidar, and shape-from-motion using a 2D camera. Multiple data sets can also be fused to optimize confidence in the recognition and provide measures of similarity between different targets and the data set.

This paper presents an overview of the 3D ATR approach and updates performance characteristics from a variety of tests that include synthetic data, lab tests, and field tests. It is shown that the approach is fast, highly robust, flexible, and is primarily limited by the quality of sensor data. Particular emphasis is placed on the shape-from-motion application since this capability can make use of widely used operational 2D imaging sensor packages.

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6567-01, Session 1

Impact and point prediction using a neural extended Kalman filter with multiple sensors

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The neural extended Kalman filter is an adaptive estimation technique that has been shown to learn on-line the maneuver model of a target's trajectory. This improved motion model can be used to better predict the location of a target at given point in time especially when the target has limited maneuvering capabilities such as mortar shell. In this paper, the neural extended Kalman filter is used to predict impact point and impact time of a ballistic-like projectile when the drag on the shell was not accurately modeled in the motion model using measurement reports provided by multiple sensor systems. In previous work, the neural extended Kalman filter was shown to work well with a single sensor with a uniform sample rate. Multiple sensors incorporate two major modifications into the complexity of the problem. The first is to handle a non-uniform update rate of the measurements to the tracking system. While most tracking systems can easily handle this difference, the adaptation of the parameters can be deleteriously affected by such variations. The second modification is that related to the multiple aspect angles and related uncertainty that affects the model adaptation. The changing data accuracies and sensor models can cause transient instabilities in the feedback adaptation unless properly compensated. In this effort, performance of the neural extended Kalman filter as an adaptive and predictive scheme, with the modifications in implementation, is shown to provide a quality impact estimate.

6567-02, Session 1

Markov chains for the prediction of tracking performance

P. O. Arambel, M. Antone, BAE Systems Advanced Information Technologies

Highly accurate predictions of tracking performance usually require high fidelity Monte Carlo simulations that entail significant implementation time, run time, and complexity. In this paper we consider the use of Markov Chains as a simpler alternative that models critical aspects of the tracking process and provides reasonable estimates of tracking performance, while maintaining much lower cost and complexity. We describe a general procedure for Markov-Chain based performance prediction, and illustrate the use of this procedure in the context of an airborne system that uses a steerable EO/IR sensor to track multiple targets in non-overlapping fields of view. We discuss the effects of key model parameters, including measurement sampling rates, track termination, target occlusions, and missed detections. We also present plots of performance as a function of occlusion length, target maneuverability, confuser density, and sensor slew rate, as well as platform and target geometries.

6567-03, Session 1

Two solutions to the localization using time difference of arrival problem

T. Sathyan, T. Kirubarajan, McMaster Univ. (Canada)

In this paper, two solutions to the problem of emitter localization using time difference of arrival (TDOA) measurements are proposed. The maximum likelihood estimation for this problem will result in a nonlinear, nonconvex optimization, and hence is very difficult to solve. The solutions presented in this paper consider an alternate formulation, which is based on the sensor-target geometry. Even this formulation results in nonconvex (however, linear) optimization problem. The first solution presented relaxes the original optimization problem into a semi-definite program (SDP). Using the solution to this relaxed SDP, emitter is localized using a randomization technique. The second solution forms the Lagrangian dual of the original problem, and it is shown that the dual is a SDP. From the solution to the dual problem a solution to the original problem is found. It has to be noted that this solution to the original problem will be optimal if strong duality holds. This is currently being analyzed. Initial simulation results, however, suggest that both these solution techniques gives localization accuracies that are better than the other techniques found in literature.

6567-04, Session 1

Acoustic signature analysis and data fusion of vehicles based on acoustic sensor arrays

T. Viangteeravat, A. H. Shirkhodaie, H. Rababaah, Tennessee State Univ.

Considerable interest has arisen in the recent years utilizing inexpensive acoustic sensors in the battlefield to perform targets of interest identification and classification. There are many advantages of using acoustic sensor arrays. They are low cost, and relatively have low power consumption. They require no line of sight and provide many capabilities for target detection, bearing estimation, target tracking, classification and identification. Furthermore, they can provide cueing for other sensors and multiple acoustic sensors responses can be combined and triangulated to localize an energy source target in the field. In practice, however, many environment noise factors affects their performance in detecting targets of interest reliably and accurate. In this paper, we have proposed a novel approach for detection, classification, and identification of moving target vehicles. The approach is based on Singular Value Decomposition (SVD) coupled with Particle Filtering (PF) technique. Using SVD dominant features of vehicle acoustic signatures are extracted efficiently. Then, these feature vectors are employed for robust identification and classification of target vehicles based on a particle filtering scheme. The performance of the proposed approach was evaluated based on a set of experimental acoustic data from multiple vehicle test-runs. It is demonstrated that the approach yields very promising results where an array of acoustic sensors are used to detect, identify and classify target vehicles in the field.

6567-05, Session 1

Structural and metric correlation of electro-optical and radar generated tracks

B. Kovalerchuk, Central Washington Univ.

Integration of electro-optical and radar generated tracks is critical for providing a single integrated picture (SIP) of the dynamic situation. This paper proposes a new, robust, real-time algorithm to (i) correctly correlate data from several sensors and the existing system track, and (ii) identify when the data represent new tracks. The proposed algorithm uses metric data, linear, and area features extracted from optical and radar images. The major novelty of the algorithm is in use of robust and affine invariant structural relations built on the features for accurate correlation. A constructed measure of confidence with the correlation decision is based on both structural and metric similarities of tracks to estimate both bias and random errors. The similarities are based on concepts from the abstract algebraic systems, generalized Gauss-Markov stochastic processes, and Kalman filters for n-dimensional time series that explicitly model measurement dependence on k previous measurements, M(t/t-1,t-2,...,t-k). The algorithm identifies groups of tracks that form a cluster using this measure of confidence. These techniques are combined with the hierarchical matching approach to increase the overall track accuracy. Only tracks that are not distinguished in every hierarchical level are clustered into a single track. The proposed search algorithm for track correlation/matching is suitable for both centralized and distributed computing architecture.

6567-06, Session 1

Tracking partially occluded objects in moving cameras by extended recursive least-squares filtering with forgetting factor

C. Li, B. Li, J. Si, Arizona State Univ.; G. P. Abousleman, General Dynamics C4 Systems

Many applications require tracking of moving objects within a moving background that is caused by camera motion. One example arises from airborne video. The task becomes even more challenging when taking into account additional compounding factors such as noise, model deformation, and occlusion. We propose a new tracking system to address target tracking in moving backgrounds when the target is partially occluded. The proposed algorithm comprises three steps: Fast geometric constraint global motion (FGCGM) estimation, extended recursive least-squares filter (ERLSF) with forgetting factor, and direction-guided (DG) search. The FGCGM estimation obtains a more accurate affine model by reducing the error from moving targets. The object position and velocity are formulated by dynamic state and observation equations based on the affine model and the position estimation from the DG search. The ERLSF with forgetting factor can then be used to update the position and the velocity estimation simultaneously. The DG search uses the predicted position and velocity from the filter to construct a compact search region for the next frame. The search result is then provided to the filter as an observation. The filter is a key step to provide accurate velocity estimation in the presence of disturbances. The adaptive template maintains the consistency between the template and the current target's appearance. The DG search reduces the probability of mismatching between target templates and candidates. The proposed recursive algorithm can track objects in video sequences precisely and in real time, even if some of the frames are corrupted by noise, and/or the targets are partially or fully occluded in some frames.

6567-07, Session 2

Fuzzy decision trees for planning and autonomous control of a coordinated team of UAVs

J. F. Smith III, Naval Research Lab.

A fuzzy logic resource manager that enables a collection of unmanned aerial vehicles (UAVs) to automatically cooperate to make meteorological measurements will be discussed. Once in flight no human intervention is required. Planning and real-time control algorithms determine the optimal trajectory and points each UAV will sample, while taking into account the UAVs' risk, risk tolerance, reliability, mission priority, fuel limitations, mission cost, and related uncertainties. The control algorithm permits newly obtained information about weather and other events to be introduced to allow the UAVs to be more effective. The approach is illustrated by a discussion of the fuzzy decision tree for UAV path assignment and related simulation. The different fuzzy membership functions on the tree are described in mathematical detail. The three different methods by which this tree is obtained are summarized including a method based on using a genetic program as a data mining function. A second fuzzy decision tree that allows the UAVs to automatically collaborate without human intervention is discussed. This tree permits three different types of collaborative behavior between the UAVs. A genetic program based method for obtaining this tree is also summarized. The tree's relationship to an older fuzzy sum rule is discussed. Simulations illustrating how the tree allows the different types of collaboration to be automated are provided. Simulations also show the ability of the control algorithm to allow UAVs to effectively cooperate to increase the UAV team's likelihood of success.

6567-08, Session 2

Random set tracking and entropy based control applied to distributed sensor networks

D. W. J. Stein, J. Witkoskie, S. Theophanis, W. S. Kuklinski, The MITRE Corp.

This paper describes random set based sensor fusion algorithms, and companion sensor-network control algorithms. The sensor-network control algorithms specify sensor actions designed to minimize the expected entropy of the variable length multiple-target state-vector Global Density, subject to operational constraints. Our random set approach to target tracking avoids association ambiguity by statistically weighing all possible hypotheses and associations. Additionally, to limit computational complexity, our method involves the re-parameterization of the posterior Global Density using a Gaussian mixture approximation, as required. Specific traditional approaches to multiple target tracking, such as Multiple Hypothesis Trackers (MHT) and Joint Integrated Probabilistic Data Association (JIPDA) trackers are shown to be special cases of our Random Set Tracker (RST). The computational complexity of the RST is minimized using information theoretic criteria that avoid many of the limiting assumptions inherent in the MHT and JIPDA. A resource management algorithm based on minimizing the expected entropy of the Global Density defined on the multiple-target state-space is described in detail. The entropy minimization is performed, subject to operational constraints on energy expenditure associated with sensor operation, computation or inter-node communications. The RST, MHT and JIPDA are applied to a multiple-target road-constrained tracking problem to allow comparison of their performance. Field data from a sensor network comprised of multiple range radars, and acoustic arrays, that measure angle of arrival, are used for this comparison. The entropy based resource manager is also applied to this tracking problem, and, for various scenarios, the relationship between energy expenditure and uncertainty in target state-vector estimates, as measured by entropy, is also provided.

6567-09, Session 2

Adaptive sensor tasking using genetic algorithms

P. J. Shea, J. Kirk, D. Welchons, Black River Systems Co.

Today's battlefield environment contains a large number of sensors, and sensor types, onboard multiple platforms. The set of sensor types includes SAR, EO/IR, GMTI, AMTI, HSI, MSI, and video, and for each sensor type there may be multiple sensing modalities to select from. In an attempt to maximize sensor performance, today's sensors employ either static tasking approaches or require an operator to manually change sensor tasking operations. In a highly dynamic environment this leads to a situation whereby the sensors become less effective as the sensing environments deviates from the assumed conditions.

Through a Phase I SBIR effort we developed a system architecture and a common tasking approach for solving the sensor tasking problem as applied to a radar and EO/IR sensor mix. Our sensor tasking considers multiple layers within the task hierarchy ranging from the mission level, where tasking focuses on mission requirements, down to where sensor tasking focuses on radar sub-mode and waveform selection. We also developed a genetic algorithm based task scheduling approach and demonstrated the ability to automatically task and schedule sensors in an end-to-end closed loop simulation. In the proof of concept we demonstrated the ability to schedule multiple radar sensors simultaneously. This provides a solid foundation for our future efforts including incorporation of EO/IR and other sensor types. As we have moved forward into the second phase of this effort, we are increasing the fidelity of the simulation and tasking approach by considering other factors such as environmental constraints and other sensor limitations.

This paper will describe our approach for scheduling using genetic algorithms as well as our concept for a multi-layer architecture. We will also describe our end-to-end closed loop software simulation environment. We will conclude with a discussion of results for a sample problem and of the path forward.

6567-10, Session 2

Distributed sensor resource management and planning

D. Khosla, J. Guillochon, HRL Labs., LLC

The goal of sensor resource management (SRM) is to allocate resources appropriately in order to gain as much information as possible about a system. In our previous paper, we introduced a centralized non-myopic planning algorithm called Centralized Sparse Planning (C-SPLAN) that uses sparse sampling to estimate the value of resource assignments. In this paper we extend our approach to a distributed framework and present the Distributed Sparse Planning (D-SPLAN) algorithm. Sparse sampling is related to Monte Carlo simulation. In the SRM problem we consider, our network of sensors observes a set of tracks; each sensor can be set to operate in one of several modes and/or viewing geometries. Each mode incurs a different cost and provides different information about the tracks. Each track has a kinematic state and is of a certain class; the sensors can observe either or both of these, depending on their mode of operation. The goal is to maximize the overall rate of information gain, i.e. rate of improvement in kinematic tracking and classification accuracy of all tracks in the Area of Interest. We compare and test the algorithm performance on several tracking and target identification problems to that of other algorithms. We compare the performance as well as computational and communications costs of C-SPLAN and D-SPLAN as well as near-term planners.

6567-11, Session 2

Integrated tracking and sensor management based on expected information gain

K. A. B. White, Defence Science and Technology Organisation (Australia)

The availability of flexible sensors offers new opportunities for enhanced tracking performance. Management of such sensors must consider their characteristics and the tracking situation picture. Shannon's information measure provides a means of quantifying the potential gains from various sensor deployment options.

The problem of tracking targets with an electronically scanned array radar is addressed. The radar can be commanded to conduct surveillance of the search volume in a manner that is analogous to mechanically scanned radar. In conjunction with the surveillance mode, a revisit mode permits the radar to be commanded to form beams to illuminate a specific volume, such as in the vicinity of a track. An expected information gain is computed which is a function of the probability of detecting the tracked target with the revisit beam. It is also a function of the predicted track uncertainty in the event that the target was not detected, and of the expected fused track uncertainty if the target is detected. A high value for the expected information gain occurs when a measurement is likely to yield a significant improvement in the track uncertainty and there is a sufficiently high probability of detecting the target being tracked. Results from implementing the expected information gain in an integrated tracking and radar management system are presented and discussed.

6567-12, Session 2

Distributed simulation of an information-based sensor management system

J. P. Malachowski, K. J. Hintz, George Mason Univ.

A sensor, like any other tool, is wasted in the hands of the ignorant. It falls to the responsibility of the sensor manager to utilize the sensor as intelligently as possible.

The nonlinear operation and non-stationary stochastic environment of sensor managers requires the use of simulation techniques to verify their behavior. This is particularly evident when comparing the effectiveness of different approaches to sensor management. It is important to consider which possible performance metrics are of interest and are useful to the evaluation and comparison of competing designs.

The simulated environment, sensors, tracking, and fusion simulation must be generic enough to provide an even playing field for comparing different approaches to sensor management while still having enough fidelity to be useful and conclusive.

This paper talks about the evaluation of an information-based sensor management system. The problems and solutions to the need for a top level design, accurate and realistic data, computational complexity, required storage, and inter-modular communications are also discussed. Much of the simulation has been written in Matlab under Linux though the design ideas do not necessarily preclude other environments.

The paper concludes with a preliminary comparison of the performance of a conventional rule-based sensor management system to an information-based sensor management system.

6567-13, Session 3

UAV-based distributed ATR under realistic simulated environmental effects

X. Chen, N. A. Schmid, S. Gong, M. Valenti, West Virginia Univ.

Over the past several years, the military has grown increasingly reliant upon the use of unattended aerial vehicles (UAVs) for surveillance missions. There is an increasing trend towards fielding larger and larger swarms of UAVs operating as large-scale sensor networks in the air [1]. Such systems tend to be used primarily for the purpose of automatic target recognition (ATR), the computer processing of image data obtained by one or more sensors with the goal of acquiring, identifying, and tracking objects of interest. These trends have been paralleled by advances in both distributed detection [2], image/signal processing and data fusion techniques. Furthermore, swarmed UAV systems must operate under severe constraints on environmental conditions and sensor limitations.

In this work, we investigate the effects of environmental conditions on target detection and recognition performance in a UAV network. We assume that each UAV is equipped with an optical camera, and use a realistic computer simulation to generate synthetic images. The detection algorithm relies on Haar-based features while the ATR algorithm relies on K-Bessel and Principal Component Analysis features. The performance of both algorithms is evaluated using simulated images that closely mimic data acquired in a UAV network under realistic environmental conditions. We design a model-based fusion technique using principles of classical and modern detection theory and analyze both the case of a single observation and the case of multiple observations of the same target.

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6567-14, Session 3

Real-time vehicle detection in infrared and visible images

C. Yu, Z. Yue, P. N. Topiwala, FastVDO LLC

Real time object detection is a challenging computer vision problem, especially in uncontrolled environments. Unlike traditional classification problems, where the statistical models can be properly described by the training data, it is much harder to discriminate certain object class from rest of the world with limited negative training samples. Due to the large variation of negatives, sometimes the intra-object class difference may be even larger than the difference between objects and non-objects. Besides this, there are many other problems that obstruct object detection, such as pose variation, illuminance variation and partial occlusion.

Previous studies also demonstrated that infrared (IR) imagery provides a promising alternative to visible imagery. Detectors using IR imagery are robust to illumination variations and able to detect object under all lighting conditions including total darkness, while detectors based on visible imagery generally fail in these situations. However, IR imagery has several drawbacks: (1) It is sensitive to temperature changes in the surrounding environment, which means IR images should be captured in a controlled environment. (2) It is sensitive to variation in the heat patterns of the object. For example, vehicles display different heat patterns with the engine on/off. (3) IR is opaque to glass.

In contrast to IR imagery, visible imagery is more robust to the above factors. This suggests a better detection system by fusing the information from both visible and IR imagery.

Moreover, the object detector needs exhaustive search in both spatial

and scale domain, which inevitably lead to high computation load.

In this paper, we propose to use boosting based vehicle detection in both infrared and visible imagery. Proper decision level fusion method is introduced for better performance. Experiments are carried out using ATR helmet device with both EO and IR sensors.

6567-15, Session 3

Information theoretic partitioning and confidence-based weight assignment for multiclassifier decision level fusion in hyperspectral target recognition applications

S. Prasad, L. M. Bruce, Mississippi State Univ.

There is a growing interest in using multiple sources for automatic target recognition (ATR) applications. The key idea behind such an approach is to take multiple, independent observations of a phenomenon and perform a feature level or a decision level fusion for ATR. This paper proposes a method to utilize these types of multi-source fusion techniques to exploit hyperspectral data when only a small number of training pixels are available. Conventional hyperspectral image based ATR techniques project the high dimensional reflectance signature onto a lower dimensional subspace using techniques such as Fisher's linear discriminant analysis (LDA), subspace LDA and stepwise LDA. While some of these techniques attempt to solve the curse of dimensionality, or small sample size problem, these are not necessarily optimal projections. In this paper, we present a divide-and-conquer approach to address the small sample size problem. The hyperspectral space is partitioned into contiguous subspaces such that the discriminative information within each subspace is maximized, and the statistical dependence between subspaces is minimized. We then treat each subspace as a separate source in a multi-source multi-classifier setup and test various decision fusion schemes to determine their efficacy. Unlike previous approaches which use correlation between variables for band-grouping, we study the efficacy of higher order statistical information (using average mutual information) for a bottom-up band-grouping. We also propose a confidence-measure based decision fusion technique, where the weights associated with various classifiers are based on the confidence levels learned from the training data. The proposed methods are tested using hyperspectral data with known ground truth, such that the efficacy can be quantitatively measured in terms of target detection accuracies and false alarm rates.

6567-16, Session 3

Applying target shadow models for SAR ATR

S. Papson, R. M. Narayanan, The Pennsylvania State Univ.

Recent work has suggested that target shadows in SAR images can be used effectively to aid in target classification. The proposed method has four steps - segmentation, representation, modeling, and selection. Segmentation is performed via smoothing operations and the estimation of Gaussian mixture model parameters. A chain code technique is used to represent the shadow boundary; hidden Markov modeling is applied to the chain codes to create a suitable bank of target representations. Finally, an ensemble framework is proposed for classification. The proposed selection process searches for an optimal ensemble of models based on various configurations of the target classification problem. This framework is one method in which the shadow classification technique can be integrated with more classical target recognition algorithms. A subset of the MSTAR database is used for testing. Performance is investigated as a function of aspect angle. Since the shadow is a back-projection of the target profile, some aspect angles will contain more discriminatory information then others. Additionally, the case of multiple target looks is considered. The performance is reported not only as a function of the number of images, but also as a function of the configuration. (This project is supported by Office of Naval Research (ONR) through Contract # N00014-04-1-0307.)

6567-17, Session 4

Detection and identification of human targets in radar data

S. Z. Gurbuz, Georgia Institute of Technology; W. L. Melvin, Georgia Tech Research Institute; D. B. Williams, Georgia Institute of Technology

Radar offers unique advantages over other sensors, such as visual or seismic sensors, for human target detection. In many situations, especially military applications, it may not be possible to place a video camera or implant seismic sensors in the area being observed due to security or other threats. However, radar can operate as far away from potential targets, and funtions during daytime as well as nighttim, in virtually all weather conditions. In this paper, we examine the problem of human target detection and identification using radar. The impact of stationary clutter on detection performance is considered. Human targets are discriminated by analyzing the spectrogram of each potential target. It is shown that the spectrogram of every human return is unique, and can be used not just to identify targets as human, but also to determine features about the human target being observed, such as size, gender, action, and speed. A 12-point human model, toegether with kinematic equations of motion for each body part, is used to calculate the expected target return and spectrogram. A MATLAB simulation environment is developed, including ground clutter, human and non-human targets, for testing proposed detection and identification algorithms. Simulations show human targets can be successfully discriminated from other targets, and a classification scheme is developed to extract features about the target being observed.

6567-18, Session 4

Improving throughput for temporal target nomination using existing infrastructure

P. G. Raeth, Ball Aerospace & Technologies Corp.

Earlier, we reported on predictive anomaly detection (PAD), for nominating targets within datastreams generated by persistent sensing and surveillance. This technique is purely temporal and does not directly depend on the physics attendant on the sensed environment. Since PAD adapts to evolving data streams, there are no determinacy assumptions. PAD was shown to be general across sensor types, having been demonstrated using synthetic chaotic data and in audio, visual, and infrared applications. Defense-oriented demonstrations included explosions, muzzle flashes, as well as missile and aircraft detection.

As new sensors come on line, PAD offers immediate data filtering and target nomination. Its results can be taken individually, pixel by pixel, for spectral analysis and material detection/identification. They can also be grouped for shape analysis, target identification, and track development. Data reduction from PAD analyses is generally around 95%, depending on target number and size.

While PAD's code is simple when compared to physics codes, PAD tends to build a huge model. Typically, a PAD model for 320 x 640 frames contains 14.4 million Gaussian basis functions. (PAD models grow linearly with the number of pixels and the frequency content, in the FFT sense, of the sensed scenario's background data.)

Work is needed to improve PAD's computational throughput while employing existing infrastructure, yet allowing for growth in the types of hardware employed. In this present paper, we discuss a generic cluster interface for legacy codes that can be partitioned at the data level. The discussion's foundation is the growth of PAD models to accommodate a particular scenario and the need to reduce false alarms while preserving all targets. The discussion closes with a view of future software and hardware opportunities.

6567-19, Session 4

Time-frequency transform techniques for seabed and buried target classification

M. Barbu, E. Kaminsky, R. E. Trahan, Jr., Univ. of New Orleans

An approach for processing sonar signals with the ultimate goal of ocean bottom sediment classification and underwater buried target classification is presented this paper. Work reported is based on sonar data collected by the Volume Search Sonar (VSS) as well as on simulated data. The technique is based on the Fractional Fourier Transform (FrFT) and joint time-frequency representations of the signal. The classification is based on singular value decomposition of the various time-frequency distributions applied to the impulse response obtained using Fractional Fourier transform. The set of the singular values represents the desired feature vectors that describe the properties of the signal. The relevant features (singular values) have been mapped in a reduced dimension space where competing techniques for acoustic seabed sediment classification have been employed and compared. Of particular interest for underwater classification applications are long targets such as cables of various diameters, which need to be identified as different from other strong reflectors or point targets. Synthetic test data are used to exemplify and evaluate the technique. Results are presented that illustrate the processing procedure and show that the algorithm provides an accurate way to classify buried objects with high probability of correct classification.

6567-21, Session 5

A survey of PHD filter related research

R. P. S. Mahler, Lockheed Martin Co.

The probability hypothesis density (PHD) filter has attracted increasing interest since the author first introduced it in 2000. Potentially practical computational implementations of this filter have been devised, based on sequential Monte Carlo or on Gaussian mixture techniques. Research groups in at least a dozen different nations are investigating the PHD filter and its generalization, the CPHD filter, for use in various applications. Some of this work suggests that the PHD filter may, under certain circumstances, outperform conventional multitarget filters such as MHT and JPDA. The purpose of this paper is to summarize these research efforts and their findings.

6567-22, Session 5

A unified Bayesian theory of measurements

R. P. S. Mahler, Lockheed Martin Co.

Bayesian target detection, tracking, and identification is based on the recursive Bayes filter and its generalizations. This filter requires that measurements be transformed into likelihood values. Conventional likelihoods model the randomness of conventional measurements. Other measurement types involve not only randomness but also imprecision, vagueness, uncertainty, and contingency. Conventional measurements and target states are also mediated by precise, deterministic models. But in general these models can also involve imprecision, vagueness, or uncertainty. This paper describes three major types of generalized measurements and their associated generalized likelihood functions. We also point out that for certain types of generalized measurements, fuzzy, Dempster-Shafer, and rule-based measurement fusion can be rigorously reformulated as special cases of Bayes' rule.

6567-23, Session 5

Mission-based situational awareness sensor management and information fusion

A. I. El-Fallah, A. Zatezalo, Scientific Systems Co., Inc.; R. P. S. Mahler, Lockheed Martin Co.; R. K. Mehra, Scientific Systems Co., Inc.; M. G. Alford, Air Force Research Lab.

A theoretical formulation for mission based sensor management and information fusion using advanced tools of probability theory and stochastic processes is presented. We apply Bayes' Belief Network methods to fuse features and determine a tactical significant function which is used by the sensor management objective function. The estimated multi-sensor multi-target posterior that results reflects tactical significant, and is used to determine the course of action for the given mission. We demonstrate the performance of the algorithm using the simple mission of reaching a pre-specified location while avoiding threatening targets, and discuss the results.

6567-24, Session 5

Space-based sensor management and geostationary satellites tracking

A. I. El-Fallah, A. Zatezalo, R. K. Mehra, Scientific Systems Co., Inc.; R. P. S. Mahler, Lockheed Martin Co.; D. Donatelli, Air Force Research Lab.

Sensor management for space situational awareness presents a daunting theoretical and practical challenge as it requires the use of multiple types of sensors on a variety of platforms to ensure that the space environment is continuously monitored. We demonstrate a new approach utilizing the Posterior Expected Number of Targets (PENT) as the sensor management objective function, an observation model for a space-based EO/IR sensor platform, and a Probability Hypothesis Density Particle Filter (PHD-PF) tracker. Simulation and results using actual Geostationary Satellites and resident space objects will be presented. We will also demonstrate enhanced performance by applying the Progressive Weighting Correction (PWC) method for regularization in the implementation of the PHD-PF tracker.

6567-25, Session 5

PFLib: an object-oriented MATLAB toolbox for particle filtering

L. Chen, Scientific Systems Co., Inc.; C. Lee, A. Budhiraja, The Univ. of North Carolina at Chapel Hill; R. K. Mehra, Scientific Systems Co., Inc.

Under a United States Army Small Business Technology Transfer (STTR) project, we have developed a MATLAB toolbox called PFLib to facilitate the exploration, learning and use of Particle Filters by a general user. A filter is implemented as a MATLAB object which operates in the following fashion: First, the filter object is created (initialized) with information regarding the specific problem under consideration — "function handles" of the state transition equation and measurement equation, and the statistics of the noises that enter into them additively. After this, the filtering is performed recursively. At each iteration, the filter object takes as input the newly arrived measurement, conducts internal computations and updates, and provides read-out results of the filtering, such as sample mean and covariance. The inner working of the filter is thus encapsulated and need not be programmed by a general user, while at the same time the usage of any kind of filter has a consistent Application Programming Interface (API).

There are five categories of filters implemented: the Extended Kalman Filter (EKF), the Bootstrap Particle Filter , the Particle Filter with an EKF-type "proposal distribution," the Auxiliary Particle Filter, and the Instrumental Variable Particle Filter. Resampling schemes include None, Simple Resampling, Residual Resampling, Branch-and-Kill, and System Resampling. Other available choices include sampling frequency, number of particles, and Jacobians.

The initialization and filtering described above is achieved through scripting in MATLAB. To further facilitate a general user, a Graphical User Interface (GUI) is also provided that interactively collects filter choices and parameters from the user, and then automatically generates corresponding initialization code and sample filtering code that can be cut-and-pasted into other scripts.

We are planning to release PFLib under a Free Open Source Software (FOSS) model.

6567-26, Session 6

Analytical performance evaluation for autonomous sensor fusion

K. C. Chang, George Mason Univ.; M. E. Liggins II, The MITRE Corp.

A distributed data fusion system consists of a network of sensors, each capable of local processing and fusion of sensor data. There has been a great deal of work in developing distributed fusion algorithms applicable to a network centric architecture. Currently there are at least a few approaches including naïve fusion, cross-correlation fusion, information fusion, maximum a posteriori (MAP) fusion, channel filter fusion, and covariance intersection fusion, some of which assume a fixed (global) knowledge of the communications architecture.

However, in general, in a distributed sensor system, the communication architecture is not fixed. Each node has knowledge of only its local connectivity but not the global network topology. In those cases, the distributed fusion algorithm based on information filter type of approach may not scale due to its requirements to carry a long petigree information for decorrelation.

In this paper, we focus on scalable fusion algorithms and conduct analytical performance analysis to compare their performance. The goal is to understand the performance of those algorithms under different operating conditions. Specifically, we evaluate the performance of channel filter fusion, Chernoff fusion, Shannon Fusion, and Battachayya fusion algorithms. We also compare their results to Naïve fusion and “optimal” information filter algorithms under a specific communication pattern.

6567-27, Session 6

A testbed for architecture and fidelity trade studies in the Bayesian decision-level fusion of ATR products

K. J. Erickson, Jacobs Engineering

Decision-level fusion is an appealing extension to automatic/assisted target recognition (ATR) as it is a low-bandwidth technique bolstered by a strong theoretical foundation that requires no modification of the source algorithms. The ATR problem itself provides the main hindrance to fusion, in its high cost and relative scarcity of training data, its variability in application, the inability to produce truly random samples, and its sensitivity to context. Systems utilizing decision-level fusion of ATR outputs must characterize the operating environment and exploit ATR performance models at levels commensurate with the sophistication of the fusion algorithm. The Air Force Research Laboratory (AFRL) Sensors Directorate ATR Thrust has begun the Fusion for Identifying Targets Experiment (FITE) for the express purpose of examining the tradeoffs inherent among conditions affecting the target, the fidelity of the ATR performance model, the accuracy of prior information, and the complexity of the fusion algorithm. This paper summarizes the mathematics underlying decision-level fusion in the ATR domain and describes a MATLAB-based architecture for exploring the trade space thus defined. Experiment definitions suitable for multi-look and multi-sensor fusion systems are presented.

6567-28, Session 6

Survey of approaches and experiments in decision-level fusion of automatic target recognition (ATR) products

T. D. Ross, Air Force Research Lab.

The limitations in the reliability of single-source ATR products and the growing sensor data collection capabilities of modern armed forces have made the fusion of ATR products a priority. This data combination could improve the accuracy and detail of information while simplifying its presentation. Even when restricting consideration to decision-level combination of identity data (a subset of level 1 fusion), as we do in this survey, there is a large trade space of fusion approaches. The proper approach depends on many factors, including the type of information available, the accuracy of that information, and how well the uncertainty of that information is known. Similarly, the technology requirements for fusion sources should be driven, at least in part, by what best enables contributions to a fusion system. The US Air Force Research Laboratory (AFRL) is exploring this trade space in the Fusion for Identifying Targets Experiment (FITE) program. As part of this program, a survey of decision-level fusion approaches and experiments has been conducted. This paper reports on the findings of that survey, which places the various studies in a common framework, identifies persistent trends, and makes recommendations on the additional studies that would best inform the trade space of how to fuse ATR products and how ATR products should be improved to support fusion.

6567-29, Session 6

ROC curve formulas for fused correlated classification systems

C. M. Schubert, Virginia Commonwealth Univ.; S. N. Thorsen, M. E. Oxley, Air Force Institute of Technology

The Receiver Operating Characteristic (ROC) curve can be used to quantify the performance of Automatic Target Recognition (ATR) systems. When multiple classification systems are fused, the assumption of independence is usually made in order to mathematically combine the individual ROC curves for each of these classification systems into one fused ROC curve. However, correlation may exist between the classification systems and the outcomes used to generate each ROC curve. This paper will demonstrate a method for creating a ROC curve of the fused classification systems which incorporates the correlation that exists between the individual classification systems. Specifically, we will use the derived covariance between multiple classification systems to compute the existing correlation and thus the level of dependence between pairs of classification systems. Then, given a fusion rule, two systems, and the correlation between them, the ROC curve for the fused system is produced. We generate the formula for the Boolean OR and AND rules, giving the resultant ROC curve for the fused system. This paper extends our previous work in which bounds for the ROC curve of the fused, correlated classification systems were presented.

6567-30, Session 7

Aerial video and ladar imagery fusion for persistent urban vehicle tracking

P. L. Cho, D. Greisokh, R. C. Knowlton, MIT Lincoln Lab.

Automating Urban Situational Awareness represents an increasingly critical intelligence objective. A robust capability to continuously monitor vehicle activity within complex cities is especially needed to uncover ground mover trends. Lincoln Laboratory researchers are currently building a persistent video surveillance system which exhibits impressive automated tracking ability. But maintaining lock on thousands of cars with aerial video input alone is formidably difficult.

In this talk, we report upon incorporating static 3D geometry information into the urban vehicle tracking problem. Using recent persistent video data collected over a city with minimal terrain content, we first quantify sources of automated tracking termination and identify those which could be ameliorated by detailed height maps. They include imagery misregistration (25%), roadway occlusion (15%) and vehicle deceleration (27%). We next develop tractable mathematical models to analyze the tracking value of spatial geometry knowledge in general and high resolution ladar imagery in particular. Simulation and algorithm results demonstrate how 3D information could eliminate large numbers of spurious tracks passing through impenentrable urban structures. False track rejection would in turn permit Kalman filter coasting times to be signficantly increased. Track lifetimes for vehicles occluded by trees and buildings as well as for cars turning corners or slowing down at intersections could consequently be prolonged. We find high resolution 3D imagery would ideally yield an 83% reduction in the rate of automated vehicle tracking failure.

6567-31, Session 7

Advanced activity reporting in a multilayered unattended ground sensor network

T. Joslin, Harris Corp.

Sensor networks are emplaced throughout the world to remotely track activity. Typically, these sensors report data such as target direction or target classification. This information is reported to a soldier based monitor or a command center. The ideal sensor system will have a long mission life capability and will report information-rich actionable intelligence with high data integrity with near real-time latency. This paper discusses a multi-layered approach that includes data fusion at the sensor node, sensor network, and command center layer to create cohesive reports that mitigate false alarms and multiple reports of the same target while providing accurate tracking data on a situational awareness level. This approach is influenced by low-power architecture, and designed to maximize information density and reduce flooding of sensor networks.

6567-32, Session 7

The use of optical RF network for target detection and tracking

M. Li, Consultant

An optical RF network [1] is comprised of distributed antenna subsystems and a center for processing RF signals. It is different from an optical communication or computer network. Although these networks all use optical fibers or direct lasers for networking, they are fundamentally different. In an optical RF network, the information contained in optical signals, which are being sent between antenna subsystems and the center, is usually unknown. The optical signals will only reveal the information carried by RF signals after processing at the center. This is not the case for the optical communication or computer network. The information in optical signals, which are being sent between communication or computer nodes, is known.

What information is contained in an RF signal depends on how it is processed. For instance, a direct conversion from a pulsed RF signal to a digital signal through fast RF digitizers or to an IF signal through super heterodyne only retains a small fraction of the information; but the majority of the information is lost. Hence the RF signal should never be converted before processing. The optical RF network will avoid the above problem.

The present talk will discuss the use of optical RF network, including optical fiber based radar and optical RF stereo, to advance radar technology in target detection and tracking.

1. M. C. Li, “Open Air Generic Range for Testing and Training”, Journal of Electronic Defense, (January, 1993) pp. 60-64

6567-33, Session 8

Issues and challenges in resource management and its interaction with levels 2/3 fusion with applications to real-world problems: an annotated perspective

E. P. Blasch, Air Force Research Lab.; I. Kadar, Interlink Systems Sciences, Inc.; K. J. Hintz, George Mason Univ.; C. Chong, BAE Systems Advanced Information Technologies; J. J. Salerno, Jr., Air Force Research Lab.; J. Biermann, FGAN-FKIE (Germany); S. Das, Charles River Analytics, Inc.

Resource management is critical for information fusion operation in that user, sensors, and platforms need to be informed, based on mission needs, on how to collect, process, and exploit data. To meet these growing concerns, a panel session was conducted at the International Society of Information Fusion Conference in 2006 to discuss the various issues surrounding the interaction with Resource Management and Level 2/3 fusion of Situation and Threat Assessment. This paper briefly consolidates the discussion as a means of facilitating future research to the specifics and needs for Information Fusion Exploitation. The specific issues addressed include (1) knowledge based information collection, (2) inclusion of net-centric distributed collaboration, (3) inclusion of team and group dynamics, (4) decision-theoretic analysis based on the application, and (5) dynamic, adaptive, and automatic management properties for synergistic optimization of all levels of information fusion.

6567-34, Session 8

Game theoretic behavior features change prediction in hostile environments

M. Wei, G. Chen, Intelligent Automation Inc.; J. B. Cruz, Jr., The Ohio State Univ.

In recent years substantial effort has been dedicated to predicting possible enemy’s course of actions (COA) under hostile environments. Point-pattern-based density models are popular tools for such research areas. Since it is well known that adversarial actions tend to cluster according to geography preferences and timing features, it is natural to pay attention to clustering of COAs over the geographical sites and assume such clustering will persist over a long enough time horizon so that prediction is possible. For example, a most popular and fundamental assumption in crime prediction system is “journey to crime”, which believes that COA initiators tend to choose geographically closer sites to start next COA. This assumption provides the base for various “hot-spot” prediction techniques, which are all branches of point-pattern-based density models. Recently the most widely used method is the Spatial and Temporal Analysis of Crime (STAC) program that tries to fit crimes points into ellipses. There are additional hotspot methods, and some of them apply kernel density estimation and achieve reasonable benefits.

One important point is that all these approaches assume that the enemy’s current tactics pattern or preference will persist over the future. This might be reasonable enough if the enemies are unorganized riots for in such cases the strikes approximately follow some probability distribution, such as Poisson distribution. However, intelligent and organized adversaries will not display random choices when choosing strategies. They would like to estimate the possible benefits and risks and choose or change strategy purposefully instead of choosing strategies randomly. Moreover, they might execute “surprise” attacks deliberately to “violate” predictions based solely on probability theory.

We propose a game theoretic approach to predict the possible changes of features. This is because the basic logic of game theory is to predict ahead via all available information, including past data and possible choices at current stage. It has the following advantages: 1) No delay. It does not need to wait for the enemy’s change happening firstly; 2) More trustable. Such prediction is often self-enforcing ue to the properties of Nash solutions.

This paper is organized as follows. In Section II, we will summarize the technical approach, which includes problem description, benefit updating mechanisms, objective functions, and calculation of optimal control strategies. Section III describes the experimental results and explanations. Section IV provides conclusions for the paper.

6567-35, Session 8

Statistical comparison of the hybrid approach with pure and exact inference models for fusion 2+

K. D. Lee, E. Wiesenfeld, A. Gelfand, Decisive Analytics Corp.

One of the greatest challenges in modern combat is maintaining a high level of timely Situational Awareness (SA). In many situations, computational complexity and accuracy considerations make the development and deployment of real-time, high-level inference tools very difficult. An innovative hybrid framework that combines Bayesian inference, in the form of Bayesian Networks, and Possibility Theory, in the form of Fuzzy Logic systems, has recently been introduced to provide a rigorous framework for high-level inference. In previous research, the theoretical basis and benefits of the hybrid approach have been developed. However, lacking is a concrete experimental comparison of the hybrid framework with traditional fusion methods, to demonstrate and quantify this benefit. The goal of this research, therefore, is to provide a statistical analysis on the comparison of the accuracy and performance of hybrid network theory, with pure Bayesian and Fuzzy systems and an inexact Bayesian system approximated using Particle Filtering. To accomplish this task, domain specific models will be developed under these different theoretical approaches and then evaluated, via Monte Carlo Simulation, in comparison to situational ground truth to measure accuracy and fidelity. Following this, a rigorous statistical analysis of the performance results will be performed, to quantify the benefit of hybrid inference to other fusion tools.

6567-36, Session 8

Hybrid methodology for situation assessment model development within an air operations center domain

P. G. Gonsalves, C. D. Call, S. Ho, Charles River Analytics, Inc.

Within the dynamic environment of an Air Operations Center (AOC), effective decision-making is highly dependent on timely and accurate situation assessment. In previous research efforts the capabilities and potential of a Bayesian belief network (BN) model-based approach to support situation assessment have been demonstrated. In our own prior research, we have presented and formalized a hybrid process for situation assessment model development that seeks to ameliorate specific concerns and drawbacks associated with using a BN-based model construct. Specifically, our hybrid methodology addresses the significant knowledge acquisition requirements and the associated subjective nature of using subject matter experts (SMEs) for model development. Our methodology consists of two distinct functional elements: an off-line mechanism for rapid construction of a Bayesian belief network (BN) library of situation assessment models tailored to different situations and derived from knowledge elicitation with SMEs; and an on-line machine-learning-based mechanism to learn, tune, or adapt BN model parameters and structure. The adaptation supports the ability to adjust the models over time to respond to novel situations not initially available or anticipated during initial model construction, thus ensuring that the models continue to meet the dynamic requirements of performing the situation assessment function within dynamic application environments such as an AOC. In this paper, we apply and demonstrate the hybrid approach within the specific context of an AOC-based air campaign monitoring scenario. We detail both the initial knowledge elicitation and subsequent machine learning phases of the model development process, as well as demonstrate model performance within an operational context.

6567-38, Session 9

Automatic building detection and 3D shape recovery from single monocular electro-optic imagery

D. A. Lavigne, Defence R&D Canada/Valcartier (Canada); A. Dlugan, N. Goldstein, P. Saeedi, H. H. Zwick, MacDonald, Dettwiler & Associates Ltd. (Canada)

The extraction of 3D building geometric information from high resolution electro-optical imagery is becoming a key element in numerous geospatial applications. Indeed, producing 3D urban models is a requirement for a variety of applications such as spatial analysis of urban design, military simulation, and site monitoring of a particular geographic location. However, almost all operational approaches developed over the years for 3D building reconstruction are semi-automated ones, where a skilled human operator is involved in the 3D geometry modelling of building instances, which results in a time-consuming process. Furthermore, such approaches usually require stereo image pairs, image sequences, or laser scanning of a specific geographic location to extract the 3D models from the imagery. Finally, with current techniques, the 3D geometric modelling phase may be characterized by the extraction of 3D building models with a low accuracy level.

This paper describes the Automatic Building Detection (ABD) system and embedded algorithms currently under development. The ABD system provides a framework for the automated detection of buildings and the recovery of the 3D geometric models from single monocular electro-optic imagery. The system is designed in order to cope with multi-sensor imaging of arbitrary viewpoint variations, clutter, and occlusion. Preliminary results on monocular airborne and spaceborne images are provided. Accuracy assessment of detected buildings and extracted 3D building models from single airborne and spaceborne monocular imagery of real scenes are also addressed. Embedded algorithms are evaluated for their robustness to deal with relatively dense and complicated urban environments.

6567-39, Session 9

Application of a dynamic feature selection algorithm to multisensor image registration

S. P. DelMarco, H. F. Webb, V. T. Tom, D. Lefebvre, BAE Systems Advanced Information Technologies

Image registration is usually a required first processing step for such activities as surveillance, video tracking, change detection, and remote sensing. Often, different sensors are used for the collection of the test and reference imagery. The sensor phenomenology differences can present problems for automatic selection of registration algorithm parameters because of different cross-sensor feature manifestation. In previous work involving edge-based multisensor image registration, we applied a previously-developed automated approach to parameter selection, designed specifically for edge detection. In this work, we adapt and apply a dynamic feature selection algorithm (DFSA) that we recently developed for use in registration algorithm selection for registering images with varying scene content type. We adapt and apply the DFSA to the problem of selecting appropriate registration algorithm parameter values in an edge-based registration algorithm. The approach involves generating test-to-reference feature match scores over a sampling of the transform hypothesis space. The approach is scene-adaptive thereby requiring no a priori information on image scene content. Furthermore, in the DFSA we leverage prior match score calculation generated in a hierarchical grid search to reduce additional computational expense. We give a brief overview of the registration algorithmic framework, and present a description of the dynamic feature selection algorithm. Numerical results are presented for performing test SAR-to-reference EO image registration to show the registration convergence performance improvement resulting from use of the DFSA. Numerical results are generated over images exhibiting different scene content types. We also evaluate the effect of match score normalization on the registration convergence performance improvement.

6567-40, Session 9

A verification metric for multisensor image registration

S. P. DelMarco, V. T. Tom, H. F. Webb, D. Lefebvre, BAE Systems Advanced Information Technologies

Accurate geo-location of imagery produced from airborne imaging sensors is a prerequisite for precision targeting and navigation. However, the geo-location metadata often has significant errors which can degrade the performance of applications using the imagery. When reference imagery is available, image registration can be performed as part of a bundle-adjustment procedure to reduce metadata errors. Knowledge of the metadata error statistics can be used to set the registration transform hypothesis search space size. In setting the search space size, a compromise is often made between computational expediency and search space coverage. It therefore becomes necessary to detect cases in which the true registration solution falls outside of the initial search space. To this end, we develop a registration verification metric, for use in a multisensor image registration algorithm, which measures the verity of the registration solution. The verification metric value is used in a hypothesis testing problem to make a decision regarding the suitability of the search space size. Based on the hypothesis test outcome, we close the loop on the verification metric in an iterative algorithm. We expand the search space as necessary, and re-execute the registration algorithm using the expanded search space. We first provide an overview of the registration algorithm, and then describe the verification metric. We generate numerical results of the verification metric hypothesis testing problem in the form of Receiver Operating Characteristics curves illustrating the accuracy of the approach. We also discuss normalization of the metric across scene content.

6567-41, Session 9

Detecting small changes in images with parallax

M. J. Carlotto, General Dynamics Corp.

No abstract available

6567-42, Session 9

A feature-based approach for detecting anomalies in space, time, and spectrum

M. J. Carlotto, General Dynamics Corp.

No abstract available

6567-43, Session 9

Target detection based on multiresolution singularity analysis

D. Charalampidis, G. W. Stein, Univ. of New Orleans

In this work, a target detection technique based on a multiresolution wavelet scheme is presented for SAR imaging. The technique includes a multiscale singularity detection and characterization step. This step is employed in order to extract features that identify clutter-based textural regions, as well as targets. More specifically, clutter regions are areas characterized by a significantly large number of singularities. On the other hand, targets are described by isolated singularity contours. In some cases, isolated clutter objects may exhibit properties similar to that of a target. However, examination of the singularity types though different scales can differentiate between targets and clutter objects. A significant advantage of the proposed technique compared to previous target detection approaches is that it provides excellent target localization. Therefore, multiple targets in close proximity can be detected. Furthermore, targets located nearby clutter regions can be identified. Several mixtures of targets and clutter regions are considered in order to examine various realistic scenarios. Experimental results have illustrated that the proposed technique provides higher percentage of detection than the previously introduced CFAR and Extended Fractal models.

6567-44, Session 9

Morphological component analysis and STAP filters

H. C. Morris, Modal Research; M. De Pass, Claremont Graduate Univ.

STAP is an adaptive filtering algorithm that works on space-time radar data to suppress the effects of clutter and jamming and achieve both target identification and parameter estimation in airborne and space based radar. The signals to which STAP processes are applied consist of three basic parts: target, clutter and jamming. In Morphological Component Analysis (MCA), the component signals are separated by assuming that each signal component can be sparsely represented in some suitable dictionary. It is assumed that expansions of a given signal component in the dictionaries of the other signal components, are non-sparse. The MCA algorithm seeks a solution through an optimization method that implements this sparse-representation concept. This approach has recently been applied to the analysis of ISAR images by H. Morris, M. De Pass. In this paper we consider the basic STAP equations as a problem in Multi-channel Morphological Component Analysis (MMCA). The method is illustrated by application to simulated data with K-distributed clutter.

6567-45, Session 9

High-dimensional feature space partitioning using classification catch cover digraphs

M. A. Ordaz, A. J. Patterson, D. E. Waagen, N. N. Shah, E. Whittenberger, Raytheon Missile Systems

In high-dimensional settings, direct estimation of class-conditioned probability densities is generally constrained in practice by limited class sample sizes and the associated curse of dimensionality. Yet estimating the similarities and differences of feature distributions in these spaces is necessary for evaluating feature utility and ultimately classification efficacy. Therefore an efficient and effective approach for partitioning high-dimensional spaces into 'informative' regions is of interest. In this regard, we propose application of the Classification Catch Cover Digraph algorithm for informative feature space partitioning. An evaluation of the classification efficacy of the partitions produced is demonstrated in a real-world setting.

6567-46, Session 9

A spectral independent morphological adaptive classifier

J. B. Montgomery, C. Montgomery, M&M Aviation; R. Sanderson, Air Force Research Lab.

Effective missile warning and countermeasures continue to be an unfulfilled goal for the Air Force and DOD community. To make the expectations a reality, sensors exhibiting the required sensitivity, field of regard, and spatial resolution are being pursued. The largest concern is in the first stage of a missile warning system, detection, in which all targets need to be detected with a high confidence and with very few false alarms. Typical sensors are limited in their detection capability by the presence of heavy background clutter, sun glints, and inherent sensor noise. Many threat environments include false alarm sources like burning fuels, flares, exploding ordinance, and industrial emitters. Multicolor discrimination is one of the effective ways of improving the performance of missile warning sensors, particularly for heavy clutter situations. Its utility has been demonstrated in multiple fielded systems. Utilization of the background and clutter spectral content, coupled with additional spatial and temporal filtering techniques have resulted in a robust adaptive real-time algorithm to increase signal-to-clutter ratios against point targets. The algorithm is outlined and results against tactical data are summarized and compared in terms of computational cost expected to be implemented on a real-time field-programmable gate array processor.

6567-47, Session 10

A fuzzy rule base system for object-based feature extraction and classification

X. Jin, S. Paswaters, ITT Visual Information Solutions

In this paper, we present a fuzzy rule base system for object-based feature extraction and classification on remote sensing imagery. First, the object primitives are generated from the segmentation steps. Object primitives are defined as individual regions with a set of attributes computed on the regions. The attributes computed include spectral, texture and shape measurements. Crisp rules are very intuitive to the users. They are usually represented as "GE (greater than)", "LE (less than)" and "IB (In Between)" with numerical values. It can be manually generated by query on the attributes and monitoring the resulting selected object primitives. However, the attributes of different features are usually overlapping. The information is inexact and not suitable for traditional digital on/off decisions. Here a fuzzy rule base system is built to better model the uncertainty inherent in the data and vague human knowledge. Rather than representing attributes in linguistic variables like "Low", "Median", "High", we proposed a new method for automatic fuzzification of the traditional crisp concepts "GE", "LE" and "IB". Two sets of membership functions are defined to model those concepts. One is based on the piecewise linear functions, the other is based on S-type membership functions. A novel concept "fuzzy tolerance" is proposed to control the degree of fuzziness of each rule. The experimental results on classification and extracting features such as river, roads and buildings have shown that this new designed fuzzy rule base system is intuitive to the users and facilitate the users to generate fuzzy rules.

6567-48, Session 10

Novel lock-in amplifier for identification of luminescent materials for authentication

A. D. McAulay, Lehigh Univ.

We previously, over the past decade, constructed and delivered handheld low cost electronic signal processing boxes for optical detection and identification of phosphors. We describe and simulate a novel low-cost handheld lock-in amplifier based approach, not previously proposed to our knowledge, that uses phosphor stimulation frequency, emission frequency and lifetime decays to uniquely identify a phosphor at a distance of many feet in a noisy environment. A pulsed laser diode stimulates the phosphor at a distance of several feet. The novel receiver based on the lock-in amplifier detects weak luminescence generated at a phosphor in the presence of daylight, sunlight, electronic noise and reflection of the stimulating beam. As the stimulating collimated beam diverges slowly on reflection, it is millions of times stronger at the receiver than the signal from the weak luminescence that emits over a 4 Pi beam pattern. Mirrors must be detected as counterfeit. In addition to relying on the different stimulation and emission frequencies, different luminescing materials are distinguished from their decay times by a novel matched filter technique inside the lock-in amplifier. Reading through cardboard is described where the authentification phosphor is inside a tamper proof package. Applications include pharmaceuticals, paper currency, clothing materials, and friend and foe identification from paint and clothing.

6567-49, Session 10

Robust modulation classification techniques based on hierarchical neural networks

J. DeClouet, M. Naraghi-Pour, Louisiana State Univ.

The problem of automatic modulation classification is to identify the modulation type of a received signal from the signal parameters. Modulation classification has both military and civilian applications and has been the subject of intensive research for more than two decades. In this paper we use a hierarchical neural network in which the first network identifies the modulation class while a second set of networks identify the constellation size (order) of that modulation class. The set of features we use include normalized standard deviations of amplitude, phase and frequency, as well as the fourth and sixth order cumulants of the signal samples. Identifying the constellation size of quadrature amplitude modulation (QAM) has been particularly difficult in the past. In this paper we introduce two new approaches for computing the features of a QAM signal. The first uses the concatenated in-phase and quadrature components of the signal to compute the features. The second method maps the in-phase and quadrature components to the first quadrant of the constellation by calculating the absolute value of each separately. The mean of the resulting constellation points is then subtracted before calculating the features. Simulation results will be presented for classification of several digital modulation schemes including FSK, PSK, ASK and QAM. Our results show that the proposed method significantly improves the classification error.

6567-50, Session 10

Real-time 3D target tracking and localization for arbitrary camera geometries

A. P. Kulkarni, Arizona State Univ.; G. P. Abousleman, General Dynamics C4 Systems; J. Si, Arizona State Univ.

In this paper, we describe a real-time 3-D tracking system that uses two cameras in substantially arbitrary geometries. The primary goal of the proposed system is to capture incoming stereo vision feeds, examine and compare targets across the cameras, and using a derived camera calibration matrix, project them in real-world 3-D coordinates, all in real time. The system is divided into three main components: Camera calibration, camera synchronization, and tracking and cross-camera object matching. In the proposed system, algorithms such as 8-point feature matching form the basis for the camera calibration/pose estimation mechanism, while motion frequency, color, and shape form a robust tracking and cross-camera feature matching stage. Camera synchronization issues are also addressed. The system operates in an initialization phase and in an analysis phase. In the initialization phase, the cameras' pose estimation, i.e., camera calibration, is performed. In the analysis phase, the object tracking, feature matching, and cross-camera target association are performed. The proposed system is shown to be robust and applicable to a wide variety of moving objects such as people, vehicles, and boat.

6567-51, Session 10

NIR polarization camera

G. S. Baker, MilSys Technologies LLC

A unique polarization camera has been fabricated out of a wire grid polarizer bumpbonded on to the surface of a InGaAs FPA. The wire grid was configured as a Stokes polarimeter. Data has been collected for both space and earthbound applications using both active and passive illumination. A mini-range and scaled targets of representative materials were constructed to simulate space based distances for both resolved and unresolved targets. For the purpose of providing advanced warning for rotorcraft, data has been collected on power lines to test the feasibility and appropriateness of this type of technology to aid in their detection.

6567-52, Session 10

MTF model for color Bayer detectors

Y. Elor, RAFAEL Armament Development Authority Ltd. (Israel)

We present a model for calculating the Spatial Frequency Response (SFR) for Bayer pattern color detectors. The model is based on the color detector response for B/W scenes. When a Bayer color detector is compared to a B/W detector, The SFR difference results from the interpolation process. This process exists only in the Bayer pattern detectors. In this work we ascribe the MTF and the spurious response to the interpolation process.

The model may be applied to any linear interpolation. Although the interpolation is linear it is not Shift Invariant (SI). Therefore, calculating the interpolation MTF is not a trivial task. Furthermore, the interpolation creates a spurious response. In order to calculate the interpolation SFR we introduced a separable constraint (for x and y directions) by using a scene that varies only on one axis and is fixed on the other. We further assumed that the human eye also integrates in the direction of the fixed axis. By using these two assumptions, we have been able to separate the response into two axes and calculate the SFR.

For long range scenes, colors saturation decreases, the colors are less visible and we mostly sense grey colors. In these cases the Johnson Criteria can be roughly applied. In order to apply the Johnson Criteria, we need to know the MTF of the sensing system. The sensing system MTF includes the interpolation MTF. We show that the interpolation process degrades the system performance compared to B/W sensor. Another application of the model is in comparing different interpolation algorithms.

6567-53, Session 10

Signal processing techniques for heterodyne differential absorption lidar

J. Y. Beyon, California State Univ./Los Angeles; G. J. Koch, S. Ismail, NASA Langley Research Ctr.

Different methods of energy estimation for a differential absorption lidar (DIAL) system at NASA Langley Research Center in Virginia are investigated in this paper. The system is a 2-um wavelength coherent Doppler lidar called VALIDAR that has been traditionally used for measuring wind. Recent advances in laser wavelength control have allowed the new use of this lidar for measuring atmospheric CO_2 concentration by a DIAL technique. In order to realize accurate DIAL measurements, optimal signal processing techniques are required to represent the energy of the heterodyned backscatter signals. The noise energy was estimated by minimizing the mean square error in its estimate and was used to normalize its adverse influence on accurate estimation of the concentration of CO2 in the atmosphere. The impact of different methods on the statistics of CO2 concentration measurements is compared.

6567-55, Poster Session

Signal filtering based on wavelet transform and its application in ground-penetrating radar

C. Xu, South China Normal Univ. (China); J. Li, Shanghai Jiao Tong Univ. (China)

How to improve the Signal Noise(Interfere) Ratio is the key problem of the application of the Ground-Penetrating Radar all the time. In practical GPR detection, the target echo signal is composed of direct wave, primary echo signal, other small amplitude echo signal and noise, it has abundant multi-frequency information, which makes the signal processing very difficult. Fourier transform can only identify different signal frequency in the whole range; short-time Fourier transform uses the same width analyzing window; the two classical method can¡¯t get detailed information in time domain and frequency domain at the same time, they are not optimum. The part characteristic in time-domain and frequency-domain of wavelet transform makes it effectively applied in radar signal process. A practical GPR signal processing method is proposed. Based on continuous wavelet transform, the main component of echo signal is extracted by energy analysis. Through scaled decomposition and frequency filtering, the disturbed component is eliminated. The SNR of reconstructed echo signal is improved. The procedure includes three steps: (1) Echo signal¡¯s scale decomposition and frequency filtering; (2) Dominant scale component extracting and frequency filtering; (3) Echo signal¡¯s reconstruction The processing results of real data indicate that: it¡¯s good at eliminating the interfering components and improving the processing performance well.

6567-57, Poster Session

Dwi-detector optical sensor for measuring the measuring the concentration of total suspended solids

H. S. Lim, M. Z. Mat Jafri, K. Abdullah, Univ. Sains Malaysia (Malaysia)

The design of optical sensor systems is based on the interaction between the photons of the electromagnetic radiation and suspended particles in water. The objectives of this study area are to design and develop a multi-detector optical sensor for measuring the concentration of total suspended solids, TSS, in polluted water samples. An algorithm which requires calibration analysis has been derived for estimating TSS concentrations. The proposed optical system uses a single light emitting diode, LED, as an emitter and two phototransistors are used as detectors. Detected radiations were measured at scattering angles of 900 and 1800 between the source and the detectors. The algorithm produced a high correlation coefficient and low root mean square error value.

6567-58, Poster Session

An improved DS acoustic-seismic modality fusion algorithm based on a new cascaded fuzzy classifier for ground-moving targets classification in wireless sensor networks

Q. Pan, J. Wei, H. Cao, N. Li, H. Liu, Shanghai Institute of Microsystem and Information Technology (China)

A new cascaded fuzzy classifier (CFC) is proposed to implement ground-moving targets classification tasks locally at sensor nodes in wireless sensor networks (WSN). The CFC is composed of three and two binary fuzzy classifiers (BFC) respectively in seismic and acoustic signal channel in order to classify person, Light-wheeled (LW) Vehicle, and Heavy-wheeled (HW) Vehicle in presence of environmental background noise. Base on the CFC, a new basic belief assignment (bba) function is defined for each component BFC to give out a piece of evidence instead of a hard decision label. An evidence generator is used to synthesize available evidences from BFCs into channel evidences and channel evidences are further temporal-fused. Finally, acoustic-seismic modality fusion using Dempster-Shafer method is performed. Our implementation gives significantly better performance than the implementation with majority-voting fusion method through leave-one-out experiments.

6567-59, Poster Session

Effective improvement on traditional filter to reduce envelope delay

Z. Liang, Sr., B. Li, Sr., J. Wei, Y. Liu, Sr., H. Liu, Shanghai Institute of Microsystem and Information Technology (China)

Signal envelope is needed in many applications, for example, in ground moving target detection algorithm, and demodulation in communication. Traditional filters are used in many of these algorithms, but there is always envelope delay obtained by traditional filters. The envelope delay is deadly harmful to ground moving target detection algorithm, so it is necessary to reduce the envelope delay and get a real time envelope.

Much of previous work on obtaining signal envelope is applied in signal processing and communication where real time envelope is not necessary. Further more, previous work mainly focused on the smoothness of envelope and ignored the delay of envelope which is also important in many applications, such as target detection in wireless sensor network where real time is very important.

This paper describes an approach which can reduce envelope delay effectively to improve traditional filter. In some applications, traditional filter is applied to get the envelope of signal, but there is long envelope delay using traditional filter which is not suitable for real time systems, such as ground moving target detection in wireless sensor network. This paper presents a weighted filer approach to reduce envelope delay.

6567-60, Poster Session

Adaptive target segmentation using runtime-weighted features

J. Jung, H. Lee, D. Park, Korea Advanced Institute of Science and Technology (South Korea); C. Park, J. Lee, Samsung Thales Co., Ltd. (South Korea)

Target segmentation plays an important role in the entire target tracking process. Pixel by pixel, it decides whether the current pixel belongs to the target region or not. In the previous works, extracting an intensity histogram was followed by binarization. The target region was classified according to whether the intensity of the current pixel is larger than a certain value. Many researches were focused on how to determine a proper threshold. In this paper, we employ more features such as time-average of intensity, intensity deviation, distance from the centroid of the target and etc., rather than intensity only. Each feature is weighted individually and summed. Each weighting factor is controlled by the weighting logic and target region is determined by summation of weighted features. The weighting logic compares the behavior of each feature in the target region with that in the background region. Then it gives a higher weight to the feature which has a large difference between the target region and the background region. So the proposed segmentation method can control the priority of features adaptively and is robust to condition changes of various circumstances.

6567-61, Poster Session

Real-time color transfer system for low-level light visible and infrared images in YUV color space

L. Wang, W. Jin, Beijing Institute of Technology (China)

We built a real-time color transfer system to obtain day-time color appearance for low-level light visible (LLLV) and infrared (IR) images. The system contains four parts: video decoder SAA7114, 3 pieces of Philips multi-media DSP chips TM1300, FPGA for data combination and logic control, video encoder SAA7129. CCIR656 digital video interfaces are used between each module. Two pieces of TM1300 preprocess and calculate the first order statistical parameters—mean and deviation of LLLV and IR respectively. In the third TM1300, firstly, we linearly combine LLLV and IR in YUV space to achieve a primary color image (source image) that cold targets in IR present blue color, warm targets in IR present red. At the same time, through the same linear combination formula, the statistical parameters of LLLV and IR passed from the preprocessed TM1300 are calculated as statistical parameters in Y, U, V channels. Then, the source image¡¯s color was corrected according to the statistical characteristics of daytime color images (target images) that pre-stored in the cache of TM1300. Tests shows that color transferred results in YUV space are acceptable.

6567-62, Poster Session

Radar detection using sparsely distributed apertures in urban environment

I. Son, T. K. Varslot, C. Yarman, Rensselaer Polytechnic Institute; A. Pezeshki, Princeton Univ.; B. Yazici, M. Cheney, Rensselaer Polytechnic Institute

We present a new receiver design for spatially distributed apertures aimed at detecting targets in an urban environment. First we express the received signal at each receive antennas in terms of the the received signal at the first antenna. To this end a distorted-wave Born approximation is employed when modeling the scattering environment. We use this signal model to formulate a binary hypothesis test for the detection problem. Finally, we derive the optimal linear receiver as the linear filter which maximizes the signal-to-noise ratio (SNR) of the corresponding test statistic. The receiver operation amounts to correlating a filtered version of the measurement at the first antenna with measurements made at the other receive antennas. In the free-space case, the filter applied to the measurement reduces to a delay operator. Here, this free-space receiver is referred to as a delay-correlator. We evaluate the performance of the receiver on experimental data collected in a multi-path and clutter-rich urban environment. The experimental results indicate that the delay-correlator offers significant improvement in detection performance compared to a conventional matched filter. This is attributed to the fact that matched filtering is more sensitive to inaccuracies in the assumptions about the Green's function than the delay-correlator. The delay-correlator, on the other hand, incorporates the multi-path distortion originating from the path between transmitter and target - even when free-space assumptions are employed between the target and the receive antennas.

6567-63, Poster Session

Face and automatic target recognition based on class-specific superresolution subspace

W. Asdornwised, Chulalongkorn Univ. (Thailand)

Recently, super-resolution reconstruction method of low-dimensional face subspaces has been proposed for face recognition. However, the reconstructed features obtained from the face-specific super-resolution subspace contain no class information. This paper proposes a novel method for super-resolution reconstruction of class-specific features that aims on improving the discriminant power of the recognition systems. Our experimental results on Yale and ORL face databases are very encouraging. Furthermore, the performance of our approach on the MSTAR database is outperformed several state-of-the-art Automatic Target Recognition (ATR) methods.

6567-64, Poster Session

Exact message passing algorithm for Bayesian netwrok with loops

W. Sun, K. C. Chang, George Mason Univ.

Distributed message passing algorithm provides exact probabilistic inference for polytree Bayesian networks. When applying to network with loops, a modified method called loopy propagation was developed. This "loopy" algorithm usually can converge and provide reasonable approximate solutions. However, in some cases it will oscillate between answers not necessary close to the true one. In this study, we propose an exact message passing algorithm for the networks with loops. In such case, the variables involved in computing messages are not independent as assumed in the original (Pearl's) message passing algorithm. Instead, we compute the joint distributions of corresponding variables and encode that in the message to be passed when there are loops in the network. We start with networks of continuous variables and show that similar idea can be applied for discrete or hybrid networks.

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6568-01, Session 1

GOTCHA experience report: three-dimensional SAR imaging with complete circular apertures

E. Ertin, C. Austin, R. L. Moses, L. C. Potter, The Ohio State Univ.

In this paper, we review the theory of three dimensional imaging with synthetic aperture radar (SAR) traversing complete circular apertures and present our results on the processing of GOTCHA database. GOTCHA data collection at WPAFB used a polarimetric spotlight SAR covering several complete circular apertures of 360 degrees at various elevation angles. Circular SAR collection geometry provides wide angle information about the non-isotropic reflectivity of the scattering centers in the scene. In addition, unlike the linear collection geometry circular SAR reveals three dimensional information about the location of the scattering centers in the spotlighted area. The 3D localization capability of circular SAR is strongly influenced by the reflectivity persistence of the scattering centers as a function of the azimuth angle. In this paper we provide a statistical characterization of persistence of scatterers present in GOTCHA data and discuss implications on the 3D image resolution. Second, we discuss sampling and storage requirements for coherent wideangle circular SAR imagery. Next, we present enhanced imaging algorithms for multi-elevation circular SAR, which use regularization to provide a sparse description of the target scene that is consistent with the collected SAR data to combat sidelobes and noise artifacts. Finally, we discuss low complexity three dimensional reconstruction techniques using circular layover of polarimetric features to recover contours of vehicles and buildings in three dimensional space.

6568-02, Session 1

Three-dimensional point spread function characterization of a radially displaced scatterer

M. A. Temple, Air Force Institute of Technology

For SAR data collection systems utilizing a circular aperture for target recognition, it is important to know how a target's PSF behaves as a function of various radar functional parameters and target positional changes which occur during data collection. The pivot of this research is characterizing the three dimensional point spread function (3D-PSF) behavior of radially displaced point scatterers for circular synthetic aperture radar (CSAR). For an ATR system requiring target identification with a higher degree of confidence, CSAR processing represents a viable alternative given it can produce images with resolution less than a wavelength. When very large CSAR apertures are combined with high depression angles (300 and higher), an interesting phenomenon occurs. Three dimensional imaging is possible with a single aperture and a single CSAR pass. Using the backprojection image formation algorithm, we generate point target PSF responses using various point target locations, radar bandwidths, depression angles and CSAR apertures (azimuth angle spans). Consistent with previous studies, the 3D-PSF for a point target located at the image center is cone shaped and serves as the basis for comparing and characterizing the PSFs for radially displaced scatterers. If this abstract is accepted for full paper consideration, we will present a complete 3D-PSF characterization for point scatterers by varying relevant parameters mentioned above.

"The views expressed in this paper are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government."

6568-03, Session 1

Three-dimensional resolution for circular synthetic aperture radar

L. J. Moore, L. C. Potter, The Ohio State Univ.

Three-dimensional (3-D) spotlight-mode Synthetic Aperture Radar (SAR) image processing is typically performed either by interferometry using data collected along identical azimuthal paths at multiple elevation angles or by reconstruction using data collected on a densely sampled 3-D grid in azimuth and elevation. This paper considers 3-D image formation using a circular SAR geometry with data collected along a single, circular flight path of 360 degrees azimuth at a constant elevation angle. A closed-form expression for the far-field 3-D point-spread function (PSF), or impulse response function (IPR), for circular SAR is derived as a means of evaluating 3-D resolution. Traditionally, authors have reported 3-D resolution by taking distance to first null from on-axis cuts of the 3-D IPR. Significantly, for wide apertures a point scattering assumption is inadequate; consequently, the spatial resolution is a function of both aperture and scattering response.

New measures of volumetric resolution are presented and evaluated as a function of aperture and scattering persistence. A nonparametric measure is given by the volume of level sets from the PSF. A parametric approach uses the Cramer-Rao lower bound and quantifies the relative ability to localize reflectors. The analysis reveals the inadequate and misleading conclusions drawn from the traditional, on-axis, one-dimensional description of three-dimensional resolution. And, the analysis quantifies 3-D position uncertainty as a function of aperture and scattering persistence.

6568-04, Session 1

Exploitation of UAV trajectories with perturbation for intelligent circular SAR applications

A. K. Mitra, T. L. Lewis, L. Willemsen, Air Force Research Lab.

This paper outlines a concept for exploiting UAV (Unmanned Aerial Vehicle) trajectories for detecting slowly moving targets. All the analysis and simulation results are reported under the assumption of a circular UAV trajectory with various degrees of localized perturbations in the neighborhood of a given circular trajectory. These trajectory perturbations are introduced and investigated in order to develop intelligent processing algorithms for purposes of detecting slowly moving targets. The basic concept is based on collecting sub-apertures of data over a given set of localized trajectories and intelligently parsing the collected data based on time-varying angle estimates between the localized UAV trajectory and subsets of a collection of moving point targets. This parsed data is intelligently combined over large SAR integration sub-intervals and intervals to develop a novel approach to detecting moving targets with large variations in speed and target trajectory. Simulation results are reported for three different trajectory perturbation functions: 1. A smoothly-varying or localized sinusoidal UAV trajectory in the neighborhood of a baseline circular trajectory 2. A moderately-fast localized triangular, or zigzag, UAV trajectory in the neighborhood of a baseline circular trajectory. 3. A fast localized trajectory that generates perturbations in the form of a "shaped square wave" in the neighborhood of a baseline circular trajectory.

6568-05, Session 1

Synthetic aperture imaging using sources of opportunity

C. E. Yarman, Drexel Univ.; B. Yazici, M. Cheney, Rensselaer Polytechnic Institute

We consider a Synthetic-aperture radar (SAR) system in which the transmitter and receiver are located on different platforms. Our approach applies when the transmitters are either cooperative or non-cooperative (i.e., are sources of opportunity). In this work, the transmitters can be either stationary or moving. We refer to such a system as a SAR system.

Conventional SAR systems correlate the received signal with the transmitted waveform to suppress noise. For passive SAR, however, the transmitted waveform is not necessarily known. Instead of the conventional matched filtering, we use the the spatial correlation methods presented by Attia and Steinberg, and Chan, Kuga and Ishimaru. Given a pair of receivers, the spatial correlation method compares the received signals to identify a target within the illuminated scene. We combine this with microlocal techniques used by Nolan and Cheney to develop a filtered backprojection (FBP) type inversion method for passive SAR.

Our method has the additional advantage that knowledge of the total travel time, from transmitter to target to receiver, is not needed. The microlocal techniques, moreover, provide approximate FBP type inversion methods, which are known for their computational efficiency. Additionally, they have the desirable property that the visible edges of the scene not only appear at the right location with the right orientation but also at the right strength in the reconstructed image.

We form our images in three steps: First correlate the received signals; next filter the correlated signal; and finally backproject the filtered correlation signals along certain surfaces. In our final manuscript, we will present an analysis of the computational complexity of the proposed method and demonstrate its performance in numerical simulations.

6568-06, Session 1

Bistatic synthetic aperture inversion for arbitrary flight trajectories

C. E. Yarman, Drexel Univ.

In this paper we present an approximate analytic inversion method for bistatic synthetic aperture radar. We consider a bistatic synthetic aperture radar (Bi-SAR), where a scene of interest is illuminated by electromagnetic waves that are transmitted from positions along an arbitrary, but known, flight trajectory and the scattered waves are measured from positions along a different flight trajectory which is also arbitrary, but known. Furthermore, we assume that the transmitter and receiver antennas have poor directivity; that the single-scattering approximation holds for the radar data; and that the ground topography is known but not necessarily flat.

Reconstruction algorithms for monostatic SAR with poor antenna directivity traversing straight and arbitrary flight trajectories have been developed by various authors, while, to our knowledge, the acquisition geometry of bistatic SAR studies for the case of poor antenna directivity are limited to isotropic antennas traversing certain flight trajectories (straight or circular flight trajectories) over flat topography.

In this paper, we focus on bistatic SAR with poor antenna directivity and address the image reconstruction problem when transmitter and receiver are traversing arbitrary, but known, flight trajectories over known, but not necessarily flat, topography. In particular, we use microlocal techniques to develop a new filtered-backprojection (FBP) type Bi-SAR inversion method for arbitrary flight trajectories over non-flat topography. These FBP type reconstruction methods have the advantage that they are computationally efficient. In our final manuscript, we will present an analysis of the computational complexity of the proposed method and demonstrate its performance in numerical simulations.

6568-07, Session 1

Shadow detectors for moving target focusing

F. A. Lee-Elkin, R. L. Dilsavor, SET Corp.; M. McClure, DARPA

In this paper, we explore non-traditional approaches to track and locate movers. These approaches are enabled by persistent RF sensing. In particular, we assume the availability of continuous-look (sliding aperture) SAR and change detection data streams and explore the feasibility of tracking vehicle shadows in those data streams. Those tracks provide accurate vehicle location even though the RF energy backscattered from the moving vehicle itself is smeared and displaced in the images. Shadow Detectors developed by SET Corp. include an Order Statistic CFAR, Complex Coherence and Non-Coherent Change detection. The details of the shadow detection techniques will be reviewed and a comparison between various techniques will be made. We also explore the feasibility of using the track kinematics to support moving target image formation and feature-aided tracking. These approaches provide the potential benefits of high-accuracy continuous revisit tracking and single mode, single platform, and single channel implementation that avoids expensive multiplatform coordination and logistics challenges.

6568-08, Session 1

A comparison of nonquadratic regularization implementations on the backhoe data set

A. S. Kondrath, B. D. Rigling, Wright State Univ.

A sparse-aperture imaging problem arises in synthetic aperture radar (SAR) when parts of the phase history data are corrupted or incomplete. The resulting images reconstructed from the sparse aperture SAR are degraded, with elevated sidelobes. One effective method for enhancing these images has been nonquadratic regularization. Regularized SAR image formation employs a cost function which contains two terms: one to measure image formation error and a second term to emphasize feature enhancement. In the past, a quasi-Newton's method was used to minimize the nonquadratic regularization cost function. We present two alternative approaches which employ a stochastic gradient descent. In this paper, these three algorithms are applied to corrupted phase history data and evaluated based on output image quality and time required for image generation. Experiments were performed on the backhoe data set.

6568-09, Session 1

Joint enhancement of multichannel SAR data

N. Ramakrishnan, E. Ertin, R. L. Moses, The Ohio State Univ.

In this paper we study iterative methods for joint enhancement of multichannel Synthetic Aperture Radar (SAR) data. Previous work by Cetin and Moses introduced nonquadratic regularization methods for image enhancement using sparsity enforcing penalty terms. Modern SAR system can collect multichannel data providing diversity in elevation and polarization. One approach is to image and enhance each channel separately, which can lead to degraded performance in postprocessing tasks such as SAR Interferometry for height estimation. We propose a method for joint enhancement of multichannel SAR data with additional constraints for stable postprocessing. We develop two iterative methods for solving the constrained optimization problems with non-quadradatic sparsity penalty terms and demonstrate the performance of the proposed methods on IFSAR height extraction problem from multielevation data using the AFRL Backhoe datadome.

Finally, we characterize noise immunity of joint and single channel enhancement methods using simulation studies.

6568-10, Session 1

Resolution analysis for wide-angle SAR imaging

S. He, National Univ. of Defense Technology (China)

In wide angle synthetic aperture radar (WASAR), two problems different from conventional SAR are presented. First, the support region of imaging is fanlike, not coincident with the rectangle support region approximatively assumed in conventional SAR. Second, the resolution formulation for conventional SAR imaging is not right any more .Based on the point spread function of the imaging system (PSF), the resolution for wide angle SAR imaging is defined. And the resolution formulation versus the signal bandwidth and synthesized aperture for wide angle SAR is deduced. Further research implied that the range and cross-range resolution all increased as the increase of synthesized aperture angle, if only the coherent aperture angle is wide enough even if the signal bandwidth is narrow, high range resolution can be gotten, as is absolutely different from the conventional SAR imaging. To further explain the above conclusion, A SAR imaging method for the single frequency-carrier and wide angle SAR is simulated. This signal is produced based on the scattering center model, the scattering centers' locations and amplitudes can be estimated through the signal decomposition using the RELAX method. Simulation imaging results verified the validity of resolution formulation and the imaging algorithm for wide angle SAR.

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6568-35, Session 1

Characterizing geolocation ambiguity responses in SAR-GMTI

M. E. Holston, Air Force Institute of Technology; M. J. Minardi, Air Force Research Lab.; M. A. Temple, M. A. Saville, Air Force Institute of Technology

No abstract available

6568-11, Session 2

Raider Tracer: a MATLAB-based electromagnetic scattering simulator

B. D. Rigling, Wright State Univ.

No abstract available

6568-12, Session 2

Indoor range for spatially resolved radar signature acquisition of targets

U. Aulenbacher, M. John, C. T. Inaebnit, Armasuisse (Switzerland)

In conjunction with measures for target recognition as well as for the corresponding counteractive measures spatially resolved radar signatures are of high importance.

This contribution discusses new techniques and results which were conducted and obtained in an indoor measurement range with various capabilities for radar signature evaluation from X- to W-band. The measurement range is realized in a hall of size 30 x 20 x 10 m3 and is equipped with a 7.5 m-diameter target turntable with a 70-ton capacity. A crane allows the antennas to be moved along two perpendicular horizontal axes with very high accuracy (1 mm).

The presented concepts aim for a decomposition of the radar backscattering for a given frequency and aspect direction range into contributions assigned to resolution cells being considerably smaller than the overall size of the target. For microwave frequencies (e. g. X-band) a 3-D-ISAR approach provides resolution cells with linear dimensions below about 3 wavelengths and a deterministic representation of scattering data from the individual resolution cells. A reasonable adoption of this approach in the millimetre wave regime (e.g. W-band) fails in case of “large” targets (typically linear dimensions \>.4 m) due to the enormous increase in the number of resolution cells. Instead spatial resolution is obtained with directive antennas (physical aperture) and time gating. Furthermore, scattering of resolution cells is represented in terms of statistics.

In the main part of the paper results obtained for test targets in the X-band are presented and discussed with respect to their performance and their potential for radar signature models.

6568-13, Session 2

Three-dimensional characterization of radar targets by means of ISAR/SAR near-field imaging techniques

M. John, U. Aulenbacher, C. T. Inaebnit, Armasuisse (Switzerland)

Radar detection and identification of airborne and ground targets relies on a detailed knowledge about their backscattering properties. Inverse synthetic aperture radar (ISAR) imaging techniques based on indoor near-field backscattering measurements turns out to be a powerful tool for diagnostic purposes in RCS reduction and for deriving far-field RCS target models, either deterministic in terms of RCS patterns or in terms of statistical parameters.

Mostly used backscattering measurement setups with rotating turntable, but fixed antenna position and beam direction pointing perpendicular to the axis of rotation provide the well-known high-resolution image of the 2-D reflectivity distribution (RD). Since a two-dimensional projection of a three-dimensional RD is in case of complex targets (as e.g. for ground targets observed by airborne radar sensors) insufficient, we developed an advanced 3-D imaging approach, where in a novel data collection geometry in addition to the turntable rotation the antenna is moved along a linear path which is chosen in accordance with the geometry of the target and the aspect angle of interest.

Performance of this imaging system and its dependence on the choice of various parameters is discussed. The employed reconstruction algorithm is adopted from the concept of topographic imaging, but modified with respect to a compensation of the range and angular dependence of the illuminating field. Furthermore, the position in space is characterized by a configuration-specific coordinate system. Results obtained for an automobile as X-band radar target are presented in order to assess the features of the imaging system.

The presentation is complemented by a critical survey about the potential and limits of estimating far-field RCS data from reflectivity distributions which are retrieved from near-field measurements.

6568-14, Session 2

An end-to-end simulator for high-resolution spaceborne SAR systems

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The generation of experimental SAR data representative of new advanced systems is both expensive and time consuming, particularly where parameters and scenarios need to be varied. This is especially true for spaceborne systems. The need for simulation tools for analysis and evaluation is, therefore, essential and necessary. Classical point target simulators are normally used to test the focussing quality and the geometric fidelity of processing algorithms. However, for an all-embracing testing of the SAR system’s capabilities the simulated data should be similar to those detected at real SAR-mapping. Accordingly, the use of extended three-dimensional scenes is required. The purpose of this paper is to present an end-to-end simulator for high resolution spaceborne SAR systems that is capable of simulating realistic raw data and focussed images of extended three-dimensional scenes. The simulator is based on precise mathematical modeling of an overall SAR system chain and generates information on the quality of the image data and its suitability to interpret target and background signatures. The principal components of the simulator are: -the generation of the extended scene, including the fully polarimetric scattering behavior of the three-dimensional surface and man made objects, and including typical SAR effects like overlay, speckle noise, shadowing; -an accurate SAR sensor simulation (antenna, transmit and receive path); -generation of the raw data depending on the desired SAR mode (stripmap, spotlight, hybrid mode); -image processing and evaluation. The flexible and modular structure allows for adjustment and extension to fulfill different tasks. The most important modules reflecting the basic physical models will be described and simulation results will be demonstrated.

6568-15, Session 2

Efficient algorithms for target validation using 3D scattering features

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In this paper we present efficient algorithms for target validation using of 3-D scattering features. Building a high fidelity 3-D CAD is a key step in the target validation process. 3-D scattering features were introduced previously (Bhalla, et. al, SPIE 2005) to capture the spatial and angular scattering properties of a target. The 3-D scattering feature for a target is obtained by using the 3-D scattering centers predicted from the shooting and bouncing ray technique, and establishing a correspondence between the scattering centers and their associated angular visibility. The 3-D scattering feature can be interpreted to be a matched filter for a target, since the radar data projected onto the feature are matched to the spatial and angular scattering behaviors of the target. Furthermore, the 3-D scattering features can be tied back to the target geometries using the trace-back information computed during the extraction process. By projecting the measured radar data onto a set of 3-D scattering features and looking at the associated correlations and trace-back information, the quality of the 3-D target CAD used for synthetic signature modeling can be quantified. The correlation and trace-back information can point to regions of target that differ from the 3-D CAD used for simulations. Results for various targets using the algorithm will be presented.

6568-16, Session 2

Image exploitation for MiSAR

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The miniature SAR-system MiSAR has been developed by EADS Germany for light weight UAVs like the Luna-System, which the Bundeswehr is operating in Afghanistan. MiSAR adds to these UAV-systems the all-weather reconnaissance capability, which is missing until now.

In a special imaging mode MiSAR generates SAR image sequences with approximately 1 Hz framerate. Photo interpreters (PI) of tactical drones, now mainly experienced with visual interpretation, are not used to SAR-images, especially not with SAR-image sequence characteristics. So they should be supported to improve their ability to carry out their task with a new, demanding sensor system. We have therefore analyzed and discussed with military PIs in which tasks SAR image sequences can be used and how the PIs can be supported by special algorithms.

Considering the results we have developed image processing algorithms for such SAR-image sequences. These algorithms are integrated into an image exploitation system to improve the image interpreters‘ ability to get a better oversight, better orientation and helping them to detect relevant objects, especially considering flights of e.g. 2 hours.

A main component is the generation of image sequence mosaics to get more oversight. This algorithm was initially developed to process video-imagery and was adapted to the special characteristics of MiSAR-imagery. The generation of mosaics is based on the extraction of image features from successive images and matching of these features. From the matched features the transformation can be estimated and the mosaic can be generated. This mosaicing has the advantage that also non straight linear flight-paths and varying squint angles can be processed.

Another component is a screening for man-made objects to mark regions of interest in the image sequence. We use a classification based approach, which can easily adapted to new sensors and scenes.

6568-18, Session 2

SAR data exploitation: present and future computational technology for enabling algorithm development

U. K. Majumder, Air Force Research Lab.; J. W. Nehrbass, Ohio Supercomputer Ctr.; P. Buxa, E. G. Zelnio, M. J. Minardi, C. H. Casteel, Jr., Air Force Research Lab.

A fundamental issue with SAR application development is data processing and exploitation in real-time or near real-time. The power of HPC clusters, FPGA and GPU systems, and the IBM cell processors present new algorithm development possibilities that have not been fully leveraged. In this paper, we will illustrate the capability of SAR data exploitation that was impractical last decade due to computing limitations. Examples will be provided that show SAR imagery encompassing city size coverage at extremely high levels of fidelity processed at near-real time using the above technologies to empower the warfighter access to critical information for the war on terror, homeland defense, and urban warfare.

6568-34, Session 2

A comparison between imaging radar and medical imaging polar format algorithm implementations

L. A. Gorham, Air Force Research Lab.; B. D. Rigling, Wright State Univ.; E. G. Zelnio, Air Force Research Lab.

No abstract available

6568-36, Session 2

A challenge problem for 2D/3D imaging of targets from a volumetic data set in an urban environment

C. H. Casteel, Jr., L. A. Gorham, M. J. Minardi, S. Scarborough, K. D. Naidu, Air Force Research Lab.

No abstract available

6568-37, Poster Session

A comparison of SAR images from a full 360-degree aperture using backprojection and the least mean squares algorithms

J. E. Minardi II, Carroll High School; M. J. Minardi, Air Force Research Lab.

No abstract available

6568-19, Session 3

An improved multichannel clutter suppression algorithm

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The processing of airborne multi-channel radar data to cancel the clutter near moving ground targets can be accomplished through Doppler filtering, with displaced phase center antenna (DPCA) techniques, or by space-time adaptive processing (STAP). Typical clutter suppression algorithms recently developed for moving ground targets were designed to function with two-channel displaced phase center radar data. This paper reviews the implementation of a two-channel clutter cancellation approach used in the past (baseline technique), discusses the development of an improved two-channel clutter cancellation algorithm, and extends this technique to three-channel airborne radar data. The enhanced performance of the improved dual channel method is expanded upon by exploiting the extra information gained from a third channel. A significant improvement between the moving target signature level and the surrounding clutter level was obtained with the new Kahler-Keaffaber algorithm when comparing results from dual-channel and three-channel clutter suppression to the baseline two-channel technique.

6568-20, Session 3

Waveform preconditioning for clutter rejection

T. K. Varslot, B. Yazici, C. Yarman, M. Cheney, Rensselaer Polytechnic Institute; L. L. Scharf, Colorado State Univ.

We introduce the idea of preconditioning transmit waveforms for optimal clutter suppression in pulse-echo systems. The procedure involves determining a map on the space of transmit waveforms, and then applying this map to waveforms before transmission.

Waveform preconditioning for clutter suppression makes efficient use of power and computational resources by distributing power properly over a frequency band and by eliminating clutter filtering in receive processing. Hence, for a given signal-to-clutter ratio in the final image, the transmit power may be reduced. Alternatively, the signal-to-clutter ratio could be improved by boosting the transmit power which predominantly produces scattering from the target. The former will make the transmitter antenna more difficult to detect without degrading the performance, while the latter will improve performance with the same total transmit-power constraint.

The preconditioning is determined by making the composite target and clutter channel as close as possible to the target channel with respect to an optimality criterion. For radar imaging, we used the minimum-mean-square-error criterion (MMSE).

The work applies to radar, sonar and microwave imaging systems with an arbitrary number of transmit- and receive-antenna elements that are not necessarily co-located. While we focus our attention on clutter suppression specifically, the general idea of preconditioning applies also to other problems such as multipath suppression.

6568-21, Session 3

Multifrequency space time orthogonal projection (MF-STOP): radar signal processing algorithm for detecting and discriminating targets in heavy clutter

Y. Tamrat, C. J. Hatleberg, Apogen Technologies

The fundamental problem of detection and discrimination of targets in clutter and noise is to separate the signature of a target from unwanted interference. Detection and discrimination of a target in a cluttered background is a serious problem for remote sensing if the Radar Cross-Section (RCS) of the target is low relative to the clutter RCS. Prior to detection and discrimination, the interference must be mitigated. This advanced multi-frequency radar signal processing algorithm addresses the detection and discrimination of targets including those with unknown motion that are buried in heavy clutter with unknown statistics.

In this paper, we present a method of detection and discrimination based on a two stage orthogonal projection whereby target parameters can be extracted in the presence of heavy clutter and noise. The proposed technique detects targets within heavy clutter tracked by a radar system. After targets are detected, motion information is extracted that can be used to discriminate threats such as reentry vehicles from other targets.

Target detection is generated in stage one by a combination of Windowed Short Time Fourier Transform (WSTFT) processing and Principal Component Analysis (PCA). Target discrimination is done in a second stage via Partial Least Squares (PLS) using a training filter constructed from the stage one detection. The target is discriminated explicitly by metric criteria such as size or precession. These discriminate features do not have to be known a priori.

6568-22, Session 3

Single-pass detection and classification in LF FOPEN SAR

D. Blacknell, QinetiQ Ltd. (United Kingdom)

Low frequency SAR is used to achieve foliage penetration thus revealing targets concealed under vegetation canopies. At UHF, the clutter environment for target detection is quite severe as a result of the many returns from tree-trunks in particular. Conventional automated detection techniques rely on change detection to cancel out the static clutter returns and hence reveal any targets that have moved into the scene. However, change detection requires scene revisit thus putting constraints on mission planning. In this paper, a technique for detection and discrimination of targets from tree-trunk returns is developed and validated using real SAR data. The technique exploits the varying signature characteristics of targets and tree-trunks with changing aspect. The classification problem in LF SAR imagery also poses significant difficulties since the long wavelengths used reveal little of the target structure. Classification techniques using synthetically generated training imagery to classify LF ISAR turntable imagery have been considered. The baseline performance has been established using correlation-based methods. An analysis of dominant scattering events in terms of real structures on the targets has also been undertaken and classification based on the association of dominant scattering events has been investigated. The techniques are outlined and the achievable LF target classification performance is discussed.

6568-23, Session 3

Motion-segmentation based change detection

W. Ye, D. Wu, W. L. Roberts, J. Li, Univ. of Florida

Detecting regions of change in images of the same scene taken at different times is of widespread interest due to a large number of applications in diverse disciplines. Important applications of change detection include video surveillance, remote sensing, medical diagnosis and treatment, civil infrastructure, and underwater sensing. Change detection usually consists of three steps, namely, 1) geometric adjustment, a.k.a., image registration, to mitigate changes caused by camera motion, 2) radiometric/intensity adjustment to mitigate lighting variation and noise, and 3) stochastic modeling and hypothesis testing, to decide which pixel/area experiences changes of interest.

In this paper, we propose a novel motion-segmentation based approach to change detection. Under this approach, we do not even need image registration since our method is able to separate global motion from local motion (object motion). Hence, it is robust against camera motion. The key idea of our approach is as below. We first estimate optical flow based on the criterion of mean squared error or mutual information; then we use optical flow equation to estimate parameters for all possible motions; then we segment the motions based on some clustering or vector quantization method; after segmentation, we refine the estimates of the parameters for all possible motions; then we segment the motions based on new parameter estimates; we do this recursively until it converges. Experimental results demonstrate the superior performance of our scheme, compared to the existing schemes.

6568-25, Session 4

Extraction of 3D attributed scattering center features from sparse apertures

J. A. Jackson, R. L. Moses, The Ohio State Univ.

Physically-based attributed scattering feature models have shown potential in aiding automatic target recognition and scene visualization. Attributed scattering features capture physical scattering geometry, including the limited response of target scattering over wide angles, that is not discerned from traditional point scatter models. Development of tools which extract attributed features from SAR data support the need for accurate target recognition algorithms in difficult environments, such as urban areas. A number of collection geometries are currently being considered to address needs of persistent surveillance and surveillance to support urban operations. We present recent results on feature extraction from sparse collection apertures that support these surveillance needs. We build on previous work, presented at the 2006 SPIE conference, in which we presented algorithms for feature extraction using a pair of fully-polarimetric IFSAR apertures: that is, slightly displaced in elevation, and covering a linear azimuthal sweep. In this paper we consider more general apertures, including single, curved apertures that have both azimuth and elevation diversity (that is, not 'straight-line' apertures). These more general apertures present a number of complications. First, we are no longer able to exploit the energy compactness of scattering features in the SAR image domain, as was the case in the IFSAR apertures. On the other hand, the combined azimuth and elevation diversity permits estimation and disambiguation of scattering features that were in some cases indiscriminable from IFSAR aperture pairs. Finally, we present results on expected accuracy and accuracy bounds for scattering feature estimation uncertainty using these more general measurement apertures.

6568-26, Session 4

Improve ATR performance through distance metric learning

Y. Sun, M. Xue, J. Li, Univ. of Florida; S. R. Stanfill, Lockheed Martin Co.

High resolution synthetic aperture radar images usually contain much redundant and noisy irrelevant information. Eliminating these information via feature extraction can greatly enhance ATR performance, reduce processing time and increase the system robustness. Most existing feature extraction methods are either computationally expensive or can only provide ad-hoc solutions and have no guarantee of optimality. In this paper, we describe a new feature extraction algorithm based on distance metric learning. The algorithm is based on the local learning strategy and is formulated as a convex optimization problem. The algorithm is not only capable of learning the feature significance and feature correlations in a high dimensional space but also very easy to implement and does not suffer from a local minima problem. Experimental results based on the MSTAR database are presented to verify the effectiveness of the new algorithm.

6568-27, Session 4

Co-evolutionary feature synthesis for SAR target classification using transform features

Z. He, G. Kuang, National Univ. of Defense Technology (China)

Features represent the characteristics of targets. The effectiveness of the feature set plays a key role in the performance of target recognition. Ideally, the feature set should contain the fewest features needed to maximize the separation between classes. There are usually two ways to reach this goal: feature selection and feature synthesis. In this paper, we use a co-evolutionary genetic programming (CGP) approach to synthesis composite features for target recognition. The CGP uses domain-independent primitive operators to synthesis composite features from primitive ones, which contains the knowledge about the problem domain. Here, the two dimensional Fourier transform (FT), wavelet transform (WT) and Karhunen-Loeve transform (KLT) are applied to the synthetic aperture radar (SAR) imagery to extract primitive features. The motivation for using CGP is to overcome the limitations of human experts who consider only a small number of conventional combinations of primitive features during synthesis. CGP, on the other hand, can try a very large number of unconventional combinations and these ones yield exceptionally good results in some cases.

An extensive experiment on the MSTAR (Moving and Stationary Target Acquisition and Recognition) datasets is put into practice. To evaluate the performance of the algorithm, the receiver operation characteristic (ROC) curves and confusion matrices are used. The ROC curve shows the relationship between the percentage of correct detections and percentage of false alarms. The confusion matrix shows the number of targets that are correctly recognized, misclassified and rejected. The experimental results show that CGP can discover good composite features to distinguish targets belonging to several classes.

6568-28, Session 4

Preprocessing of SAR interferometric data using anisotropic diffusion filter

K. Sartor, J. D. Allen, E. Ganthier, Harris Corp.; G. B. Tenali, Florida Institute of Technology

The most commonly used smoothing algorithm in complex data processing is some variant of a blurring function (Hanning, Taylor weighting, Gaussian, etc). Unfortunately, these filters blur the edges in a Synthetic Aperture Radar (SAR) scene, reduce the accuracy of features, and blur the fringe lines in an interferogram. For the Digital Elevation Model (DEM) extraction, the blurring of these fringe lines causes inaccuracies in the height of the unwrapped terrain surface. Our goal here is to perform spatially non-uniform smoothing to overcome the above mentioned disadvantages. This is achieved by using a complex anisotropic nonlinear diffuser (CANDI) filter that is a spatially varying. In particular, an appropriate choice of the convection function in the CANDI filter is able to accomplish the non uniform smoothing. This boundary sharpening/smoothing filter acts on interferometric SAR data with noise to produce an interferogram with significantly reduced noise contents and desirable local smoothing. Results of CANDI filtering will be discussed and compared with those obtained by using the standard filters on simulated data.

6568-29, Session 4

A real-time robust feature-based object tracking algorithm

B. Han, D. Wu, J. Li, Univ. of Florida

Object tracking is an important component of many computer vision systems. It is widely used in video surveillance, robotics, 3D image reconstruction, medical imaging, and human computer interface. In this paper, we focus on unsupervised object tracking, i.e., without prior knowledge about the object to be tracked. To address this problem, we take a feature-based approach, i.e., using feature points (or landmark points) to represent objects. Feature-based object tracking consists of feature extraction and feature correspondence. Feature correspondence is particularly challenging since a feature point in one image may have many similar points in another image, resulting in ambiguity in feature correspondence. To resolve the ambiguity, algorithms, which use exhaustive search and correlation over a large neighborhood, have been proposed. However, these algorithms incur high computational complexity, which is not suitable for real-time tracking. In contrast, Tomasi and Kanade's tracking algorithm only searches corresponding points in a small candidate set, which significantly reduces computational complexity; but the algorithm may lose track of feature points in a long image sequence. To mitigate the limitations of the aforementioned algorithms, this paper proposes an efficient and robust feature-based tracking algorithm. The key idea of our algorithm is as below. For a given target feature point in one frame, we first find a corresponding point in the next frame, which minimizes the sum-of-squared-difference (SSD) between the two points; then we test whether the corresponding point gives small value under the so-called Harris criterion. If not, we further identify a candidate set of feature points in a small neighborhood of the target point; then find a corresponding point from the candidate set, which minimizes the SSD between the two points. The algorithm may output no corresponding point due to disappearance of the target point. Our algorithm is capable of tracking feature points and detecting occlusions/uncovered regions. Experimental results demonstrate the superior performance of the proposed algorithm over the existing methods.

6568-30, Session 4

Multinomial pattern matching for high-range resolution profiles

M. L. Koudelka, J. A. Richards, M. W. Koch, Sandia National Labs.

Airborne radar using ground moving target indication can track moving vehicles at large standoff distances. Unfortunately, trajectories from multiple vehicles can become kinematically confused and the tracker can no longer separate the target vehicle from others. We propose the use of high range resolution (HRR) profiles and multinomial pattern matching (MPM) for target fingerprinting and track-stitching.

Sandia's MPM algorithm is a robust, template-based identification algorithm that has been applied successfully to various target recognition problems. MPM utilizes a quantile transformation to map target pixels to a small number of grayscale values, or quantiles. The algorithm relies on a statistical characterization of the multinomial distribution of these pixel-wise quantile values for targets of interest. The quantile transformation and statistical characterization procedures are extremely well suited to a robust representation of targets for HRR profiles: they are invariant to sensor calibration, robust to target signature variations, and lend themselves to efficient matching algorithms.

In typical HRR tracking applications, target fingerprints must be initiated on the fly from a limited number of HRR profiles. Data may accumulate indefinitely as vehicles are tracked, and their templates must be continually updated without growing unbounded in size or complexity. To address this need, an incrementally updated version of MPM was developed. This implementation of MPM incorporates individual HRR profiles as they are available, and fuses data from multiple aspect angles for a given target to aid in track-stitching. This paper will provide an overview, algorithm details, and experimental results for the incrementally updated version of MPM.

6568-31, Session 4

Sparse manifold learning applied to building synthetic aperture radar ATR templates

P. L. Busarow, N. N. Shah, D. E. Waagen, Raytheon Missile Systems; V. S. Berisha, Arizona State Univ.

In real-time target recognition applications that attempt to find the best match between a test sample and stored reference samples, onboard storage and throughput limitations dictate that not all training samples can be stored and processed. It is customary to form templates, each of which spans some volume of training data, resulting in complete coverage of the training space with a reduced cardinality. For example, in the Synthetic Aperature Radar setting, each template can be a (possibly weighted) average spanning parameter bins in azimuth, elevation, range, etc. Traditionally the bin sizes have been held constant over the parameter space. For a two-class problem using the public release MSTAR dataset, we apply a Sparse Manifold Learning technique that admits unequal bin sizes. We measure the interclass divergence for templates built by averaging training samples located within either equally sized or unequally sized space-filling bins, as a function of the number of stored templates.

6568-32, Session 4

Object-image metric: properties and applications

D. G. Arnold, O. L. Mendoza, Air Force Research Lab.

Research in the area of object-image relations has transformed the ATR problem into a feature extraction and correspondence problem. This ultimately results in the problem of how to most efficiently search a large database. In this paper, we explore the properties of the recently introduced Object-Image (O-I) metric, which provides a metric for determining how close an image of an object is to the actual object. In particular, a number of search algorithms including exhaustive search, binary search, and other classic search algorithms are applied within the framework of an O-I metric algorithm. The results are compared with previous methods which did not incorporate the O-I metric. The results indicate the O-I metric is a reasonable metric.

6568-33, Session 4

Score-based SAR ATR performance models

E. M. Lavely, V. Kaufman, BAE Systems Advanced Information Technologies; T. D. Ross, E. Blasch, Air Force Research Lab.

We consider principles and applications of regression-based SAR ATR models for ATR outputs such as score likelihoods, summary score statistics and score differentials. Standard performance metrics are easily computed from these response variables. The covariates (predictor variables) are derived from ancillary measurable operating conditions (e.g., target size and class, depression, etc.) and from summary statistics of physics-derived scattering center properties (used for forward image prediction). Key model estimation difficulties include model selection (since the functional form is unknown) and variable selection (since only a subset of candidate covariates have predictive utility). We use a variety of Bayesian methods based on reversible jump MCMC to address these issues. ATR scores are random variables due to influences such as sensor noise, physical variations of targets in the field relative to idealized theoretical models, errors in assumed sensor pose parameters, etc. The largest discovered score likelihood is usually identified as the optimal target hypothesis, but confusers or similar targets may generate scores very close to or even larger than the correct hypothesis score. To capture these effects we use a Monte Carlo analysis in which birth, death and alteration processes are applied to the scattering centers, and forward images are synthesized for each realization. The synthetic and observed images are then matched to obtain likelihood scores. There are many potential applications of an ATR performance model, including online sensor management and fusion support and offline analyses where ATR performance may be predicted for an operational scenario.

6568-38, Session 4

Diffusion distances and radar data analysis

D. G. Arnold, S. Bhat, Air Force Research Lab.

No abstract available

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6569-01, Session 1

Effects of cartesian to polar transformation on target track quality

J. E. Gray, Naval Surface Warfare Ctr.; A. T. Alouani, Tennessee Technological Univ.

The Raleigh Problem [Raleigh1919], [Beckmann1987], [Barakat1988], originally arose in Lord Raleigh's investigations into scattering acoustical waves off of rough surfaces. The problem was to evaluate the probability density function (PDF) of a random sum.

Transformations of this type arises in the remote sensing community in a variety of guise such as tracking of targets (keep a recursive record) on objects with acoustical or electromagnetic sensors. A typical example of this is type of problem is found in target tracking. Target tracking in radar and sonar is done in either spherical or rectangular coordinates. Often tracking is done in one reference frame[bla] while filtering, usually Kalman, is done in another reference frame. It is commonly assumed that the PDF can be treated the same in both reference frames [Bar-Shalom2001] and [Mo1998]. An extended Kalman filter is used, under the assumption that the converted PDF can be adequately characterized by the mean and standard deviation.

If one treats the ploar coordinates as noisy measurements of a target position, the objective of this paper is to analytically characterize the PDF of the measurements in cartesian coordinates and investigate the impact of approximating the PDF using the mean and standard deviation on the target track quality.

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6569-02, Session 1

Asynchronous track fusion using constant gain filter

A. T. Alouani, Tennessee Technological Univ.; J. E. Gray, Naval Surface Warfare Ctr.

The use of multiple sensors for state estimation can lead to better quality estimates than when a single sensor is used. For the same number of resources, sensors with different data rates (asynchronous sensors) can provide better coverage than synchronous sensors. The local estimates produced by asynchronous sensors are not time coincident. In the presence of communication delays between sensor platforms and fusion center and in the presence of out-of- sequence data, the optimal centralized processing architecture may not be feasible in real time. Recently the authors derived a general track fusion algorithm that fuses data from an arbitrary number of asynchronous sensors, where communication delays exist between sensors platform and data fusion center and where data may arrive out of sequence [ata]. Because the derivation is very general, its actual implementation is a challenge. The objective of this paper is to derive similar fusion algorithms using constant gain filters instead of the Kalman filter as the local processor. Constant gain filters have been used in real world tracking systems. Once the general derivation is provided, practical assumptions will be used to simplify the new fusion algorithm and compare it to existing synchronous constant gain filters. The method for accomplishing this is to take the derivation of constant gain filters such as those found in [BarShalom1988], [Blackman1986], [Gray1989], or [Gray2001] to provide a simplified version of our track fusion algorithm that takes into account more recent work that simplifies the derivation for constant gain filters and provides a comprehensive but simplified filter [Gray2004] and [Gray2004a]. This paper is organized as follows. Section sets up the mechanism for the derivation of the constant gain filter. The changes necessary to make the derivation work for asynchronous track fusion filter of [ata] are discussed in Section 3. Section 4 has some discussions and conclusions.

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6569-03, Session 1

Alternative switching logic designs for multiple model filters

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What distinguishes a superior Multiple Model tracking filter design from a poor filter design is the speed with which the switching logic detects and then responds to a target maneuver by reshuffling the weights to match the new target dynamic configuration. Most Multiple Model (MM) filter designs incorporate a Markov Switching Matrix (MSM) as part of their switching logic. This matrix, whose values are selected in a generally ad hoc manner, has a significant impact on the response time of the switching logic to a sudden target maneuver. No "optimum" method exists for selecting values with which to populate this matrix. A set of values that may provide a "good" tracking performance against a specific target type may not yield a "good" performance against a different target type. Since one cannot know in advance what target type is going to be encountered in a given scenario, the filter designer is faced with a design dilemma. In spite of this, the MM filter structure has won wide acceptance within the academic tracking community.

Research was performed on alternative switching mechanisms for multiple model filters that do not require a MSM for their switching logic. For the Alternative Switching Logic (ASL) studied, evidence shows that performance of the ASL is comparable to that offered by the Interacting Multiple Model (IMM) for the six NSWCDD target trajectories. Studies also indicate that the ASL, which is considerably less complex than the IMM switching logic, shows a 20 percent decrease in run time over that of the IMM. The results presented are an important first step in investigating alternative design methods for multiple model switching logic. Future work should investigate other types of decision logic such as: Dempster-Shafer reasoning, fuzzy logic, and possibly neural networks.

6569-05, Session 1

Launch point estimation and impact point prediction of small ballistic munitions with an interacting multiple model estimator

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The interacting multiple model (IMM) estimator, which mixes and blends results of multiple filters according to their mode probabilities, is frequently used to track targets whose motion is not well-captured by a single model. This paper extends the use of an IMM estimator to computing launch point estimates (LPEs) and impact point predictions (IPPs) of small ballistic munitions whose motion models change when they reach supersonic speeds. Three approaches for computing LPEs and IPPs are compared. The first approach propagates only the track from the most likely mode until it impacts the ground. Since this approach neglects inputs from the other modes, it is not desirable if multiple modes have near-equal probabilities. The second approach for computing LPEs and IPPs propagates tracks from each model contained in the IMM estimator to the ground independent of each other and combines the resulting state estimates and covariances on the ground via a weighted sum in which weights are the model probabilities. The third approach is designed to take advantage of the computational savings of the first without sacrificing input from any of the IMM's modes. It fuses the tracks from the models together and propagates the fused track to the ground. Note that the second and third approaches reduce to the first if one of the modes has a probability of one. Results from all three approaches are compared in a high-fidelity radar simulation.

6569-07, Session 2

Acquisition, tracking, and pointing technology development for bifocal relay mirror spacecraft

J. J. Kim, T. A. Sands, B. N. Agrawal, Naval Postgraduate School

The purpose of the paper is to develop acquisition, tracking, and pointing technologies for the Bifocal Relay Mirror Spacecraft and verify these technologies with the experimental test bed. The Bifocal Relay Mirror Spacecraft utilizes two optically coupled telescopes to redirect a laser from the ground, aircraft or spacecraft laser source to distant points on the earth or in space. Because of the stringent accuracy requirement of the laser beam, significant research is needed to develop acquisition, tracking, and pointing technologies for the Bifocal Relay Mirror Spacecraft.

In this paper, attitude control methods for the Bifocal Relay Mirror Spacecraft are developed. The focus is on three-axis large-slew control of the flexible spacecraft with a Control Moment Gyroscope array (acquisition maneuver), as well as precision attitude control of the spacecraft (tracking and pointing). In order to provide high confidence in the development of acquisition, tracking, and pointing technologies, experimental simulations in addition to analytical simulations are highly desirable. The details on the Bifocal Relay Mirror Spacecraft experimental test bed developed at the Naval Postgraduate School are also presented. Finally, experimental results of the laser relaying operation of the Bifocal Relay Mirror Spacecraft with the proposed attitude control techniques are presented in the paper to verify these control techniques.

6569-08, Session 2

Friction effects on large, gimbaled E-O directors

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Friction is a well-known performance limitation for gimbaled E-O director systems. While much research study has been directed to bearing friction, the well-known friction models in literature, being represented in time, position, and rate domain, are not amenable to most LOS jitter analysis. Furthermore the type of mission profiles to which large gimbals are subjected have received limited attention in this field of research, so the selection of an appropriate friction model is not obvious. In this paper we review experimental test data collected on large gimbals, fit popular friction models to this data, and study the models in the frequency domain.

6569-10, Session 2

Study on bandwidth mutual benefit between the azimuth and pitch in an optoelectronic tracking system

J. Chen, L. Zhang, Changchun Institute of Optics, Fine Mechanics and Physics (China)

1.Introduction

Two-axis optoelectronic tracking equipments generally use such mode that azimuth and pitch system are independently controlled. It leads to the two structures completely uncoupled, and reduces the state space dimension. But the main problem is that the rotational inertia of azimuth is much larger than that of pitch, so to find a more suitable mechanics and more effective control strategy is necessary, for enhancing tracking performance of the optoelectronic system. Considering the tracking ability, it is possible to uniformly correct the error of both the azimuth and pitch system in real time, and obtain a better control algorithm to both systems. It is realized by cross coupling control to the azimuth and pitch, with two inputs to ensure the same dimensions in the space.

2.Bandwidth Mutual Benefit and Precision Mutual Compensation

Two independent SISO systems (azimuth and pitch) are cross coupled into one system, which is called as a MIMO system. Searching for the optimal results (the least error) to the MIMO system, the two SISO systems are uncoupled, and then controlled independently.

(Fig. 1 shows the concept of Bandwidth Mutual Benefit and Precision Mutual Compensation)

(Fig.2 shows the Model of both Bandwidth Mutual Benefit and Precision Mutual Compensation in polar coordinates)

3.The simulations

The FSM (Fast Steering Mirror), a subsystem in an optoelectronic tracking system is modeled under MATLAB/SIMULINK. Its input is the residual tracking error of the main system, with high frequency. We introduce and to simulate the disturbances.

Results demonstrate that the tracking properties of the coupling system are better than that of uncouplin g system, and improved by about 50%. With control of Bandwidth Mutual Benefit, the tracking error range from 0.5 " to 4" and the maximum is only 4.0533". While with that of Precision Mutual Compensation, the range is between 0.2 "-4", the maximum is 5.8994".

The cross coupling control strategy is a effective way to improve the tracking precision for an optoelectronic tracking system.

6569-11, Session 2

Position-leading compensation for an optoelectronic tracking system

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1. Introduction

When an optoelectronic system tracks a fast moving target, the overtune is the main part of the dynamic tracking error. The speed delay compensation may be used to decrease the error but the stability is sacrificed. We put forward the position-leading compensation to check the overtune, and the tracking precision is improved greatly.

2. The position-leading compensation

We choose a sample transfer function as the position-leading compensation section: Gp(s)=Kp* S/Tp*S+1 . Because the differential may introduce the noise to the system, it may be changed to a suitable form. The system with the position-leading compensation is shown in Fig.1.

(Fig.1 The principle system diagram with position-leading compensation)

Kp determines the ability to check the overtune, while Tp the frequency range.The system open-loop gain has a resonant peak just lower the crossing frequency with the position-leading compensation. Through the system identification, we may explain it with the Robust Controller which is based on the internal principle.

3. The simulations

The system with position-leading compensation shown in Matlab/Simulink is shown in Fig.2. The system includes the CCD tracker and prediction, a dynamic high-type controller, the position correction, the speed correction and object. When the input is the equalized sine with the accelerate 120°/s2, the speed 120°/s, the tracking precision is 0.6?which is shown in Fig.3.

(Fig. 2 The simulating diagram with position-leading compensation)

(Fig.3 120sin(1t) tracking error)

4. Conclusion

The position-leading compensation can improve the tracking ability for the fast moving target, but may deteriorate the tracking precision at low frequency range. So that, it may be used together with the dynamic high-type control. Our experiments are carried out now.

6569-12, Session 3

Tunable wavelet target extraction preprocessor

D. Yonovitz, Complex Data Systems

The key measurements of Pointing/Tracking system performance are the abilities to correctly acquire targets and to maintain low track error (the error associated with stabilizing the target in the image scene). Good target acquisition and track performance is readily attainable under "nominal" conditions, i.e. targets of high Signal to Noise Ratio (SNR) relative to clutter within the image, or targets that have easily discernable relative motion with respect to other possible targets or clutter. It is in the absence of these favorable conditions when a Track Preprocessor is highly advantageous or even necessary to meet performance requirements (e.g. a relatively small, stationary or slow moving, distant target within a field of view with considerable background). This is the thrust of the Tunable Wavelet Target Extraction Preprocessor (TWTEP).

The TWTEP enhances the video signal prior to the Track Process Function. The Track Process Function may be of any type; correlation, centroid, edge, (that utilizes a video image signal as input. The output of the TWTEP is either a high SNR image, or a target coordinate. The output image may be of processed input video or synthesized video suitable for a Track Process Function. In a typical system engineered configuration, the Track Process Function is left unaltered to accomplish its unobstructed design functionality; while scenario dependent processing is accomplished in the TWTEP where the required flexibility is readily achievable.

Different stressful scenarios require that the video be enhanced in different ways to meet overall performance requirements. The TWTEP is capable of meeting this demand by "tuning" the video enhancement in different ways appropriate to meet the varied and critical requirements of differing scenarios. This objective is performed in Wavelet Transform space. The tuning of the video refers to algorithms that manipulate (filter) the video, in Wavelet space, to either enhance the target and/or negate the background clutter video parameters. Tunable filter parameters are calculated to optimize the contributions of individual Wavelet bands in both horizontal and vertical directions to a video sum. This process continues over contiguous video images and quickly converges to filter the target's video parameters for enhancement and negation of background. This tuning process is accomplished as quick as the video frame rate or at a rate necessary to meet the dynamics of the video scene.

A key algorithmic element is the processing to determine a target region within the image, referred to as Target Definition/Extraction. Possible target regions are determined by a Pseudo-Covariance method. This method defines regions of interest within the video based upon a covariance between Wavelet Sub-bands. It then makes a determination of the target region and uses the sensor or simulated video for output to the Track Process Function. This processing eliminates noise and pixels that are not considered significant.

The functionality of the TWTEP is composed of: Sensor Input Processing, Wavelet Transform Processing, Wavelet Sub-Band Processing, Pseudo-Covariance Processing, Target Definition/Extraction Processing, Video Output Processing, and Control/Status Processing.

The algorithms performed by the TWTEP encompass the objectives of: target enhancement, background noise reduction, clutter reduction/rejection. high SNR output, and object feature determination. It accomplishes these objectives in an algorithm environment that includes memoryless independent determination (output is not dependent upon previous images), is scalable to multispectral sensors, can be configured in a closed loop target definition, and may be implemented in an automated net-centric or standalone image exploitation configuration. These objectives are accomplished without the need for "gating" a target and the target may be of arbitrary shape and size.

Based upon an understanding that valid targets exhibit filterable identifiable characteristics in different Wavelet Sub-Bands, and that á priori target characteristic knowledge and/or, a pixel covariance of Wavelet Sub-Bands is a valid measure of significant information, the TWTEP can improve the probability of correct target acquisition and lower track error.

6569-13, Session 3

Target tracking based on spatio-temporal fractal error

B. S. Allen, L-3 Communications Cincinnati Electronics, Inc.

This paper presents a novel approach to target tracking using a measurement process based on spatio-temporal fractal error. Moving targets are automatically detected using one-dimensional temporal fractal error[1]. A template derived from the two-dimensional spatial fractal error[2] is then extracted for each detected object to allow for correlation-based template matching in subsequent frames. The outputs of both the spatial and the temporal fractal error components are combined and presented as input to a kinematic tracking filter. It is shown that combining the outputs allows for improved tracking performance in the presence of noise, occlusion, and other moving objects. Furthermore, reconciliation of the spatial and temporal components also provides a useful mechanism for detecting and avoiding template drift, a problem that is typically present in correlation-based trackers. Results are demonstrated using mid-wave infrared image sequences.

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6569-14, Session 3

Bayesian tracking in actively illuminated laser tracking through deep turbulence

B. G. Fitzpatrick, Y. Wang, Tempest Technologies LLC

We present a novel methodology based on the Bayesian framework of statistical modeling and data analysis for the optical tracking of actively illuminated extended targets through turbulent atmosphere.

The Bayesian segmentation algorithm models the observed imagery as being noisy measurements of an underlying known image. The measurement distribution is a probability distribution on the intensity value of each pixel. In the simplest implementation, measurement is conditioned on whether or not that pixel is a “target” pixel (or, alternatively, a background pixel). This segmentation is initialized with a prior distribution for each pixel, having two complementary probability values for the target and the background classification. The Bayesian model keeps up with the probability of each pixel being a target or background pixel (conditioned on the observations), through the Bayes’ rule iteration. Since the turbulence is dynamic, the modeling requires a predictor step of forward modeling, so that the posterior distribution determined from the current frame can be used appropriately as the subsequent frame’s prior. The primary purpose of this model is to construct an enhanced image from which a high quality track signal can be extracted.

The algorithm is tested on experimental and simulated data and shows improvement of 10% to 50% (depending on turbulence strength) over the standard tracking algorithm. This algorithm can be efficiently implemented even on desktop workstations: we have obtained frame rates of 4950 frames per second on 2Ghz Pentium machines, with frames of 128x128 pixels.

6569-16, Session 3

A novel segmentation method for object tracking and recognition

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The increasing demand for the protection of persons and facilities requires the application of sophisticated technologies for surveillance and object tracking. For this purpose appropriate sensors are used like imaging IR sensors suitable for day/night operation and laser radar supplying 3D information of the scenario. In this context there is a requirement of automatic and semi-automatic methods supporting the human observer in his decision-making process. A prevalent task is automatic tracking of striking objects like vehicles or individual persons in an image sequence during a time slice. Classical methods are based on template matching implying certain shortcomings concerning homogeneous background or passing objects occluding the target object. We propose a new concept of generating templates for IR target signatures based on the interpretation of laser range data to optimize the tracking process. Our test bed is realized by a helicopter equipped with a multisensor suite (laser radar, imaging IR, GPS, IMU). The laser scanner itself is an 1.5 μm erbium fiber system, derived from the EADS HELLAS family, that covers a field-of-view of 14.4 degrees in horizontal and vertical direction with a resolution of 128x128 pixels and a scan rate of about 4 Hz. The infrared images are taken with an AIM 8-10 μm FPA sensor (640x480 pixels) and a slightly wider field-of-view which overlaps that of the laser.

Results are demonstrated by the analysis of an exemplary data set. A vehicle situated in a complex scenario is acquired by a forward moving sensor platform and tracked robustly by the proposed method.

6569-17, Session 3

Video surveillance of pedestrians and vehicles

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In this paper, we focus on the problem of automated surveillance in a parking lot scenario. We call our research system VANESSA, for Video Analysis for Nighttime Surveillance and Situational Awareness. VANESSA is capable of: 1) detecting moving objects via background modeling and false motion suppression, 2) tracking and classifying pedestrians and vehicles, 3) detecting events such as person entering or exiting a vehicle, and 4) recognizing vehicles across space and time. Moving object detection utilizes a multi-stage cascading approach to identify pixels that belong to the true objects and reject any spurious motion, (e.g., due to vehicle headlights or moving foliage). Pedestrians and vehicles are tracked using a multiple hypothesis tracker coupled with a particle filter for state estimation and prediction. The space-time trajectory of each tracked object is stored in an SQL database along with sample imagery to support video forensics applications. The detection of pedestrians entering/exiting vehicles is accomplished by first estimating the three-dimensional pose and the corresponding entry and exit points of each tracked vehicle in the scene. A pedestrian activity model is then used to probabilistically assign pedestrian tracks that appear or disappear in the vicinity of these entry/exit points. A vehicle classification module is used to identify vehicles across arbitrarily long time periods. Histogram of Oriented Gradients, or HoG features, are extracted from image chips belonging to vehicles and stored in the database. A cover tree index is constructed over all the HoG feature vectors in the database to perform efficient matching. We evaluate the performance of motion detection and tracking modules on an extensive data set collected in a challenging real-world scenario.

6569-18, Session 3

Zoom techniques for achieving scale invariant object tracking in real-time active vision systems

E. D. Nelson, J. C. Cockburn, Rochester Institute of Technology

In a surveillance system, a camera operator follows an object of interest by moving the camera, then gains additional information about the object by zooming. As the active vision field advances, the ability to automate such a system is nearing fruition. One hurdle limiting the use of object recognition algorithms in real-time systems is the quality of captured imagery; recognition algorithms often have strict scale and position requirements where if those parameters are not met, the performance rapidly degrades to failure. The ability of an automatic fixation system to capture quality video of an accelerating target is directly related to the response time of the mechanical pan, tilt, and zoom platform—however the price of such a platform rises with its performance. The goal of this work is to create a system that provides scale-invariant tracking using inexpensive off-the-shelf components.

Since optical zoom acts as a measurement gain, amplifying both resolution and tracking error, a new second camera with fixed focal length assists the zooming camera if it loses fixation—effectively clipping error. Furthermore, digital zoom adjusts the captured image to ensure position and scale invariance for the higher-level application. The implemented system uses two Sony EVI-D100 cameras on a 2.8GHz Dual Pentium Xeon PC. This work presents experiments to exhibit the effectiveness of the system.

6569-19, Session 3

Passive ranging of boost-phase missiles

M. Hawks, G. P. Perram, Air Force Institute of Technology

The depth of absorption bands in observed spectra of distant, bright sources can be used to estimate range to the source. Previous efforts in this area have relied on measuring infrared CO_2 bands, with disappointing results. A novel approach has been developed that uses observations of the O_2 absorption band near 762 nm. This band was selected because it is spectrally isolated from other atmospheric bands, and O2 levels in the atmosphere are easily predicted from simple meteorology data. Range is estimated by comparing observed values of band-average absorption, $\bar{A}$, against predicted curves derived from either historical data or model predictions. Accuracy of better than 0.5% has been verified in short-range (up to 3km) experiments, and models are used to predict results at longer ranges. A notional passive sensor to augment the active ranging sensor on the ABL system is used to guide parameter selection for this analysis. Range accuracy of 5% is predicted for ranges up to 400 km in this scenario. Performance can be much better at shorter ranges or at night.

6569-20, Session 3

Results from precision tracking tests against distant objects

J. F. Riker, Air Force Research Lab.

No abstract available

6569-21, Session 3

Optimization of the tomographic scanning (TOSCA) imager

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The tomographic scanning (TOSCA) imager was invented by the author in 2003. Initially, the system was based on reconstructing an image from the signal of a simple single pixel, conical scan FM-reticle sensor using tomographic techniques. Although the system has been used for several decades for real-time tracking purposes, the imaging properties of the single pixel conical scan reticle system was left undiscovered until recently, although multi-target discrimination was demonstrated with multispectral versions of the system. The initial system presented by the author demonstrated the ability to discriminate between multiple spots in the field of view in a fairly simple scenario. Advances have been made in both theory and technology, mainly with the introduction of the nutating circular aperture in the scanning optics, and the use of Fourier transform ramp filters during reconstruction, and TOSCA is in principle found to be a perfect imaging system, only limited by practical aspects such as the number of angular scans, the spatial sampling, noise and vibration. The simplicity of the hardware, together with the rapid advances in high performance, low cost computing means the system has a potential for low-cost applications such as in expendable multispectral thermal imagers.

This paper will present the current state of the technology, including improvements in algorithms and reticle shapes, and look at artifacts found in various images due to different geometries, as well as ways to handle these artifacts. Several noise generating processes and their effects will be presented and illustrated with results from digital simulations. Requirements for image processing in terms of computing power are investigated, together with the potential for parallelization.

6569-23, Session 4

Angel Fire: a real-time open-source video tracking system

B. R. Secrest, J. R. Vasquez, Air Force Institute of Technology

Angel Fire can be used in either military operations or homeland defense. Multiple cameras are mounted on an airplane that flies in a circle and point to a central location. The images are pre-registered and a single large image is sent to a ground station at the rate of a frame per second. Although real-time human surveillance of the video provides useful benefit, it is desired to have real-time automatic target tracking to aid the observer. The first step needed for tracking is measurements. The video undergoes additional registration and processing to produce two-frame motion detections. These measurements are passed to the tracking algorithm. Due to the precise nature of the measurements, we avoid the traditional challenge of clutter, however tracking through an urban environment has its own unique challenges. Targets frequently cross paths, go behind one another, and go behind buildings or into shadowed areas (where no measurements can be generated). Additional challenges include Move-Stop-Move, parallax, and track association with highly similar targets. All of these challenges need to be overcome with a thousand moving vehicles, so processing speed is crucial. The project is Open-Source to aid in overcoming these technical challenges. Alternative trackers (IMM, MHT), features, association methods, track-initiation and deletion (M/N or LU), state variables, or other specialized routines (for Move-Stop-Move, parallax, etc.) will be tried and analyzed with representative data. By keeping it Open-Source, any ideas to improve the system can be easily implemented and analyzed. This paper presents current findings and state of the project.

6569-25, Session 4

Comprehensive evaluation of tracking systems by non-photorealistic simulation

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As more and more research effort is drawn into object tracking algorithms, the ability to assess the performance of these algorithms quantitatively has become a fundamental issue in computer vision. Because tracking systems have to operate in widely varying conditions (different weather conditions, background and target characteristics, etc), a large test bed of video sequences is needed in order to obtain a comprehensive evaluation of a tracker across the whole range of its operating conditions. However, it is very unlikely that a dataset of real video sequences representative of the whole range of operating conditions of a tracker together with its ground truth could be obtained, and building a realistic synthetic dataset of such sequences would require costly advanced simulation platforms.

In the new evaluation method proposed in this paper, the operational criteria of the tracking system are turned into objective measures and used to generate a pseudo-synthetic dataset, non-photorealistic, but statistically representative of the whole range of operating conditions. The assessment of an algorithm using our method provides both a quantitative evaluation of the algorithm and the borders of its validity domain. The performance measurement of an algorithm on a pseudo-synthetic sequence is shown to be consistent with the measurement on a real sequence with the same criteria. The benefit of this approach is twofold: it provides the developer with a way to concentrate on the weaknesses of his algorithm, and helps the system designer to choose the algorithm that best fits the operating constraints.

6569-26, Session 4

A method for tuning a standard Linux kernel to be used in signal processing systems

R. Herbel, Raytheon Co.

There is a desire to be able to use the Linux operating system in real time applications for sensors and also for a test bed for these system. Normally, there is some “acceptable” time (system spec) between the hardware interrupt and the time the operating system enters the interrupt handler. If the time is longer than the system spec we can miss interrupts and miss data or we can fail to perform some critical control function in the system. There is also a very large number of places in the Linux kernel where interrupts are blocked. The majority of these involve device drivers which are not part of your system and are not used. This involves a finding a needle in the haystack problem. Industry has tried to solve this. One approach is to try to write a microkernel under Linux to handle interrupts. This is used by RTAI and RTLinux. In this approach Linux does not handle the interrupts but is passed down from the “micro” OS. The other approach is to try to make Linux more preemptable ie reduce the latency. This is used by several companies Timesys, Montavista etc. This paper presents a new approach which includes an investigation technique to determine what interrupt blocking calls in the Linux kernel are causing the system to fail the interrupt latency requirements of the system. The paper also shows several techniques once those area’s are identified to modify the kernel to meet the interrupt latency requirements of the system.

The first step of the technique is to identify the area's of the Linux kernel which are causing the interrupt latency issues. Blocking interrupt calls in the Linux kernel are architecture dependent (they are different for power pc, Intel, etc) . However, the actual interrupt blocking call is normally in one place in the Linux kernel. This enabled us to add some code to take a time measurement when the operating system blocked interrupts and another one when the operating system unblocked interrupts. We then compared the measured interrupt latency to our system requirements and stored the area's which did not meet our system requirements. We also captured the memory location of the calling function so we can then use the Linux memory map to find the offending area of the Linux kernel. We made this information available through the proc area of the Linux kernel. We now have list offending area of the Linux kernel which needs to be tuned to meet our interrupt latency requirements.

In addition, There is some benefit that this list may grow our shrink depending on the interrupt latency requirements.

The next step is to modify those area's to eliminate the interrupt latency. In our project, we had three main area's of improvement. The first area was to get rid of unneeded functionality of the Linux kernel. We found an area in SELinux was causing some of our interrupt latency issues. We did not need this functionality so we simply recompiled our kernel removing this feature. The second was to change a "lazy" kernel driver writer. He was writing a device driver where he did not need to block all interrupts but he did it anyways. We modified this device driver to only block his interrupt and not all. This caused our critical data collection interrupt not to be blocked. The next area we had to modify was in the generic Ethernet system of the Linux kernel. This area is a little more interesting because the kernel writer needed to block all interrupts because he was doing some critical list manipulation and didn't wants his hardware device adding our subtracting from the list. As he was writing a generic network subsystem, he had no idea what hardware interrupt the network subsystem was associated with. In our project, we had some preknowledge of what interrupts our network device were associated with. So, we changed the blocking calls to just block only the network interrupts and not our critical data collection interrupt. Using these techniques, We successfully modified a standard Linux kernel to meet the interrupt latency requirements of our subsystem.

6569-27, Session 4

IRLooK: an advanced mobile infrared signature measurement, data reduction, and analysis system

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During the development of countermeasures against infrared threats, it is extremely important to develop high quality infrared signature databases of targets that are intended to be protected from these threats. IRLook is a mobile surface-to-air infrared signature measurement system, which is developed to perform infrared signature measurements of infrared countermeasures military and civil platforms such as fixed/rotary wing aircrafts, tracked/wheeled vehicles and navy vessels in the field. It is also transportable by C-130 aircraft. IRLook has the capabilities of data acquisition, pre-processing, post-processing, analysis, storing and archiving over shortwave, mid-wave and long wave infrared spectrum by means of its high resolution radiometric sensors and highly sophisticated software analysis tools in the field. Additionally, post-processing, analysis and archiving can also be handled in a stationary facility.

The sensor devices include imaging and non-imaging radiometers and spectroradiometers. Single or simultaneous multiple in-band measurements as well as high radiant intensity measurements can be performed. The system provides detailed information on the radiant intensities, spectral and spatial characteristics of the targets and the countermeasures.

Both of automatic and manual modes of tracking of target are available by its high quality field proven two-axes tracking mount. The tracking is accomplished by using a passive imaging tracker during day and night time operations. The system also includes a high quality meteorological station and field calibration equipment such as cavity and extended area blackbodies.

6569-28, Session 4

Practical to tactical: an evolution of the dual line-of-sight experiment

D. J. Riedle, Boeing-SVS, Inc.

In early 2001 Boeing-SVS began an Internal Research and Development (IRAD) project, dubbed the Dual Line of Sight (DLOS) experiment, to perform risk-reduction on the development of the control systems and mode logic for a strategic laser relay mirror system. The DLOS experiment uses primarily Commercial Off-the-Shelf (COTS) hardware and real-time system software, plus internally-designed gimbals and flexible mode logic tools to emulate a scalable relay mirror engagement. The high-level, nominal engagement sequence begins with the laser source gimbal establishing a line of sight with the relay receiver gimbal by closing passive acquisition and fine-tracking loops. Simultaneously, the receiver gimbal closes passive acquisition and fine-tracking loops on the laser source, and a low-power 660 nm alignment laser is propagated through the system. Finally, the transmitter gimbal closes passive acquisition and fine-track loops on a target, and the system propagates a simulated high-energy laser on that line of sight onto target models. In total, the DLOS experiment closes 28 control loops. For the strategic scenario, a model rocket target is illuminated with a light-emitting diode, and tracked by the Boeing-SVS Advanced Reconfigurable Trackers, using a centroid algorithm. The strategic scenario also uses a 532 nm laser to close an active track loop using a Linux tracker. To better align with our business capture strategy, the emphasis of the experiment in 2005 has shifted to emulating an urban tactical engagement, and developing weapon system operator consoles.

6569-29, Session 5

Adaptive filtering and feed-forward control for suppression of vibration and jitter

E. H. Anderson, R. Blankinship, L. P. Fowler, R. Glaese, P. Janzen, CSA Engineering, Inc.

This paper describes the use of adaptive filtering to reduce vibration and optical jitter. Adaptive filtering refers to a class of signal processing techniques developed over the last 30 years, and applied since to applications ranging from communications to image processing. The paper applies adaptive filtering methods to feedforward control of structures and systems including precision optical assemblies. The authors have fielded several feedforward control systems, and measured performance will support concepts and methods presented in the paper.

Active vibration control has have most often been realized via feedback control, and jitter control for optical systems generally uses feedback servo architectures. Such realizations make use of actuators, error sensors, control system hardware and software, and a variety of control architectures and algorithms. While feedback designs often incorporate information about system disturbance inputs, for example through the use of weighting filters in H2-optimal designs, they are generally not configured to process and adapt to changing disturbances in real time.

Adaptive filtering methods, beginning with techniques such as the least mean squares (LMS) algorithm, have been successful and are used widely in signal processing applications. The extension to processing of measured vibration signals has been demonstrated over the last two decades. Recent advances in digital signal processors (DSPs) and other digital hardware have made real-time adaptive filtering feasible for a broader range of vibration control applications including optical jitter control.

The paper will review basic concepts in adaptive filtering and feedforward control, including the relationship between and simultaneous implementation of feedback and feedforward algorithms. A series of examples in vibration, motion and jitter control will illustrate the effectiveness of the adaptive methods. These applications make use of information and signals that originate from system disturbances and minimize the correlations between disturbance information and performance and error measures. The examples will illustrate a variety of disturbance types including periodic, multi-tonal, broadband stationary and non-stationary. Control effectiveness with slowly-varying narrowband disturbances can be extraordinary, reaching 60 dB of reduction or rejection. In other cases, performance improvements may be only 30%, but such reductions are significant in many applications. The paper will provide realistic performance expectations for different disturbance types and physical systems. Physical systems to be discussed include vehicle interiors, ground-based active optics systems, flight motion simulators, wind turbines and airborne optical beam control systems.

Adaptive filtering applied to feedforward control is a powerful addition to servo and feedback control methods. The paper will conclude by highlighting areas with future potential and will describe the mathematical, computational, and physical challenges that must be met.

6569-30, Session 5

Real-time optimal sensing strategies for active control of optical systems

S. Moon, Adaptive Technologies, Inc.; L. P. Fowler, CSA Engineering, Inc.; R. L. Clark, Jr., Duke Univ.; E. H. Anderson, CSA Engineering, Inc.

The pointing and imaging performance of precision optical systems is degraded by disturbances on the system that create optical jitter. These disturbances can be caused by structural motion of optical components due to vibration sources that (1) originate within the optical system, (2) originate external to the system and are transmitted through the structural path in the environment, and (3) are air-induced vibrations from acoustic noise. Beam control systems can suppress optical jitter, and active control techniques can be used to extend performance by incorporating information from accelerometers, microphones, and other auxiliary sensors. In some applications, offline fixed gain controllers can be used to minimize jitter. However there are many applications in which a real-time adaptive control approach would yield improved optical performance. Often we would like the capability to adapt in real-time to a system which is time-varying or whose disturbances are non-stationary and hard to predict. In the presence of these harsh, ever-changing environments we would like to use every available tool to optimize performance. Improvements in control algorithms are important, but another potentially useful tool is a real-time adaptive control method employing optimal sensing strategies. In this approach, real-time updating of reference sensors is provided to minimize optical jitter. The technique selects an optimal subset of sensors to use as references from an array of possible sensor locations. The optimal, weighted reference sensor set is well-correlated with the disturbance and when used with an adaptive control algorithm, results in improved line-of-sight jitter performance with less computational burden compared to a controller which uses multiple reference sensors. The proposed technique is applied to an experimental test bed in which multiple proof-mass actuators generate structural vibrations on a flexible plate. These vibrations are transmitted to an optical mirror mounted on the plate, resulting in optical jitter as measured by a position sensing detector. Accelerometers mounted on the plate are used to form the set of possible optimal reference sensors. Reduction of the structural vibration of optical components is attained using a fast steering mirror which results in a reduction of the corresponding jitter. Experiments were completed in the spring of 2006.

6569-31, Session 5

Jitter control in actively illuminated laser tracking

Y. Wang, L. Liu, B. G. Fitzpatrick, Tempest Technologies LLC

Actively illuminated laser systems operating through turbulent atmosphere suffer from performance limitations and reductions from a variety of sources. Atmospheric jitter, platform jitter, misalignments, and signal-to-noise problems are just a few of the error sources in system performance of optical systems. In this paper, we present studies for the use of adaptive least squares controllers to mitigate the impact of local loop jitter on optical systems. All of the sensing and control is of an optical nature: no accelerometer or active vibration control is needed. The jitter control is an augmentation of the track loop controller, adding a signal to cancel the effects of the platform disturbance. We demonstrate that one additional optical sensor can be integrating into the tracking control loop to eliminate platform jitter with the tracking steering mirror. By this statement we mean that we can recover at least 95% of the idealized strehl, which is computed with no platform jitter. We have studied the problem of platform jitter for the AirBorne Laser (ABL) system, using a simulation tool called WaveTrain, developed by MZA Associates for the study of optical control systems operating in atmospheric turbulence. When simulating platform jitter without additional control, platform jitter reduced Strehls by more than 50%. The algorithm we employ is a recursive least squares estimation technique, which works in a manner similar to active noise cancellation methods. The recursive least squares algorithm adaptively constructs an estimate of the jitter signal to remove this noise from the track loop. The techniques described herein have also been tested in optical bench experiments and relay mirror simulations with very promising performance.

6569-32, Session 5

Real-time, low-latency stabilization for micro-autonomous unmanned vehicles

S. D. Martinez, Honeywell, Inc.

Recent advances in small air and ground-based autonomous robotic platforms equipped with electro-optical and infra-red cameras have demonstrated the utility of video data to enable missions such as IED detection and border and port surveillance. Many current Unmanned Vehicle Systems (UVS) also support gimbaled sensors allowing significant flexibility in video stabilization and tracking while moving.

Unfortunately, many stabilization systems are heavier and bulkier than desired for the very small vehicles envisioned for the future. These new platforms are extremely weight, size and power constrained, forcing each sensing and processing system to do double and triple duty where possible. Current off-the-shelf stabilization systems do not support this level of integration and many do not control video latency and throughput sufficiently to support real time UVS control requirements.

To satisfy this need, an approach involving a combination of smaller, but less capable mechanical stabilization / tracking, in combination with electronic stabilization purposely designed for these applications is warranted. Using this approach, suppression of parasitic vehicle motion during arbitrary but measurable maneuvers while allowing intentional platform motion provides an integrated solution satisfying overall system-level performance goals. This paper summarizes the real time video stabilization requirements for such an integrated system, develops candidate stabilization algorithmic and hardware approaches for the underlying functions, presents comparisons and provides descriptions of a mapping to custom real time hardware environments. Synthetic and representative real data sets are used to evaluate algorithm performance and hardware mapping efficiency.

6569-33, Session 5

Vibration evaluation of a precision inertial reference unit

P. H. Merritt, J. Friel, B. Spanbauer, Air Force Research Lab.; J. Donaldson, R. E. Walter, Boeing-SVS, Inc.

Inertial Reference Units (IRUs) are the basic reference for a precision pointing system. These units must provide a very stable inertial light source to be used as the reference to align the outgoing laser beam and to reject beam train jitter due to vibrations. The IRU will be subjected to six degree of freedom motion at its mounting location, usually very close to the primary mirror. The correct operation of an IRU requires it to measure the angular motion and not be affected by the linear input vibration. Testing of these units is a difficult problem since the vibration input motion may be perfectly correlated between the angular inputs and the linear inputs. This correlation makes it impossible to separate the angular and linear IRU responses during a test, even with perfect measurements of the input vibrations. The solution to this problem is to obtain a vibration test station that can provide linear motion without any angular motion, and angular motion without linear motion. The Central Inertial Guidance Test Facility (CIGTF) at Holloman AFB, NM has developed a vibration table that can provide this test requirement. Recent testing of the linear vibration system indicates that the vibration table when inputting 0.2 gs linear vibration only moves 300 nanoradians in pitch and 6 nanoradians in yaw. Clever mathematical routines were developed to permit measurements of this resolution. This paper will describe the evaluation of the test tables and the type of tests that the Air Force suggests for Inertial Reference Units.

6569-34, Session 5

An alternative alignment beam approach for tactical systems

D. C. Herrick, V. M. Beazel, Air Force Research Lab.; S. Gibson, P. Orzechowski, Univ. of California/Los Angeles; M. Mahajan, B. Wen, Teledyne Scientific Co.

Optical line of sight stability of an HEL weapon is maintained by employing a high bandwidth jitter control system. This controller needs a “clean” measure of beam train line of sight jitter. This is usually accomplished by inserting a stabilized laser beam that passes over most mirrors in the optical train. The stabilization of this beam is accomplished by mounting a small fiber fed collimator on an inertially stabilized platform. Functionally these devices look a bit like a fast steering mirror with gyros and optics attached to the “mirror” surface. For tactical systems which have small apertures, packaging becomes critical and allowable jitter levels are relatively large. For this case a compact approach is proposed where no mechanical stabilization is attempted. A transmissve liquid crystal beam dithering device is mounted in front of the collimator. The rotational motion of the collimator is measured and fed forward to a beam dithering device to stabilize the emerging alignment beam. This approach is enabled by calibrating the feed-forward filter using adaptive techniques. This presentation describes the liquid crystal beam dithering device, the adaptive feed-forward filtering and laboratory experiments which assess the performance limits of such an approach.

6569-06, Poster Session

Collaborative multimodel Rao-Blackwellised particle filter for target tracking in acoustic sensor networks

Z. Yu, J. Wei, J. Zhao, H. Liu, Shanghai Institute of Microsystem and Information Technology (China)

An energy-aware, collaborative target tracking algorithm is proposed for ad-hoc wireless sensor networks. At every time step, current measurements from four sensors are chosen for target motion estimation and prediction. The algorithm is implemented distributively by passing sensing and computation operations from a subset of sensors to another. A robust multi-model Rao-Blackwellised particle filter algorithm is presented for tracking high maneuvering ground target in the sensor field. Not only is the proposed algorithm more computation efficient than generic particle filter for high-dimension nonlinear and non-Gaussian estimation problems, but also it can tackle the target’s maneuver perfectly by stratified particles sampling from a set of system models. In the simulation comparison, a high maneuvering target moves through an acoustic sensor network field. The target is tracked by both generic PF and the multi-model RBPF algorithms. The results show that our approach has great performance improvements, especially when the target is making maneuver.

6569-22, Poster Session

IR and CCD-based object tracking using active shape model

J. Lee, Samsung Thales Ltd. (South Korea)

Heterogeneous camera based surveillance systems provide us with a more robust tracking of objects. To take advantage of additional cameras, it is necessary to establish geometrical relationship between the cameras and relationship between an object and a camera.

This paper presents an algorithm that can track a non-rigid objects in real-time in the night watch system which does not contain sufficient light.

The proposed method adopted hierarchical active shape model(ASM) for real-time tracking and adaptive landmark point assignment for reducing computational load at each level.

Active Shape Model trains contour information of an object using landmark points.

Active Shape Model is robust for tracking non-rigid objects and overcomes the occlusion, because it changes an average shape of an object with trained contour information of an object.

Therefore Active Shape Model can extract an contour of an object in an image with much noise.

Active Shape Algorithm can be divided into 4 steps.

(v) Assigned landmark point on the contour of the object.

(vi) Principal component analysis

(vii) Model fitting

(viii) Modeling a local structure

This proposed tracking algorithm uses the information from CCD sensor for tracking objects in the day time, and uses the information form IR sensor for tracking objects in the night time.

When the perfect occlusion occurs, the proposed algorithm predicts movements of an object using the historical tracking information and it can keep the object tracking.

Through the results of this experiment, we found out that we can track an object both day and night with an trained contour information of an object, and confirm that robust tracking can be done in a perfect and a part occlusion.

Therefore, the proposed algorithm we will develop a real-time region alignment algorithm for a heterogeneous camera-based surveillance system under a complex environment.

6569-35, Poster Session

Laser-beam director system monitoring the alignment state with a null reflector

Y. Kim, H. Kim, Y. Park, E. Kang, Agency for Defense Development (South Korea); S. Lee, J. Kim, H. Eom, Doosan Infracore Co., Ltd. (South Korea)

The Laser Beam Director consists of two mirror telescope and several relay mirrors. It has a long optical coude path. So, small structural deformations by operational disturbances or rotational jitter of the turret can greatly deviate the direction of the laser beam. These effects must be monitored and corrected. We do this using a null reflector and a position sensor. Main laser beam is transmitted to the target after reflected off the secondary and primary mirror sequentially. While, monitoring laser beam returns along the same path after reflected off the annular and primary mirror because both mirrors consist of null optics. The annular mirror is attached just outside the aperture of the secondary mirror. The monitoring He-Ne laser beam, which is made annular by two axicon lenses, is collimated and sized to fit the aperture of the annular mirror. The return beam is sensed by quad-detector and gives information about the alignment state of the system. Rotational jitter of the turret can be corrected by the fast steering mirror located between the primary and secondary mirror. In case of the irreversible structural deformation, the Laser Beam Director must be realigned.

6569-36, Poster Session

Image seeker simulation for short-range surface-to-surface missile

S. Jin, H. Kang, Nex1 Future Co., Ltd. (South Korea)

This paper presents a seeker simulation including seeker software, target motion, image sensor modeling and gimbals dynamics. We define the seeker control software architecture having a transparent layer. It enables developing re-usable software which can be applied both seeker simulator and real embedded computer. We also explain tracking software simulator implemented in windows C/C++, dynamic motion simulator implemented in MATLAB and combination of two modules based on windows common object model (COM). This allows interactive studies between seeker tracking algorithm and control system design. And this also can be used efficiently as a seeker software development tool. We show current results from implanted software and plans for future improvement.

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6570-01, Session 1

Defending against Internet worms using a phase space method from chaos theory

J. Hu, J. Gao, Univ. of Florida

Enterprise networks are facing ever-increasing security threats from Distributed Denial of Service (DDoS) attacks, worms, viruses, intrusions, Trojans, port scans, and network misuses, and thus effective monitoring approaches to quickly detect these activities are greatly needed. In this paper, we employ chaos theory and propose an interesting phase space method to detect Internet worms. An Internet worm is a self-propagating program that automatically replicates itself to vulnerable systems and spreads across the Internet. Most deployed worm-detection systems are signature-based. They look for specific byte sequences (called attack signatures) that are known to appear in the attack traffic. Conventionally, the signatures are manually identified by human experts through careful analysis of the byte sequence from captured attack traffic. We propose to embed the traffic sequence to a high-dimensional phase space using chaos theory. We have observed that the signature sequence of a specific worm will occupy specific regions in the phase space, which may be appropriately called the invariant subspace of the worm. The invariant subspace of the worm separates itself widely from the subspace of the normal traffic. This separation allows us to construct three simple metrics, each of which completely separates 100 normal traffic streams from 200 worm traffic streams, without training in the conventional sense. Therefore, the method is at least as accurate as any existing methods. More importantly, our method is much faster than existing methods, such as based on expectation maximization and hidden Markov models.

6570-02, Session 1

Information fusion and visualization of large complex attack graphs for networks security

H. Chen, G. Chen, Intelligent Automation Inc.; M. Kruger, Office of Naval Research; E. Blasch, Air Force Research Lab.; D. Penwell, Alion Science and Technology Corp.

We propose a comprehensive and innovative approach for analysis and visualization of large complex multi-step cyber attack graphs. First, we select the radial space-filling hierarchy visualization module for large complex multi-step cyber attack graph due to its strengths in space efficiency and ease of interpretation. Once an attack is correlated, the attack notification service retrieves the correlated alerts that comprise the attack scenario and uses it to instantiate an attack node, binding formal parameters to arguments along the way. Second, we build our plan recognition system after a low-level alert correlation step that includes alert aggregation and alert correlation. Third, we do not require a complete ordered alert sequence for inference. We have the capability of handling partial order and unobserved activity evidence sets. Fourth, we provide advanced approaches to predict potential attacks based on observed intrusion evidence. Bayesian Network based predication can incorporate prior knowledge of attack transition patterns and handle uncertainty in the correlation process. Moreover, we apply dynamic games for graph-based attack prediction and response since the integration of attack graphs and alert correlation graphs provide “perfect” knowledge about the attacker’s strategy space which is necessary to compute (Nash) equilibriums out of any mathematical game.

6570-03, Session 1

Summary of results on optimal camera placement for boundary monitoring

R. J. Holt, Queensborough Community College/CUNY; H. Man, J. Wang, I. Mukherjee, R. Martini, R. Netravali, Stevens Institute of Technology

We consider problems of placing cameras so that every point on a three-dimensional perimeter is covered while using the smallest number of cameras. Taken into consideration are visibility concerns, where features such as mountains must not be allowed to come between a camera and a boundary point that would otherwise be in a camera’s field of view.

One problem involves finding the positions and orientations of cameras so that each boundary point is covered at least once, while using the minimal number of cameras. Another considers double coverage, with the camera positions staggered so that they may be calibrated. We find configurations where average or maximum calibration error is minimized. We provide an iterative algorithm that accomplishes these tasks.

Furthermore, we investigate a joint optimization camera placement problem. This involves the placement of a second set of cameras after an initial minimal configuration where each boundary point is at least singly covered. The second set of cameras is chosen with the simultaneous aims of minimizing calibration error while using the minimal number of cameras. In this scenario the user may choose a threshold for the maximum calibration error, and a tradeoff between the number of cameras and this threshold ensues. Again an algorithm is provided.

6570-04, Session 1

Evaluation of data mining techniques for suspicious network activity classification using honeynets data

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As the amount and types of network services increases, their log analysis has become a very difficult task. The filtering of relevant information by a network administrator is a very time consuming task, which may be impossible to accomplish if the network in question is large.

There are several ways to optimize this hard work in order to provide a reduced log for analysis. Some of them are whitelisting (or “artificial ignorance”) and intrusion detection system tools (which only identify pre-known signatures), but all of these techniques require a lot of tuning work and can still let pass false-negatives or ignore interesting log entries.

Nowadays, researchers are evaluating data mining-based approaches for intrusion detection in network logs, such as genetic algorithms, neural networks, clustering algorithms, etc. Some of those yield good results, but require a very large number of attributes gathered by network traffic to detect useful information.

We apply some of those approaches (self-organizing maps and decision trees) in a reduced number of attributes on some log data sets acquired from honeynets to classify traffic logs as “normal” or “suspicious”. Our results allow us not only to identify unlabeled logs but also to describe which attributes were used for the decision and which logs fall neither in the “normal” or “suspicious” categories but should be better examined for further identification.

This approach will provide a very reduced amount of logs to the network administrator, improving the log analysis task and helping to discover new kinds of attack in their networks.

6570-05, Session 1

Selection of intrusion detection system threshold bounds for effective sensor fusion

C. Thomas, N. Balakrishnan, Indian Institute of Science (India)

The motivation behind the fusion IDS was the realization that with the increasing traffic and increasing complexity of attacks, none of the present day stand alone Intrusion Detection Systems can meet the high demands for a very high detection rate and a low false alarm rate. Multi-sensor fusion can be used to meet these requirements by a refinement of the combined responses of different Intrusion Detection Systems. In this paper, we show the design technique of Sensor Fusion to best utilize the useful response from multiple sensors by an appropriate adjustment of the fusion threshold. The threshold is usually chosen according to the past experiences or by an Expert system. In this paper, we show that the choice of the threshold bounds according to the Chebychev inequality principle performs better. This approach is also helping to solve the problem of scalability and has the advantage of failsafe capability. This paper theoretically models the fusion IDS for the purpose of showing its improved performance, supplemented with the empirical evaluation.

An experimental Packet Header Anomaly Detector (PHAD), that monitors the 33 fields of the Ethernet, TCP, UDP, and ICMP protocols is chosen as one of the sensors for the combination.Observing the header fields makes it efficient to detect Probes and DOS attacks. The second IDS chosen is Application Layer Anomaly Detector (ALAD)and it complements PHAD in detection by monitoring incoming TCP connections to well known server ports. ALAD has six attributes for detection, namely source IP address, destination IP address, destination port, TCP flags, application keywords and the application argument. It detects the R2L attacks with high detection rate since R2L attacks normally exploits the application layer.

The combination of these sensors is shown to detect more attacks than the individual components. Since PHAD and ALAD detect sufficiently different attacks, their results can be merged for improved performance. The combination is done in different ways like (i) taking all the alarms from each system and avoiding the duplicates, (ii) taking the alarms from each system by fixing threshold bounds (false alarms between 100 and 200) and (iii) rule-based fusion with a prior knowledge of the individual sensor performance. A number of evaluation metrics were used, and the results indicate that there is an overall enhancement on the performance of the combined detector using simple rule-based fusion and significantly better results using sensor fusion incorporating the threshold bounds.

6570-29, Session 1

BOT armies as threats to network security

S. B. Banks, Calculated Insight; M. R. Stytz, Institute for Defense Analyses

"Botnets", or "bot armies", are large groups of remotely controlled malicious software. Bot armies pose one of the most serious security threats to all networks; whether they are civilian or government owned, or carry classified or unclassified message traffic. Botnets, remotely controlled and operated by bot masters or bot herders, can launch massive denial of service attacks, multiple penetration attacks, or any other malicious network activity on a massive scale. While bot army activity has, in the past, been limited to fraud, blackmail, and other forms of criminal activity, their potential for causing large-scale damage to the entire internet, for launching large-scale, coordinated attacks on government computers and networks, and for large-scale, coordinated data gathering from thousands of users and computers on any network has been underestimated. This paper will discuss the challenges posed by the bot army problem by examining their means for infiltration, operation, control, and cleansing . At the present time, all bot activity is illegal. The use, creation, or distribution of bots is an illegal activity as is the use, creation, or distribution of any of the technologies that bots employ except for internet chat, also called internet relay chat (IRC). So, this paper will not discuss how to build bots but the threats they pose.

In a "botnet" or "bot army", computers can be used to spread spam, launch denial-of-service attacks against Web sites, conduct fraudulent activities , and prevent authorized network traffic from traversing the network. On the internet in 2004, it was estimated that over 70% of all spam messages are coming from bot armies , the number today is estimated to be higher. Running a bot army can be highly profitable; for example, in today's civilian "bot army" economy, a botmaster could have 100,000 machines under his control and will contract to send a million e-mail. Because of the number of machines under his control, the bot master will have each machine send out only 10 messages. It's very hard for the owner of a machine that is compromised to know that 10 [e-mail] messages went out on any given day. As a result, it's virtually impossible for an average person to know whether or not their machine has been drafted into a bot army and is being used for nefarious purposes, and the presence of bots on classified computers cannot, at this time, be ruled out. Because of the threat posed by bot armies and the possibility that any computer could, at any time, host one or more bots we have undertaken research to characterize bot infections, bot army tactical and strategic operations, and the technologies that bots rely upon. Our goal is to use this knowledge to provide better defenses against bots and bot army operations.

In the paper we will discuss botnet technology and the technologies that underlie this threat to network and computer security. The first section of the paper introduces our research in botnets and motivates the need for improved protection against botnets, their technologies, and for further research about botnets. The second contains background information about bot armies and their key underlying technologies. The third section presents a discussion of the types of attacks that botnets can conduct and potential defenses against them. The fourth section contains a summary and suggestions for future research and development.

A "folksy" introduction to the topic of bots and bot armies can be found at http://zine.dal.net/previousissues/issue22/botnet.php

One exception is rootkit use to protect copyrights, a controversial use of this powerful technology; see http://www.sysinternals.com/blog/2005/10/sony-rootkits-and-digital-rights.html for more information.

The fraudulent activities are becoming more organized and closely resemble the Mafia in organization, see Http://www2.csoonline.com/blog_view.html/?CID=23687&source=csonewswatch

Steve Linford as reported byIllett, D. ZDNet UK, 2004.

A botmaster or botherder is the person (or group) who developed and/or control the bot army.

6570-07, Session 2

Mining unknown patterns in data when the features are correlated

R. S. Lynch, Jr., Naval Undersea Warfare Ctr.; P. K. Willett, Univ. of Connecticut

In this paper, unsupervised learning is utilized to mine unknown patterns in training data when the feature space is correlated [1,2]. The approach utilized to mine all unknown patterns is based on the Bayesian Data Reduction Algorithm (BDRA), which has been developed into a patented system called the Data Extraction and Mining Software Tool (DEMIST). The primary contribution of this work will be to demonstrate the impact that correlation has on the ability to automatically find unknown (to the classifier) patterns in simulated training data. This will be accomplished by controlling the statistical dependency between all features, and, for each case, computing the probability of error in correctly identifying patterns in the data. Note, by controlling the correlation between features any interesting trends in computed error probabilities will reveal explicitly the relationship between statistically dependent features and mining patterns in the data. Further, results of applying the classifier DEMIST to real world training data will also be illustrated.

[1] R. S. Lynch, Jr. and P. K. Willett, "Bayesian Classification and Feature Reduction Using Uniform Dirichlet Priors," IEEE Transactions on Systems, Man, and Cybernetics, vol. 33, no. 3, June 2003.

[2] R. S. Lynch, Jr. and P. K. Willett, "Use of Bayesian Data Reduction for the Fusion of Legacy Classifiers," Information Fusion Journal, vol. 4, March 2003.

6570-08, Session 2

Image information mining from geospatial archives based on combination of the wavelet transform and Fourier phase descriptor

V. P. Shah, N. H. Younan, S. S. Durbha, R. L. King, Mississippi State Univ. and GeoResources Institute

In general, reflectance and spatial patterns characterize the geospatial data. Current semantic-enabled framework image retrieval systems for geospatial data extract primitive features based on color, texture (Spatial Gray Level Dependency - SGLD matrices), and shape from the segmented homogenous region. However, the form of extracting textural information is computationally expensive. The state-of-the-art image mining system for multimedia image archives uses the wavelet transform for feature extraction to quickly and efficiently capture color and texture information. Since an image consists of three bands, color information is captured by converting the RGB space into HSV space. Thus, a different approach is required to capture the complete reflectance pattern, an important characteristic of geospatial data.

This work proposes a new method to perform fast coarse image segmentation using descriptors obtained by combining the Fourier transform along the spectral axis and the 2D-wavelet transform along the spatial axis to capture color and texture information for segmentation. These features are later on used for the region-based retrieval in the earth observation data archives. This work also develops an approach to adaptively select the number of decomposition level required for the wavelet transform to effectively capture textural information in an image. Initial results show promising use of these features for image information mining from geospatial data archives.

6570-10, Session 2

Genetic program-based data mining of fuzzy decision trees and methods of improving convergence and reducing bloat

J. F. Smith III, Naval Research Lab.

A data mining procedure for automatic determination of fuzzy decision tree structure using a genetic program (GP) is discussed. A GP is an algorithm that evolves other algorithms or mathematical expressions. Innovative methods of accelerating convergence of the data mining procedure and reducing bloat are given. In genetic programming, bloat refers to excessive tree growth. It has been observed that the trees in the evolving GP population will grow by a factor of three every 50 generations. When evolving mathematical expressions much of the bloat is due to the expressions not being in algebraically simplest form. So a bloat reduction method based on automated computer algebra has been introduced. The effectiveness of this procedure is discussed. Also, rules based on fuzzy logic have been introduced into the GP itself to accelerate convergence, reduce bloat and produce a solution more readily understood by the human user. These rules are discussed as well as other techniques for convergence improvement and bloat control. Comparisons between trees created using a genetic program and those constructed solely by interviewing experts are made. A genetic program evolved tree is shown to be superior to one created by hand using expertise alone. A new co-evolutionary method that improves the control logic evolved by the GP by having a genetic algorithm evolve pathological scenarios is discussed. The effect on the control logic is considered. Finally, additional methods that have been used to validate the data mining algorithm are discussed.

6570-13, Session 3

Maximizing information recovery from rank-order codes

B. B. Sen, S. Furber, The Univ. of Manchester (United Kingdom)

The central nervous system encodes information in sequences of asynchronously-generated voltage spikes, but the precise details of this encoding are not well-understood. Thorpe proposed rank-order codes as an explanation of the observed speed of information processing in the human visual system. Our work here is inspired by the performance of SpikeNET, a biologically inspired neural architecture using rank-order codes for information processing. The purpose is to find a means of extracting the maximum possible perceptually important information contained in the rank-order encoded visual stimulus with respect to the original. For this, we simulate a model developed by VanRullen and Thorpe which mimics retinal information processing by passing an input image through a bank of Difference of Gaussian (DoG) filters and then encoding the resulting coefficients in rank-order. To test the effectiveness of this encoding in capturing the information content of an image, the rank-order representation is decoded to reconstruct the input. Since the DoG filters are approximately orthogonal functions, they are treated as their own inverses in the reconstruction process. We use a slightly modified version of an objective metric proposed by Petrovic and observe that around 75% of the perceptually important information is retained in the reconstructed stimulus with respect to the original. In the present work we reconstruct the input using a pseudo-inverse of the DoG filter-bank with the aim of improving the reconstruction. We observe that there is an increase of 10 - 15% in the information retrieved from a reconstructed stimulus as a result of inverting the filter-bank.

6570-14, Session 3

Impact of information assurance on the performance of secure messaging systems

S. V. Belur, J. A. Gloster, The Van Dyke Technology Group, Inc.

An analytical performance model for generic secure messaging systems is formulated as an multi-class queuing model. Findings of sensitivity analysis carried out to show how the model can be used in assessing the impact of various information assurance features on the overall performance of the messaging system, is presented. The impact of number of messages/users, effect of SSL, increasing security strength, secret key encryption etc on performance is also analyzed. Finally, the description of how the model can be adopted for practical performance analysis is outlined.

6570-15, Session 3

Cluster analysis of temporal trajectories of hospital laboratory examinations

S. Tsumoto, S. Hirano, Shimane Univ. (Japan)

This paper presents a cluster analysis method for multidimensional time-series data on clinical laboratory examinatios. Our method represents the time series of test results as trajectories in multidimensional space, and compares their structural similarity by using the multiscale comparison technique. It enables us to find the part-to-part correspondences between two trajectories, taking into account the relationships between different tests. The resultant dissimilarity can be further used with clustering algorithms for finding the groups of similar cases. The method was applied to the cluster analysis of Albumin-Platelet data in the chronic hepatitis dataset. The results demonstrated that it could from interesting groups of cases that have high correspondence to the fibrotic stages.

6570-16, Session 3

Discovery of exacerbating cases in chronic hepatitis based on cluster analysis of time-series platelet count data

S. Tsumoto, S. Hirano, Shimane Univ. (Japan)

This paper reports the results of temporal analysis of platelet (PLT) data in chronic hepatitis dataset. First we briefly introduce a cluster analysis system for temporal data that we have developed. Second, we show the results of cluster analysis of PLT sequences. Third, we show the results of PLT value-based temporal analysis aiming at finding years for reaching F4, years elapsed between stages, and their relationships with virus types and fibrotic stages. The results of cluster analysis indicate that the temporal courses of PLT can be grouped into several patterns each of which presents similarity in average PLT level and increase/decrease trends. The results of value-based analysis suggests that liver fibrosis may proceed faster in the exacerbating cases.

6570-23, Session 3

Support online learning with games

J. Yao, Univ. of Regina (Canada)

This paper will present a study on Web-based learning support systems. The system contains two subsystems: A Web-based game learning facility and an Intelligent Web Search Engine (IWSE). The Internet and the Web may be considered first recourse for students seeking for help. However, much of the information online is either not related to course content or wrong. The IWSE subsystem provides students with precise, relative and adaptable information about certain courses or classes. Therefore, students do not have to spend time to verify the legislative of the contents and their relationship the class. The game learning subsystem enables students to review their studies and perform self-evaluation through Web-based games. During the challenge and fund evaluation process, it is hoped that students will eventually understand and master the course concept easily. The goal of developing such a system is to provide students with an efficient and effective learning environment.

6570-27, Session 3

Enabling distributed simulation multi-level security using virtual machine and virtual private network technology

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The modeling and simulation community (M&S) continues to strive for increased fidelity within simulation environments. However, this quest for increased fidelity often requires the use of classified information, models, and processing techniques. The use of classified information and software greatly complicates the development, testing, and use of the simulation environment. The problems associated with high-fidelity simulation environments that rely upon classified information and software are compounded by the use of unclassified software, techniques, and data. The mix of classified and unclassified data, software, and computations further complicates simulation development and activities and, typically, results in the classification of the entire simulation environment. This approach, while proven and trustworthy, is no longer necessary. Two technologies are now available that would permit the secure deployment of multi-level security simulation environments at only a modest increase in cost and effort above that required for the development of an unclassified simulation environment. The common practice of simply increasing simulation environment security to the highest classification level of any data or software within it unnecessarily increases simulation development costs and unnecessarily complicates simulation environment development. The two technologies that should be used are virtual machine technology and virtual private network technology.

Virtual machine and virtual private network technologies are not new; for example, virtual machine technology was first devised in the 1960s. However, we currently only now have the computational power become available in conjunction with an ease of use and deployment to permit these technologies to be efficiently employed in military simulations. Together, they allow the simulation environment designer to develop environments and applications within them wherein computations are isolated, information is assured to be protected, and information communication between the different computational engines within the computer are secure.

Briefly, virtual machines and virtual private networks operate in the following manner. In a virtual machine all components of a given computer hardware/operating system combination are replicated within a host operating system to provide the computational illusion that all applications executing within the virtual operating system are running on the original software/hardware combination hardware; however, this situation is not the case. A virtual machine does not add functionality to the operating systems (and applications within them) that it hosts but instead provides functionality and a software interface to them that is identical to the replicated system and also controls communication between the virtual machines. In this environment, there is complete protection of all actual system resources and hardware from each of the virtual machines; each virtual machine is also isolated from all other virtual machines. Communication between virtual machines is possible, and is usually patterned upon network communication, an important point to remember as it indicates that the use of virtual private networks is practicable. A virtual private network (VPN) uses a public transport system - typically the Internet - for private communications by applying encryption to preserve privacy . VPNs are most commonly used to connect two networks at different locations. This technique plugs the remote computers into the local network, consolidating the two physical nets into a single logical network. The combination of full participation by all resources coupled with assured privacy networks, while using a public network link, is the hallmark of a VPN. The compelling appeal of the VPN is that it is inexpensive relative to other forms of providing private communication.

In this paper we will discuss our approach to the use of virtual machine and virtual private network technology to increase simulation security. The first section of the paper introduces our research area and motivates the need for improved security for computations and inter-computation communication within simulation environments. The second contains background information about virtual machines and virtual private networks. The third section presents our generalized design for the use of VMs and VPNs in simulation environments and shows how the general design can be used to increase simulation environment security. The fourth section contains a summary and suggestions for future research and development.

1)A VPN is typically defined as the emulation of a private wide area network facility using IP technologies.

6570-17, Session 4

AutoCorrel II: A neural network event correlation approach

M. G. Dondo, P. Mason, Defence Research and Development Canada (Canada); N. Japkowicz, R. D. Smith, Univ. of Ottawa (Canada)

We have successfully implemented a two-stage event correlation model for IDS alerts. The model is designed to automate alert and incidents management and reduce the workload on an IDS analyst. We achieve this correlation by clustering similar alerts together, thus allowing the analyst to only look at a few clusters instead of hundreds or thousands of alerts. The first stage of this model uses an ANN-based autoassociator. The autoassociator is trained to reproduce each alert at its output, and it uses the error metric between its input and output to cluster similar alerts together. The accuracy of the system is improved by adding another machine-learning stage which attempts to combine closely related clusters produced by the first stage into super-clusters. The second stage uses the EM clustering algorithm. The model and performance of this model are tested with intrusion alerts generated by a Snort IDS on DARPA's 1999 IDS evaluation data as well as incidents.org alerts.

This work is a follow-up of our earlier work, Autocorrel I, in which we attempted to make an IDS analyst's job easier by clustering similar alerts together, thereby reducing the number of alerts that an analyst has to deal with. In this work we try to address the shortcomings of Autocorrel I, in particular the accuracy of the results. In our conclusions to the Autocorrel I model, we identified the source of our errors was in the collapsing of a 42-tuple input pattern into a single threshold value which was used to perform the clustering. Therefore, in this work we add a second stage to provide a second layer of clustering. This second stage combines the threshold heuristic of the first stage (Autocorrel I) with raw attributes from Snort alerts.

We propose to use a neural network-based novelty detection approach and a machine-learning clustering algorithm to identify and cluster alerts into smaller attack categories. In this way, the analyst's job is made significantly easier.

6570-18, Session 4

New metrics for blog mining

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Blogs represent an important new arena for knowledge discovery in open source intelligence gathering. Bloggers are a vast network of

information sources (human and, increasingly, some non-human) monitoring the foreign policy and terrorism news stream, as well as other blogs, for items of interest upon which they comment. Increasingly, issues erupt from the blog world and into the real world, as we have seen in episodes such as when controversy over the Danish cartoons of Mohammed erupted into riots world wide. In order to monitor blogging about foreign policy and terrorism issues, we must develop models and metrics that represent blogs correctly. The structure of blogs requires new techniques for evaluating such metrics as the relevance, specificity, credibility and timeliness of blog entries; techniques that have been developed for standard information retrieval purposes (e.g. Google's PageRank) are suboptimal when applied to blogs because of their high degree of exophoricity, quotation, brevity, and rapidity of update. In this paper, we motivate new approaches to evaluating metrics related to blog entry relevance, specificity, timeliness and credibility and report on the evaluation of a new blog search and analysis tools we are developing. These tools utilize new blog-specific metrics and techniques for extracting the necessary information from blog entries automatically, using some shallow natural language processing techniques supported by background knowledge captured in domain-specific ontologies.

6570-19, Session 4

Adaptive Grahm-Schmidt orthogonalization for the projection-slice synthetic discriminant function filter

V. R. Riasati, Boeing Satellite Systems; D. Grishin, Univ. of California/Davis

In the past, we have used various methods to reduce the data that represent synthetic discriminant function filters, specially, the projection-slice synthetic discriminant filter (PSDF). One of the primary reasons for using the PSDF is the inherent data dimension reduction that is achieved through the use of the projection-slice theorem, (PST). The use of the PST allows for a powerful technique to segment informational content into lower dimensional spans while simultaneously providing a complete and naturally linked data set. Shannon provides a formula for maximum information capacity in a channel that utilizes as the most efficient informational coding independent data samples, as this spreads the spectrum evenly across the channel band. This implies that independent information that represent a correlated set contains maximal information if the "key" that represents the correlated-ness of the data is known, otherwise the independent data are purely random. By using a novel Adaptive Grahm-Schmidt (AGS) procedure we form a method that identifies patterns in correlated data for the removal of the inter-dependence and thereby maximization of information content. In this work we subject the lower-dimensional data sets in the PSDF to the AGS to maximize the information content of the PSDF and share some of our findings, results, and deductions.

6570-20, Session 4

Semantic search via concept annealing

K. A. Dunkelberger, Northrop Grumman Corp.

Annealing, in metallurgy and materials science, is a heat treatment wherein the microstructure of a material is altered, causing changes in its properties such as strength and hardness. We define concept annealing as a lexical, syntactic, and semantic expansion capability (the removal of defects and the internal stresses that cause term- and phrase-based search failure) coupled with a directed contraction capability (semantically-related terms, queries, and concepts nucleate and grow to replace those originally deformed by internal stresses). These two capabilities are tied together in a control loop mediated by the information retrieval precision and recall metrics coupled with intuition provided by the operator. The specific representations developed have been targeted at facilitating highly efficient and effective semantic indexing and searching. This new generation of search capability enables additional processing (i.e. all-source tracking, relationship extraction, and total system resource management) at rates, precisions, and accuracies previously considered infeasible. In a recent experiment, an order magnitude reduction in time to actionable intelligence and nearly three orders' magnitude reduction in false alarm rate was achieved.

6570-21, Session 4

Three-way aspect model (TWAPM) and co-training for image retrieval

A. Doloc-Mihu, V. V. Raghavan, Univ. of Louisiana at Lafayette

The effectiveness of a CBIR system depends on the choice of visual features and of the similarity metric that models the user perception of similarity. Since the latter is very difficult to model, the current tendency in the Image Retrieval community is to use both content-based image retrieval and text-based image retrieval to enhance the performance of the Image Retrieval System. Learning and result merging in this context have been a concern of both the Information Retrieval community (see [3] for a survey) and the multimedia database community [4,5].

In a CBIR system, there is a question of how to combine or to use the information derived about an image based on different feature types (e.g., annotation, color, shape, etc.). In this work, we assume that an image is described by multiple feature types, both textual (annotation) and visual (color). In this context, searching for images involves the mixture of these different feature types. The problem is that, in real web based applications, it is not known a priori the importance of each feature to the user request. We are interested in effective and efficient modalities of dynamically learning the weights of the feature types necessary to form a final best ranking of the image collection. Our final goal is building an effective and efficient Web-based Adaptive Image Retrieval System.

The goal of this work is to investigate the applicability of two approaches, namely Three-Way Aspect Model [8,9] and Co-Training [2,7], to our image retrieval problem, when we employ learning via feedback from user. To our knowledge, similar type of study was done for text retrieval, with different results on real collections (e.g. [7]), but not for images.

In the following, we briefly present the framework in which we apply these approaches. In this work, we are using color representations of images in RGB color space (256 colors), and annotation obtained by using same approach as in [1]. User gives feedback on image(s), i.e. query-by-example approach, as relevant and not relevant (binary relevance).

The Three-Way Aspect Model [8] was proposed in order to unify collaborative and content-based approaches for recommender systems. This probabilistic model extends the aspect model proposed by Hofmann [6] to include three-way co-occurence data among users, documents and document content. Further, the authors extended their work to improve this model [9,10]. However, to our knowledge, this model has not been applied to image collections.

In our view, images from our collections can fall under several topics. A characteristic of the Three-Way Aspect Model is that it can handle such data, which motivates us to investigate its applicability to our image retrieval task.

In our context, a user gives feedback on a set of images X={d1,d2,...,dN}, which together with the annotations A={a1,a2,...,aM} and colors C={c1,c2,...,cS} they contain, form observations (d,a,c), which are associated with one of the latent variables z in Z={z1,z2,...,zK}. We think of the latent variables as they are representing topics. An image might pertain to several topics, but an observation belongs to only one topic (latent variable z). Images, annotations, and colors are assumed independent, given the topic.

Conceptually, a user chooses a topic, which generates images and their content according to topic specific distributions. Similar to [8,9], model parameters are learned by using EM algorithm to find a local maximum of the log-likelihood of the training data, and then, not seen images are ranked according to P(d,a,c).

The Co-Training algorithm [2,7] uses two distinct, assumed independent, representations of the entire image collection to learn from seen (by the user) and not seen images. In our case, the two representations correspond to annotations, and color histograms in RGB. The algorithm is initialized with the seen images, i.e to which the user gave feedback, and, based on this information, builds

incrementally two classifiers, one for each image representation set. At each iteration, each classifier labels two not seen images, one as relevant and one as not relevant. For classification, each classifier chooses the image for which it has the highest confidence. Then, each classifier learns from the new set of seen images. The process is repeated until all not seen images are classified in either relevant or not relevant class.

Researchers [2,7,8,10] tested these two approaches for document retrieval on different collections. The applicability of either method seems to depend on the collection characteristics. However, to our knowledge, in case of images a such study is missing. Moreover, one can notice that both algorithms assume that the image representations are independent, an assumption which is not realistic for images. Therefore, to study their applicability to real image collections, experiments are necessary.

Experimental tests on four image test collection of sizes 5000 and 10000 are in progress, and we hope the results will offer useful insights on applicability of either approach to a web-based adaptive image retrieval system. For both algorithms we use naive Bayes. In our experimental study, we also investigate several improvements (regarding both effectiveness and efficiency) for both approaches, which are proposed in the literature, such as the similarity matrix used to overcome the overfitting in TWAPM [9], and the pool size in Co-Training [7].

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6570-22, Session 4

A flexible self-learning model based on granular computing

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Granular Computing (GrC) is an emerging theory which simulates the process of human brain understanding and solving problems. Rough set theory is a tool for dealing with uncertainty and vagueness aspects of knowledge model. SMLGRC algorithm introduces GrC to classic rough set algorithm, and make the length of the rules relatively short, but it can not process mass datasets. In order to solve this problem, based on the analysis of the hierarchical granular model of information table, the method of granular distribution list (GDL) is introduced to generate granular, and the granular computing algorithm (SLMGrC) is improved. Sample covered factor (SCF) is also introduced to control the generation of rules when the algorithm generates conflicted rules. The improved algorithm can process mass datasets directly without influencing the correction rate of the SLMGrC. Experiments demonstrate the validity of our method.

6570-25, Poster Session

The solution of solving materialized views selection using random algorithm

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The data warehouse is a repository of information collected from multiple, possibly heterogeneous, autonomous, distributed databases. The information stored at the data warehouse is in form of views, referred to as materialized views. The selection of the materialized views is one of the most important decisions in designing a data warehouse. Materialized views are stored in the data warehouse for the purpose of efficiently implementing on-line analytical processing queries. The first issue for the user to consider is query response time. So, in this paper, we develop algorithms to select a set of views to materialize in data warehouse in order to minimize the total view maintenance cost under the constraint of a given query response time. We call it query_cost view selection problem.

First, cost graph and cost model are presented. Second, the methods for selecting materialized views by using random algorithms are presented. The genetic algorithm is applied to the materialized views selection problem. But with the development of genetic process, the legal solution produced become more and more difficult, so a lot of solutions are eliminated and producing time of the solutions is lengthened in genetic algorithm. Therefore, improved algorithm has been presented, which is the combination of simulated annealing algorithm and genetic algorithm for the purpose of solving the query cost view selection problem. Finally, in order to test the function and efficiency of our algorithms, experiment test is adopted. The experiments show that the given methods can provide near-optimal solutions in limited time and woks better in practical cases.

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6571-01, Session 1

A novel method to evaluate the performance of pan-sharpening algorithms

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Recently, Alparone et. al. proposed a QNR index to evaluate the joint quality of pan-sharpened image without using the original high resolution reference image. Their experimental results show that the QNR index for a pan-sharpened image, obtained by multiplying the multispectral image with a constant, is high compared to few other state-of-the-art techniques, which indicates that this index maybe biased to algorithms that preserve the spectral information. Moreover, the current technique for joint evaluation of spatial and spectral quality without reference does not allow to quantitatively associate importance to a particular image quality. Pan-sharpened images are useful in a wide variety of applications. Hence, giving quantitative importance to spatial or spectral quality, depending on the nature of target application, may be required to yield maximum benefit of pansharpening.

This work proposes a novel global index based on harmonic mean theory to jointly evaluate the performance of pan-sharpening algorithms without using a reference image. The harmonic mean of relative spatial information gain and relative spectral preservation provide a unique global index to compare the performance of different algorithms. The normalized average information divergence of pan-sharpened image and source multispectral image are used to measure the amount of spectral fidelity. Synthetic pan images are generated from the pan-sharpened and source multispectral images. Mutual information between the original pan and synthetic pan images is used to calculate the relative gain. The relative gain helps to quantify the amount of spatial information injected by the algorithm. The trend of the proposed index will be compared with other quality indexes using well-known pan-sharpening algorithms on high resolution (IKONOS and Quickbird) and medium resolution (LandSat 7 ETM) datasets.

6571-03, Session 1

Real-time object-based image registration using improved MRAN

Z. Yue, P. Narasimha, FastVDO LLC; K. Subbarao, M. T. Manry, The Univ. of Texas/Arlington; P. N. Topiwala, FastVDO LLC

The registration of images from cameras of different types and/or at different locations is of great interest for both military and civilian applications. Most available techniques are pixel level registration and use intensity correlation to spatially align pixels from the two cameras. Lots of computation is consumed to operate on each pixel of the images and as a result, it would be difficult to register the images in real time. Furthermore, images from different types of cameras may have different intensity distributions for corresponding pixels which will degrade the registration accuracy.

In this paper we propose to use improved Minimal Resource Allocation Network (MRAN) to solve the image registration problem from two cameras. Potential features are added to improve the performance of MRAN. There are two main contributions in this paper - First, weights going directly from inputs to outputs are introduced and these parameters are updated by including in the extended Kalman filter algorithm. Second, initial number of hidden units for the sequential training of MRAN are specified and the means of the initial hidden units are precalculated using Self Organizing Maps. The experimental results show that the proposed algorithm peforms very well both in speed and accuracy.

6571-04, Session 1

Convergence rate improvement in NMI-based multisensor image registration

J. H. Lee, J. B. Ra, Korea Advanced Institute of Science and Technology (South Korea)

Recently, a multi-sensor image fusion system is widely investigated due to its growing applications. In the system, robust and accurate multi-modal image registration is essential and the fast registration is required for many applications. This paper proposes a fast registration algorithm for multi-modal image sequences that are acquired from two different electro-optic (EO) and infrared (IR) sensors. In the registration of multi-modal images, a normalized mutual information (NMI) based registration algorithm is preferred due to its robust and accurate performance. However, it suffers from a high computational complexity in the optimization process. The downhill simplex optimization method is popular in NMI based registration because of its fast convergence rate. However, a reduction of computational complexity is still required in the method for (semi-)real-time applications. In this paper, we attempt to minimize the computational complexity in the registration process. We first modify the searching methodology for unconstrained function minimization in the ordinary downhill simplex algorithm. In the modified scheme, to reduce the number of function evaluations, we suggest new vertex movements related to the fast vertex contraction and the direction determination of succeeding simplex. We also minimize the function evaluation time by adopting the linearization process of the projective transformation model in the interpolation routine. Simulation results show that the proposed algorithm noticeably reduces the computational complexity by 30% compared to the conventional NMI based registration algorithm.

6571-06, Session 2

Cross-sensor fusion approach for visible and infrared imagery

M. Ouendeno, S. P. Kozaitis, Florida Institute of Technology

We used a method for combining cross-sensor image data that preserves sensor-unique characteristics of visible and infrared imagery. The basis of our approach is a set of forward wavelet transforms, optimized to preserve the individual information content of each sensor image followed by a common inverse transform that is designed to simultaneously preserve the most desirable information characteristics from each image after fusion. We used denoising methods in our reconstruction to reduce any errors introduced in the reconstruction process. Because of the unique nature of our approach we compared different fusion algorithms and reported on the results. We found that our approach could form the basis of fusion approach when information between sensors is correlated.

6571-07, Session 2

Real-time EO/IR sensor fusion on a portable computer and head-mounted display

Z. Yue, P. Topiwala, FastVDO LLC

Multi-sensor platforms are widely used in surveillance video systems for both military and civilian applications. The complimentary nature of different types of sensors (e.g. EO and IR sensors) makes it possible to observe the scene under almost any condition (day/night/fog/smoke). In this paper, we propose an innovative EO/IR sensor registration and fusion algorithm which runs real-time on a portable computing unit with head-mounted display. The EO/IR sensor suite is mounted on a helmet for a dismounted soldier and the fused scene is shown in the goggle display upon the processing on a portable computing unit. The linear homography transformation between images from the two sensors is pre-computed for the mid-to-far scene, which reduces the computational cost for the online calibration of the sensors. The system is implemented in a highly optimized C++ code, with MMX/SSE, and performing a real-time registration. The experimental results on real captured video show the system works very well both in speed and in performance.

6571-08, Session 2

Fusion and kernel type selection in adaptive image retrieval

A. Doloc-Mihu, V. V. Raghavan, Univ. of Louisiana at Lafayette

The goal of this work is to investigate the relationships between features representing images, fusion schemes for these features and kernel types used in an Web-based Adaptive Image Retrieval System. Using the Kernel Rocchio learning method, several kernels having polynomial and Gaussian forms are applied to general images represented by annotations and by color histograms in RGB and HSV color spaces. Different fusion schemes, which incorporate kernel selector component(s) based on score distribution models, are proposed and plan to be studied through experiments. Experimental tests on four image test collection are in progress, and we hope the results will offer useful insights on this issue.

6571-09, Session 2

Merging infrared and color visible images with an contrast enhanced fusion method

G. Li, K. Wang, Jilin Univ. (China)

We propose a contrast enhanced fusion (CEF) method for merging infrared and color visible images. The method transforms the original RGB color visible image into a perceptually decorrelated color space in order to treat the achromatic and chromatic components separately. The achromatic component and infrared image are combined by a grayscale fusion scheme, and the original achromatic component is replaced by the grayscale fused image. Before the data are retransformed back into the RGB color space, the means and variances between the original achromatic component and the grayscale fused image are matched by a linear remapping. The remapping procedure can fairly enhance the contrast of the final color fused image. We used the CEF method to merge long wave infrared and color TV images. The experimental results show that the proposed method can effectively produce a high-contrast color fused image with the similar natural characteristics as the original color visible image. In addition, we have also illustrated that hybrid of simple/complex CEF methods can be applied as a region of interest (ROI) image fusion solution, which allows ROIs to be fused with better quality than the rest of the original images.

6571-10, Session 3

Multisensor detection and fusion technique

A. Bhargave, B. E. Ambrose, F. S. Lin, M. I. Kazantzidis, Broadata Communications, Inc

A multi-sensor detection and fusion technology is described in this paper. The system consist of inputs from three sensors, Infra Red, Doppler Motion, and Stereo Video. This choice of sensors is designed to give high reliability, infra red and Doppler to provide detection ability at night, stereo video has the ability to analyze depth and range information. The combination of these sensors has the ability to provide high probability of detection and very low false alarm rate. The technique consists of three processing parts corresponding to each sensor data, and a fusion module, which makes the final decision based on the inputs from the three parts. The signal processing and detection algorithms process the inputs from each sensors and provides a specific information to the fusion module. Fusion module is based on bayes belief propagation theory. It takes the processed inputs from all the sensor modules and provides a final decision on the presence and absense of objects, as well as their reliability based on the iterative belief propagation algorithm operating on decision graphs. A prototype system was built using the technique to study the feasibility of intrusion detection for NASA's launch danger zone protection. The system verified the potential of the proposed algorithms and proved the feasibility of high probability of detection and low false alarm rates compared to many existing techniques.

6571-11, Session 3

A novel classification fusion technique for improved performance

T. Liu, G. A. Lampropoulos, G. Gigli, A.U.G. Signals Ltd. (Canada)

The objective of this paper is to present an innovative fusion technique to optimum fuse the classification results to improve the overall classification performance.

The key innovation is the transformation of static classifiers so that they adapt to their local clutter environment. This is the adaptation and extension of CFAR detection techniques that adjust both the clutter model and target model based on a sampling of the local data environment, so as to maintain the CFAR constraint. It will guide the development of similar approaches for classification. Based on the statistics of different classes, the confidence levels will be assigned to each pixel for all the classes. The confidence levels present the information that to what level we can trust this decision. The fusion will be processed using not only the decisions resulted from different classification algorithms, but also the corresponding confidence levels. There are two general approaches to using all the information. The first is linearly combining the decisions according to their confidence levels to optimize the final decision. The second approach is to treat all of the outputs as an intermediate feature space, regardless of the context, and then train a new classifier on this intermediate feature space.

Testing results using hyperspectral data will be presented. Confusion matrices will be given to show the performance enhancement. Applications in agriculture, forestry, mining and exploration, and the military will benefit from the proposed classification fusion system.

6571-12, Session 3

Classifier combination and feature selection methods for polarimetric SAR classification

G. Gigli, A.U.G. Signals Ltd. (Canada); R. Sabry, Defence Research and Development Canada (Canada); G. A. Lampropoulos, A.U.G. Signals Ltd. (Canada)

Training classifiers individually, and then fusing their results, has the potential to improve classification accuracy; often, dramatic improvements are realized. In this paper we examine how training classifiers using multiple polarimetric features such as the Cloude-Pottier decomposition, even and odd bounce and the Polarimetric Whitening filter and then fusing their results affects performance of ship classification. We explore and compare two currently competing technologies of classifier bagging and classifier boosting for classifier fusion and then detail and compare the results with a new approach which conducts a search through solution space to configure an optimal classifier given a library of classifiers and features. A related and important facet of this work is feature selection and feature reduction methods. We explore how the selection and removal of different features affects classification performance of the classifier fusion methods and contrast the efficacy of filter approaches using classifier bagging and boosting with the wrapper technique used by our new approach for classifier fusion. We also explore estimates of the classifier error and provide estimates for noise bounds on the data and compare performance of the different methods compared to the noise present in data.

6571-13, Session 3

Bayesian framework for ATR decision-level fusion experiments

D. R. Morgan, BAE Systems Advanced Information Technologies; T. D. Ross, Air Force Research Lab.

The US Air Force Research Laboratory (AFRL) Fusion for Identifying Targets Experiment (FITE) aims to determine the benefits of object-level or decision-level sensor fusion via stochastic system modeling and Monte Carlo simulation. This paper describes the Bayesian framework used in multiple aspects of the effort: the stochastic model of the overall fusion system is represented as a Bayesian network, the Bayes Net Toolbox (BNT) software package is being enhanced to support the system model, and multiple fusion algorithms, such as maximum a posteriori (MAP) and maximum likelihood (ML) processing, use Bayesian probability computations. Bayesian networks conveniently organize the large sets of random variables and distributions appearing in fusion system models, including the differing sets used in Monte Carlo instance generation and in the fusion algorithm computations.

6571-14, Session 3

Operating condition modeling for ATR fusion assessment

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Real world Operating Conditions (OCs) influence sensor data that in turn affects the performance of target detection and identification systems utilizing the collected information. The impact of operating conditions on collected data is widely accepted, but not fully characterized. OC's that affect data depend on sensor wavelength and associated scenario phenomenology, and can vary significantly between electro-optical (EO), infrared (IR), and Radar sensors. This paper will discuss what operating conditions might be modeled for each sensor type and how they could affect automatic target recognition (ATR) systems designed for their respective sensory data. The OC's are broken out into four categories; target, sensor, environment, and ATR algorithm training. These main categories will further contain subcategories with varying levels of influence. The purpose of this work is to develop an OC distribution model for the "real world" that can be used to realistically influence the performance of multiple ATR systems, and ultimately the decision made from the fused ATR results. An accurate OC model will greatly enhance the performance assessment of ATR and fusion systems.

6571-15, Session 4

A full-scale prototype multisensor system for fire detection and situational awareness

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The need for automated monitoring and assessment of events of interest within a space, such as chemical agent dispersal, toxic chemical spills, and fire or flood detection, has been a significant motivation for the development and use of multisensor, multicriteria sensing systems [1]. Such multimodal sensing platforms offer theoretical benefits over more conventional point detection systems in terms of robustness, sensitivity, selectivity, and applicability. Multimodal, spatially dispersed and network-enabled sensing platforms can generate complementary datasets that can be both mined with pattern recognition and feature selection techniques and merged with event-specific data fusion algorithms to effectively increase the signal to noise ratio of the system (an effect analogous to signal averaging) while also offering the potential for detecting a wider range of analytes or events. Additionally, such systems offer potential for resilience to missing data and spurious sensor readings and malfunctions that is not possible with individual sensing units. In this way, multimodal systems can provide faster and more accurate situational awareness than can be obtained with conventional sensor implementations. Finally, a spatially, or even geographically, dispersed array of networked sensors can provide the necessary platform flexibility to accommodate diverse configurations of fixed or mobile, standoff or point sensors to satisfy a wide range of monitoring and assessment needs.

Advances in communications and sensor technologies in recent years have made possible sophisticated implementations of heterogeneous sensor platforms for situational awareness. However, such networked multisensor systems present their own unique set of development and implementation challenges [2,3,4]. Care must be taken in selecting sensing modalities and sensors that provide complementary information appropriate to the sensing application being developed. A suitable network architecture and communications interface must be designed that is amenable to the differing data formats and interfaces typical of commercially developed sensors. To realize the benefits of a multimodal approach, sensor data must be combined and evaluated in a manner that enhances performance without increasing false positives [5]. These challenges are in addition to those common to conventional sensor implementations: developing pattern recognition and feature extraction algorithms tailored to multiple event recognition and implementing a real-time data acquisition and analysis and command and control framework for the sensing system.

NRL has recently developed a real-time, remote detection system, called "Volume Sensor," for damage control and situational awareness on U.S. Navy ships. The new system was developed under the Advanced Volume Sensor Task, an important element of the U.S. Navy's Office of Naval Research, Future Naval Capabilities, Advanced Damage Countermeasures (ADC) program, which seeks to develop and demonstrate improved damage control capabilities for reduced manning aboard future naval vessels [6]. The objective of the Advanced Volume Sensor Task was to develop an affordable detection system that could identify shipboard damage control conditions and provide real-time threat level information for events such as flaming and smoldering fires, explosions, pipe ruptures, flooding, and gas releases. Volume Sensor was designed to be a robust, low cost system that eliminated false alarms typical of fire detections systems in industrial environments.

The Volume Sensor uses a multisensor, multicriteria system approach combining low cost commercial-off-the-shelf (COTS) hardware components integrated with intelligent software and smart data fusion algorithms developed at NRL. A schematic diagram is shown in Figure 1. This effort took advantage of existing and emerging technology in the fields of optics, acoustics, image analysis and computer processing to add functionality to conventional surveillance camera installations planned for in new ship designs. A diverse group of sensing modalities and network components was chosen using criteria that emphasized not only their capability to provide pertinent damage control information, but also their cost and ability to be integrated into existing ship infrastructure. Various spectral and acoustic sensors, new video imaging techniques, and image recognition methods were investigated and evaluated. The down-selected sensing platforms were integrated into "sensor suites" that incorporated video cameras, long wavelength (near infrared) filtered cameras, single element spectral sensors, and human-audible microphones. A multisensory data fusion approach was used to provide overall detection capabilities for standoff identification of damage control events within shipboard spaces. Data fusion decision algorithms were used to improve event detection rates while reducing false positives and, most importantly, intelligently combine all available sensor data and information to provide the best possible situational awareness.

Implementation of this approach required the development of an efficient, scalable, and adaptable design framework. A number of challenges specific to multisensor systems were addressed during Volume Sensor development and were met with solutions that are applicable to heterogeneous sensor networks of any type. These solutions include: 1) a uniform, but general format for encapsulating sensor data, 2) a communications protocol for the transfer of sensor data and command and control of networked sensor systems, 3) the development of event-specific data fusion algorithms, and 4) the design and implementation of modular and scalable system architecture. These solutions are transferable to other monitoring and assessment applications such as the detection of chemical warfare agents and toxic chemicals and this approach to multisensor integration can serve as a template for heterogeneous sensor integration for situational awareness.

This paper describes the development and evaluation of the full-scale, multi-compartment prototype Volume Sensor. Two Volumes Sensor Prototype (VSP) systems were built and evaluated in a shipboard test series onboard the Navy's full-scale fire test facility, the ex-USS Shadwell [7]. The performance of the VSPs was compared to two commercial video image detection (VID) systems and three spot-type fire detection systems that were simultaneously evaluated. During this testing, the two prototype Volume Sensor systems demonstrated the capability to provide highly accurate and timely situational awareness regarding damage control events while simultaneously imparting a negligible footprint on the ship's 100 Mbps Ethernet network and

maintaining smooth and reliable operation in a real-time fashion. Analysis of test results has shown that the two VSPs demonstrated comparable or better fire detection performance to the commercial systems, with faster response times and excellent nuisance source immunity. The VSPs also demonstrated capabilities beyond those of the commercial systems, adding situational awareness for pipe ruptures and flooding scenarios, fire suppression system activations, and gas release events [8,9].

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6571-16, Session 4

A Markov game theoretic approach for cyber situational awareness

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There are increasing needs for research in the area of cyber situational awareness. The protection and defense against cyber attacks to computer network is becoming inadequate as the hacker knowledge sophisticates and as the network and each computer system become more complex. Current methods for alert correlation to detect and identify network attacks rely on data mining approaches that use features or feature sets of network data to discover an attack. These approaches are useful for simple attacks but for complex or coordinated cyber intrusions, they have various issues such as false positive, limited scalability, limits on detecting new types of attacks.

This paper proposes an innovative information fusion based situation awareness and impact assessment approach for cyber network defense. There are two main parts: data fusion module and dynamic/adaptive feature recognition module. Alters generated by Intrusion Detection Sensors (IDSs) or Intrusion Prevention Sensors (IPSs) are fed into the L0 and L1 data fusion components. The fused objects and related pedigree information are used by a feature/pattern recognition module to generate primitive prediction of intents of cyber attackers. If the observed features are already associated with adversary intents, we can easily obtain them by pattern recognition. In some time-critical applications, the primitive prediction can be used before it is refined by relatively time-consuming high-level data fusion.

High-level (L2 and L3) data fusion based on Markov game model and Hierarchical Entity Aggregation (HEA) are proposed to refine the primitive prediction generated in stage 1 and capture new unknown features. Markov (Stochastic) game method is used to estimate the belief of each possible cyber attack graph. Game theory can capture the nature of cyber conflicts: the determination of the strategies of attacking force is tightly coupled to the determination of the strategies of the defense force and vice versa. Also it can deal with the uncertainty and incompleteness of the available information.

The captured unknown or new cyber attack patterns will be associated to related L1 results in dynamic learning block, which takes deception reasoning, emotion reasoning, trend/variation identification, and distribution model and calculation into account. Our approach to deception detection is heavily based on the application of pattern recognition techniques to detect and diagnose what we call out-of-normal conditions in the cyber environment. The proposed emotion reasoning approach is mainly based on Peircean reasoning, which recognizes and articulates the human reasoning process as being comprised of three components; abduction, deduction, and induction. The results of dynamic learning or refinement shall also be used to enhance L2 and L3 data fusion. This adaptive process may be considered as level 4 data fusion (process refinement, see JDL model).

Simulation results are presented to illustrate the effectiveness of the Markov game theoretic data fusion approach for cyber situational awareness.

6571-17, Session 4

Hierarchical high-level information fusion technologies for detection of weapons of mass destruction in a Naval environment

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In this paper, the progression of Level 2/3 fusion of informational content to obtain an advanced multi-intelligent system for hierarchical high level decision making processes is introduced. The goal is the development of an information integration mechanism to simplify human decision making solving operational problems. As technology continues to advance, and the proliferation of sensors in all platform increases, the human decision makers are being overwhelmed with data. In this work, a novel approach in the near “real-time” detection of hypotheses in asymmetric warfare scenarios (i.e. urban warfare) is developed. In particular, we introduce a Hierarchical High Level Information Fusion Technologies architecture with the following objectives: 1) Create three stages of high level fusion (local, distributed and network centric) so that the amount of data transmitted between stages is minimized but remains complete and comprehensive; 2) Each stage will give the corresponding decision-maker the appropriate level of information; 3) Understand the difference and similarities of the different stages of fusion within each environment (ground, maritime and air); 4) Measure the gain and lose of transmitting higher level fused data among stages rather than Level 0/1 data; 5) Determine the loss of granularity versus the gain in communication efficiencies both from a bandwidth perspective as well as the human-in-the-loop; 6) Drive an optimization set of tools that will manage the sensors from the requirements of the fusion process (optional to this program); 7) Understand the advantages of a “pull-approach” rather than a “push-approach” in data gathering/fusion based on the ultimate needs of decision-makers. We assume all required Level 1 type sensor information is available a priori, so that the primary focus of the work is Level 2/3 fusion. The hypotheses are tested using a developed simulation software package with predefined evaluation metrics. The evaluation metrics include Level 2/3 fusion assessment tools using a realistic naval threat scenario example. The software model simulates a naval threat from an incoming vessel (such as a cargo ship containing a weapon of mass destruction), included in a group of non-threatening vessels, to access the Level 2/3 algorithm. The simulation package is used as an evaluation measure and performance platform providing an operational utility assessment tool. Although sensor data is assumed to be available the simulation package has the capability of delaying sensor information in time to model the lag in available sensor data.

6571-18, Session 4

Fusion of disparate information sources in a hybrid decision-support architecture

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Disparity of information sources presents both an opportunity and a challenge for decision-support systems. Many decision-making problems can benefit from - and some of them require - simultaneous consideration of multiple sources, dissimilar in terms of the semantics of the information they provide. These sources may be sensors of multiple modalities, collocated, spatially distributed, or both, as well as sources other than sensors (sometimes referred to as “context” in sensing systems). Inclusion of diverse information modalities offered by disparate sources - sensors or other types - offers the potential to improve decision-making performance beyond the level attainable by exploiting a single modality, and is particularly desirable in difficult decision-making tasks. However, fusion of disparate information sources is not straightforward and remains an open research topic.

Fusion of disparate and uncertain multisensor information in the setting of biodefense-oriented decision-making is the objective of our ongoing research program. Within this program, we have proposed and are developing a machine-intelligence based decision-support architecture termed FLASH (Fusion, Learning, Adaptive Super-Hybrid). The FLASH cognitive-processing architecture involves multiple machine-learning and reasoning paradigms, integrated in a cohesive hybrid-of-hybrids structure, as discussed in our previous papers. The current paper reports on the recent progress of the FLASH effort. The issues arising from disparate sensing modalities in a multisensor network environment are discussed. This includes tradeoffs involving the value of multiplicity and diversity of information sources, and the increased difficulty of the recognition problem due to the presence of such multiple sources. The issue of feature-level fusion vs. decision-level fusion is considered. The uncertainty estimation problem is investigated and the techniques for generation of uncertainty measures are presented. The background type determination aspect is discussed. Results to date are presented. The investigations and results presented are in the context of the bioattack detection application. However, the FLASH architecture and methods discussed in the paper are also relevant to other decision-support domains and tasks.

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6571-19, Session 4

Collective agents interpolative integral (CAII) for asymmetric threat detection

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Information fusion, as a field of modern information technology, assists military commanders by automating the process of combining multiple sets of lower level data from diverse resources into a single set of higher-level meaningful information that is greater than the sum of its contributing parts for complex situation assessment and decision making. To provide the US military substantially increased combat capabilities through aligned and integrated information presentation, situation assessments, and awareness, the agent-based data fusion and decision aid system needs to know and understand the relationships among diverse sets of data and the nature of their resources so as to combine them and produce an actionable result. However, there is a serious disparity in the way humans and automatic systems perform the intelligence analysis and data integration tasks. For example, most computational tools for handling information uncertainties are numeric and quantitative, whereas most human thinking in this aspect is symbolic and qualitative. Moreover, inference mechanisms on hybrid data sets often do not work together. Approximate inference, such as discretization, has serious limitations when applied to the data of geological or categorical symbols.

This paper presents a system for Asymmetric Threat Detection (ATD) through fusing large amounts of heterogeneous information collections. The research particularly addresses the near real-time fusion and aggregation of multi-source information by applying an interpolative inference technique, with the goal of revealing potential threat implications and explicitly quantifying the uncertainties of the situation. The system, called Collective Agents Interpolation Integral (CAII), addresses the high level data fusion processes by combining, in a mathematically sound manner, the information provided by sets of domain experts, called authorities. The authorities may be human operators, such as intelligence analysts, or software agents with an ability to characterize data from various resources (including sensors) autonomously. CAII can pool the judgments and evidence from a set of domain experts and generate a consensus opinion that reduces uncertainty and improves decision-making effectiveness.

One difficulty in the knowledge exploration process of information fusion is the overabundance of patterns; that is, even with proper statistics, it is too easy to find many significant knowledge patterns that are obvious, redundant, or useless. To remedy this situation, one may focus on the changes (because obvious patterns will not change), or incorporate rule-refining methods with domain knowledge and heuristics, as well as other techniques. However, as shown in the existing literature, to avoid the generation of too many pointless patterns, a simple but useful technique is to start the process by specifying what kind of knowledge is sought. In other words, users should be allowed to provide criteria (or some kind of task-oriented bias) as the original goal to guide the direction of discovery from data sets. It is clear that to successfully address the questions the agent system has to be equipped with multiple models for representing the data sets and for reasoning on the input data so as to properly evaluate the relevant hypotheses and generate correct outputs.

The use of the multi model approach in the modeling, analysis and control of non-linear complex and/or ill-defined systems was advocated by many researchers. This approach supposes the definition of a set of local models valid in a given region or domain. Different strategies exist based on a partitioning of the non-linear system’s full range of operations into multiple smaller operating regimes, each of which is associated with a locally valid model or controller. However, most of these strategies, which suppose the determination of these local models as well as their validity domain, remain arbitrary and are generally fixed with respect to certain a priori knowledge of the system. Meanwhile, the transition problem between the different models, which may use either a simple commutation or a fusion technique, is still pending.

The central problem of this research is to gather, analyze, and integrate vast amount of information from diverse data resources in various heterogeneous types and forms, and to distill from them the valuable intelligence leads or cohesions with respect to asymmetric threat detection. Under the setting of these requirements, CAII was positioned as an intelligent inference structure that accommodates integration of hybrid reasoning mechanisms with quantitative accounts of data certainties and source reliabilities. Key abilities of the CAII are to gather and combine evidences drawn from multiple sources and perform chains of reasoning processes. In this structure, the results of one reasoning process are fed as input to another reasoning process involving a different set of hypotheses and internal/external attributes. The incremental reasoning integration process enables more quickly recognizing critical situation and simultaneously evaluating/updating multiple action/reaction alternatives.

CAII uses a hybrid inference structure to handle the reasoning and information integration on disparate inputs. A major functionality of CAII is to perform multiple levels of probabilistic reasoning formulated in a multi-model structure of inference. A goal-directed agent autonomous pattern recognition approach is applied to deal with particular reasoning processes, which include three basic CAII functions: (1) Model definition - which refers to defining the functionals and constraints of the models using a priori knowledge and heuristics, (2) Model selection - which refers to identifying the models applicable to a given situation by using belief measurements such as the Kullback-Leibler (K-L) divergence and likelihood evaluations, and (3) Model integration - which refers to combining the results from individual models using belief combination techniques such as Dempster-Shafer theory and subjective logics to form a consolidated presentation. CAII provides the following tools and technologies leveraged for this effort: KR-Shell knowledge representation module, Inter-agent communication modules, Database Interface to WordNet, VisionAgentTM autonomous video surveillance module, Document characterization agents, and Social Network characterization agents. Agents in CAII are organized hierarchically, so there may exist multiple levels of agent authorities where each level is an agent that applies a consensus operation on the inputs of multiple information sources.

The paper will be organized as follows. After the introduction section I, we will discuss the problems and issues concerning with information fusion for asymmetric threat detection in section II. Section III describes the CAII system organization and its functionalities. The CAII functional modules and its multi-model inference structures are described in sections IV and V respectively. In section VI the multi-agent system architecture of CAII is presented. Section VII will demonstrate a prototypical implementation of the CAII with a scenario, an operating environment, and some running examples. Section VIII contains concluding remarks.

6571-20, Session 5

Real time data fusion of road traffic and ETC data for road network monitoring

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Transportation systems are motivated to obtain reliable information for monitoring and control operations. Providing real-time traffic information is one of the critical issues for the success of Intelligent Transportation Systems (ITS) programs and becomes a major challenge for public institutions and private companies (FHWA, 2003).

Many ITS applications, such as Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS), have been and are still developed in order to improve traffic performance and safety. They mainly rely on real-time data or, more precisely, indicators that are used to manage traffic flows, react on emergency cases, and inform road users. Nevertheless, most conclusions in the studies and researches of this field point out that the weak spot of such applications is the poor quantity and quality of real-time data available for input.

Different automatic data collection techniques are of potential use to apprehend traffic conditions and derive relevant indicators for user's information and guidance. The travel time is one of the forms in which this information is presented, and a number of systems are based on its dissemination. This raises the problem of estimating travel times with an acceptable degree of accuracy, within multiple data configuration. As a result, travel time estimation becomes a typical data fusion problem.

This paper concentrates on data fusion for Travel time using conventional data source and Electronic Toll Collection (ETC) data. The data fusion processes developed aim to provide a consistent and comprehensive picture of network conditions.

6571-21, Session 5

Real-time target tracking simulations in large disparate sensor networks

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A parallelized search based data fusion algorithm for large disparate sensor networks using a simulated annealing approach is presented. The simulated networks are composed of large numbers of low fidelity binary and bearing-only sensors, and small numbers of high fidelity position sensors, such as radars. The disparate networks can take advantage of low cost and high detection precision of the primitive sensors as well as high reliability of the expensive position sensors. The primitive sensors provide limited information, not sufficient to locate the targets; the position sensors can report both range and direction of the targets. The target positions are determined through fusing measurement information from all types of sensors. A score function, which takes into account the fidelity of sensors of different types, is defined and used as the evaluation function during the optimization search. The fusion algorithm is parallelized using spatial decomposition so the fusion process can finish before the arrival of the next sensor data. Simulations for real time target tracking are performed on a Linux cluster with communication between nodes facilitated by the Message Passing Interface (MPI). The networks have randomly distributed hundreds of thousands of primitive sensors and a few hundreds of position sensors over an 800 mile by 800 mile area. The probability of detection (POD), false alarm rate (FAR), and average deviation (AVD) are used in evaluating the network performance. The input target information for all the simulations is a set of target track data created from a theater level air combat simulation.

6571-23, Session 5

Prospects for dynamic ISR tasking and interpretation based on standing orders to sensor networks

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This research is intended to contribute to the development of automated and human-in-the-loop systems for higher level fusion to respond to the information requirements of command decision making. In tactical situations with short time constraints, the analysis of information requirements may take place in advance for certain classes of problems, and provided to commanders and their staff as part of the control and communications systems that come with sensor networks. In particular, it may be possible that certain standing orders can assume the role of Priority Intelligence Requirements. Standing orders to a sensor network are analogous to standing orders to Soldiers. Trained Soldiers presumably don't need to be told to report contact with hostiles, for example, or to report any sighting of civilians with weapons. Such standing orders define design goals and engineering requirements for sensor networks and their control and inference systems. Since such standing orders can be defined in advance for a class of situations, they minimize the need for situation-specific human analysis. Thus, standing orders should be able to drive automatic control of some network functions, automated fusion of sensor reports, and automated dissemination of fused information. We define example standing orders, and outline an algorithm for responding to one of them based on our experience in the field of multisensor fusion.

6571-22, Session 6

Distributed fusion and tracking in multisensor systems

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The goal of sensor fusion is to take observations of an environment from multiple sources and combine them into the best possible track picture. For simplicity, this is usually done by sending all measurements to a single node whose sole task is to fuse measurements into a coherent track picture. This paper introduces a new framework that does not rely on a single "full-awareness node" to fuse observations, but rather turns every sensor into a fusion center. Moving a network from a centralized to a distributed architecture complicates sensor fusion, but provides many tangible benefits. Since each sensor is both a source and a sink of information, the loss of any individual component means that only one of many possible information channels has been destroyed. In this paper, we discuss how to fuse both tracking and classification observations in a distributed network, and compare its performance to a centralized framework. Each track has both a kinematic state and a belief state associated with it. Components utilize the information form of the Kalman filter for kinematic tracking, while target type is determined using a hierarchical belief structure to determine object classification, recognition, and identification. Each component in the network maintains its own independent picture of the environment, and information is exchanged between components via a queued messaging system. This paper compares the performance of centralized architectures to distributed architectures, and their respective communication and computation costs.

6571-25, Session 6

Evaluating rank-score diversity to select fusion operations for SLAM

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In this paper, we evaluate the use of a rank-score diversity measure for selecting sensory fusion operations for a Simultaneous Localization and Mapping (SLAM) application. It has been shown in previous work that this measure is a useful criterion for selecting dynamically between a score-based and a rank-based sensory fusion, and for selecting which features to include in the fusion, when tracking multiple targets that can undergo mutual occlusions. Our current application involves robot mapping and navigation in an outdoor urban search and rescue situation in which we have many similar and mutually occluding landmarks. The robot is a 4-wheel direct drive platform equipped with visual, stereo depth and ultrasound sensors. In this paper, we report an expirement in which rank-score diversity was used to select a combination of visual input features, stereo depth information and ultrasound information as input to a SLAM algorithm. We informally review and evaluate some of the automatic fusion operation choices made during the experiment, and we present a performance comparison with use of a single, good fusion rule.

6571-26, Session 6

Maximum likelihood ensemble filter applied to multisensor systems

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Maximum Likelihood Ensemble Filter (MLEF) is an alternative deterministic ensemble based filter technique that optimizes a non-linear cost function along with a Maximum Likelihood approach. In addition to the common use of ensembles for calculating error covariance, the ensembles in MLEF are exploited to efficiently calculate Hessian preconditioning and the gradient of the cost function.

This study is divided into two segments. The first part presents a one sensor approach, were MLEF is compared to different filters using Lorenz 63 system. These filters are: Kalman Filter, Extended Kalman Filter, Ensemble Transform Kalman Filter, and Square Root Ensemble Kalman Filter.

The second part develops a multi-sensor system. Here we study a moving particle on an orbit obtained from the same Lorenz system. We analyze the information content of MLEF's ensemble subspace for each sensor and consider the effects of different number of ensembles on the fusion process.

In practice, when using ensemble based filtering techniques, a large ensemble size is required to obtain the best results. In this study we show that MLEF can obtain similar results using a smaller ensemble size by utilizing an information matrix, where essential characteristics are captured. This is a vital consideration when working with multi-sensor data fusion systems.

6571-27, Session 6

Digital terrain mapping from multispectral and high-resolution satellite data for defense studies

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Multispectral and High resolution satellite imageries increasing their resolutions capabilities in terms of spatial and spectral reflectance time to time some of these are LANDSAT, IRS, IKONOS and Digital Globe, these imageries are being used effectively and efficiently in certain applications, whereas to register spectral reflectance in different channels of electromagnetic spectrum is the prime characteristic of multi spectral satellite imageries. The real time nature of remotely sensed data can be of high value for mapping and analyzing surface terrain.

This paper explores the application of remote sensing analysis for terrain mapping from high and Multispectral satellite data, the accuracy of digital elevation model has been verified from various surface interpolation algorithms in which contour and point interpolation techniques were extensively used. The study reveals that digital interpretation has become more sharpened on a large scale and terrain mapping with high and multi spectral satellite data along with GPS Mobile mapper can be done for any region, through this paper it is proved that sensor can navigate army movements.

6571-29, Session 6

Assessing the value of information in a fuzzy cognitive map

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Fuzzy cognitive maps have been used as a technique for modeling the essential relationships that exist in a multi-sensor, multi-attribute, multi-decision environment. By qualitatively capturing the key cause-effect relationships that subject matter experts believe exist, whether "hard" data from a sensor or "soft" data from an analyst about the intent of an adversary, the map synthesizes, i.e. fuses, disparate data into usable knowledge and information about the emerging problem and the impact of various strategies on its resolution. A key feature of the inference process in a fuzzy cognitive map is that states of attributes are compared to states of attributes, allowing a variety of different types of data to be incorporated seamlessly without the need for a common metric. In many instances, not all data will be available when an inference is made. With any architecture for multi-attribute information fusion, it is important to understand how an outcome would change if additional data were available. In addition, the acquisition of additional data normally will have a cost, in both the time involved and the additional resources necessary, associated with it. The value of additional information then becomes assessing the impact it has on the outcome versus the cost associated with acquiring it.

In this paper, a technique will be presented for establishing the value of acquiring data on attributes unavailable at the time an initial inference is made from a fuzzy cognitive map. The technique involves three steps. In the first, an assessment is made of the reachability of unavailable attributes to the final outcomes. This involves determining whether a chain of causality from the attribute of interest to the outcome is present. If not, the attribute of concern can not affect the outcome and can be eliminated from further consideration. For those nodes that can affect the outcome dominance in the chains of causality are determined within the map. This is the second step in the process. If other paths dominate the chain of interest such that the attribute can not affect the outcome regardless of its value, then it can also be eliminated from further consideration. In the final step, assuming that the cost of acquiring the required information has been incorporated into the map, a determination is made of the value of having the additional data.

6571-30, Session 6

Sensitivity analysis of OWA operator with respect to the optimism degree

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The successful design of the Ordered Weighted Averaging (OWA) method as an aggregation operator depends on the efficient computation of its order weights. The most popular methods for determining the order weights are Quantifier Guided approach and the Minimal Variability method. These methods give different behavior patterns for OWA. This paper compares them by using Sensitivity Analysis on the outputs of OWA with respect to the optimism degree of the Decision Maker. Sensitivity Analysis requires different approaches for the different models. A case study is introduced concerning a water resources management problem. The Quantifier Guided approach gives more information about the behavior of the OWA outputs in comparison to the MV method. However in using the Minimal Variability method, the OWA has a linear behavior with respect to the optimism degree and therefore it has better computation efficiency.

6571-31, Session 6

Application of a static and dynamic united decoupling method for non-gyro inertial measurement unit

M. Ding, Q. L. Wang, C. Wang, Harbin Institute of Technology (China)

Most current inertial measurement units (IMU) use linear accelerometers and gyroscopes to sense linear the acceleration and angular rate of a moving body respectively. In a non-gyro inertial measurement unit (NGIMU), accelerometers are not only used to acquire the linear acceleration, but also replace gyroscopes to compute the angular rate according to their positions in three-dimension space. NGIMU has the advantages of anti-high g value shock, low power consumption, small volume and low cost. It can be applied to some specific occasions such as tactic missiles, intelligent bombs and so on.

Many scholars studied this technique deeply and acquired many fruitful achievements. They proposed many accelerometer configurations, algorithms and practical analysis. But few of them studied the coupling problem of the system, and also none of the static and dynamic decoupling methods is reported. A generalized definition of the coupling error is that the response of an actuation includes the additional information about the other actuation which would not affect the response. In a NGIMU system, the coupling error defines that the output of a single-axis accelerometer contains the additional information of other accelerometer in other direction. The coupling error is mainly arisen from the reasons of the location deviation of the sensing element in the accelerometer, the location deviation of the accelerometer in the design and the low manufacture level of the rigid body.

Also, when a NGIMU system is working, the static coupling error and the dynamic coupling error all exist. That is to say, the accelerometer output signal is coupled by not only the static signal but also the dynamic signal. The general decoupling treatment method is first to use the static decoupling to the accelerometer, and then the dynamic decoupling. The process is sequential, and the static decoupling method and the dynamic decoupling method make up of a serial network. This network makes the accelerometer signal processing complex to some extent.

In this paper, basing on a nine-accelerometer configuration of NGIMU and the definition of the coupling error, a new static and dynamic united decoupling method is applied to NGIMU. The method overcomes the complexity, which is aroused by using the static decoupling method and dynamic coupling method respectively, and simplifies the following processing system. Finally, a simulation case for estimating the error of the angular rate in three axes is investigated. The simulation results show that after the static and dynamic decoupling, the navigation precision is improved effectively. In addition, the method can be easily to extend to the coupling situation of many dimensions such as the situation that three accelerometers with different sensing directions are located at one point.

6571-33, Poster Session

Multisensor fusion of images for target identification

A. Muthukumar, G. Anitha, J. Shanmugam, Madras Institute of Technology (India)

Multisensor data fusion is an emerging technology applied to defense and non-defense applications. In this paper, a image fusion algorithm using different texture parameters is proposed to identify long-range targets. The method uses a semi-supervised approach for detecting single target from the input images. The procedure consists of three steps: Feature extraction, Feature level fusion and Sensor level fusion. In this study, two methods of texture feature extraction using co-occurrence matrix and run-length matrix are considered. Texture parameters are calculated at each pixel of the selected training image, and target nontarget pixels identified manually. Some of the texture features calculated at the target position differ from those in the background. Discriminant analysis is used to perform feature level fusion on the training image, which classify target and non-target pixels. By applying the discriminant function to the feature space of textural parameters, a new image is created. The maxima of this image correspond to target point. The same discriminant function can be applied to the other images for detecting the trained targets regions. Sensor level fusion combines images obtained from feature level fusion of visual and IR images. The method was first tested with synthetically generated images and then with real images. Results are obtained using both co-occurrence and run-length method of texture feature extraction for target identification.

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6572-01, Session 1

DSP-enabled coherent optical communications

G. Goldfarb, G. Li, College of Optics & Photonics/Univ. of Central Florida

Digital Signal Processing has recently been used in conjunction with homodyne phase diversity receivers to allow demodulation of various modulation formats. Digital signal processing allows laser phase noise estimation (thus avoiding the need for a phase-locked-loop). Moreover, finite/infinite impulse response filters may be used to provide first-order chromatic dispersion compensation. The different techniques used for phase noise tracking and dispersion compensation are presented in this paper. Experimental results are provided to demonstrate the feasibility of use of digital signal processing to achieve signal demodulation and impairment mitigation using coherent detection.

6572-02, Session 1

All-optical carrier phase and polarization recovery for coherent optical communications

I. Kim, K. A. Croussore, X. Li, G. Li, College of Optics & Photonics/Univ. of Central Florida

Polarization insensitive all-optical carrier recovery scheme from BPSK data is proposed and demonstrated in experiment for the first time. The proposed scheme uses a degenerate optical parametric oscillator built with phase sensitive amplifier.

6572-03, Session 1

Coherent optical receiver with widely tunable local oscillator laser

C. Wree, D. Mohr, D. A. Becker, A. M. Joshi, Discovery Semiconductors, Inc.

Recently, there has been a renewed interest in coherent optical detection. The reasons for this are: a) coherent optical receivers achieve high receiver sensitivities; b) multilevel modulation formats can be detected very efficiently; c) optical WDM systems with high spectral efficiency can be implemented; and d) preservation of the optical phase allows electrical equalizers to efficiently compensate optical channel impairments. These advantages of coherent optical detection over direct detection can be used to overcome some of the obstacles that limit the data capacity and the reach of current direct detection systems, both fiber and free-space based.

The essential part of the coherent optical receiver is the optical local oscillator (LO) laser. It has to provide a high optical output power with low linewidth and low relative intensity noise (RIN). With a widely tunable LO laser a frequency-agile receiver can be constructed.

To determine the best candidates for tunable LO lasers, different laser technologies are discussed in terms of output power, power variation, electrical power dissipation, switching time, control leads, package dimensions, tuning range, linewidth and RIN.

A heterodyne receiver to detect 10 Gb/s signals has been implemented with a standard distributed feed back (DFB) laser. Upgrades of the coherent receiver with a widely tunable LO will be presented. Experimental comparison of the LO lasers and their impact on the receiver sensitivity will be shown.

6572-04, Session 1

All-optical phase and amplitude regeneration of phase-shift keyed signals

K. A. Croussore, G. Li, College of Optics & Photonics/Univ. of Central Florida

All-optical regeneration of phase-shift keyed (PSK) signals is described theoretically and demonstrated experimentally. Differential phase-shift keyed (DPSK) signals can be processed with phase-sensitive amplifiers (PSAs) based on either 2nd or 3rd order optical nonlinearities. Simulations predict, and experiments confirm these devices are capable of providing simultaneous phase-and-amplitude regeneration. The improvement in both amplitude and phase noise properties by PSA-based regeneration is analyzed for various device architectures. Higher order PSK signals such as quadrature phase-shift keying (QPSK) can not be processed with conventional PSAs, since these will inherently destroy information encoded in the quadrature-phases. The amplification and regeneration of these formats using novel forms of phase-sensitive amplification is therefore studied theoretically and through numerical simulations, using QPSK as an example.

6572-05, Session 1

1310 nm WDM transmission of differential phase-shift keying (DPSK) signals using semiconductor optical amplifiers

X. Li, G. Li, College of Optics & Photonics/Univ. of Central Florida

We demonstrated multi-wavelength transmission of DPSK signals in the 1310 nm window using bulk semiconductor optical amplifiers (SOAs) as booster, in-line and pre amplifiers. Quantum-dot SOAs (QD-SOAs) can potentially be used to improve the performance of such transmission systems.

6572-06, Session 2

40GHz optoelectronics polyphase analog to digital converter

C. Villa, Univ. of Connecticut; M. J. Hayduk, R. J. Bussjaeger, Air Force Research Lab.; E. J. Donkor, Univ. of Connecticut

We demonstrate a novel scheme for optoelectronic analog-to-digital converters based on a parallel connection of single decimation electro-optical stages. A single decimation stage consists of a self-synchronizer optical circuit that uses a main optical clock (optical pulses) to generate three optical signals: a primary optical signal having a repetition rate f, and two secondary optical signals each having a repetition rate of f/2. One of the secondary signals is in phase with the even optical pulses of the primary signal, whereas the other secondary signal is also in phase with the odd pulses of the primary signal. The primary signal is used to sample the RF input signal to generate an electrical sampled signal with sampling rate of f. Thereafter, the two secondary optical signals are used to further sample the odd and even pulses of the sampled RF signal. This second sampled step fold down the sampling rate to f/2, and relax the speed requirements for the quantizers. By connecting such single stages in parallel and then delaying the main optical clock pulses relative to each one, we are able to switch an array of reverse bias photodiodes to generate a group of polypahse sampled signals that are in turn fed to interleaving electronics quantizers.

[In this way] Our scheme can currently achieve sampling rates of up to 40 GHz with a relaxed quantization rate of 5GHz for interleaving electronic quantizers. Experimental results for 8 bits of resolution quatizers were obtained.

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6572-07, Session 2

Programmable microwave transversal filter using acousto-optic tunable filtering

F. N. Ghauri, N. A. Riza, College of Optics & Photonics/Univ. of Central Florida

To the best of our knowledge, for the first time, Programmable broadband Radio Frequency (RF) filters are demonstrated using a compact retro-reflective optical design using an Acousto-Optic Tunable Filter and a Chirped Fiber Bragg Grating. This design enables fast microseconds domain analog-mode control of RF filter time delays and weights. Two proof-of-concept filters are demonstrated including a two-tap notch filter and a 4-tap band-pass filter. Both filters can have Microwave band tunability and a microseconds domain reset time.

6572-08, Session 2

Control of an adaptive, ultra wideband arrays using time reversal

H. Zmuda, Univ. of Florida; R. J. Bussjaeger, AFRL; R. K. Erdmann, M. L. Fanto, M. J. Hayduk, J. E. Malowicki, Air Force Research Lab.

This paper presents the optical implementation of a new method for dynamic, adaptive control of a microwave phased array antenna. It is well established that optical signal processing methods provide the antenna array designer with unique capabilities generally not available using conventional microwave techniques. When compared with an all-microwave approach, the utilization of optical components, especially the incorporation of low loss optical fiber, can provide significant reduction in the size and weight of the system as well as providing a high degree of immunity to electromagnetic interference (EMI) and electromagnetic pulse (EMP) effects making them attractive for use with secure communications and in electromagnetically rich environments. More importantly, however, the extremely broad microwave bandwidth generally associated with photonic systems allows for antenna control and processing with RF/microwave bandwidths that are unobtainable using all-microwave processing.

Most beamforming systems extant, optically-based or otherwise fall into one of two categories; delay-and-sum beamforming or Fourier-based beamforming. Problem posed by these systems include an a-priori knowledge of the exact position of where one wishes to steer the array, precisely specified stable antenna array locations, difficulty in specifying and generating antenna stable nulls to counteract the effect of interference, and very significantly the inability to account for how atmospheric effects influence array control. This paper examines what can be viewed as a paradigm shift in array beamforming with its associated optical implementation. First, an RF pulse is transmitted from any one array element, with all other elements set to operate in the receive mode. The backscattered signal(s) from the desired location is captured by each array element and is then used to modulate a pulsed laser source. An electrooptic switch acts as a time gate that can eliminate any unwanted signals such as those reflected from other targets whose range is different from that of the desired transmit/receive location. A chromatic dispersion processor is used to extract the exact array parameters of the received signal location. Hence, other than an approximate knowledge of the steering direction, needed only to approximately establish the time gating, no knowledge of the target(s)'s position, and hence no knowledge of the array element time delay is required. The process is repeated at a rate determined by the repetition rate of the pulsed laser source. Target and/or array elements motion is automatically accounted for in the adaptation process while also automatically compensating for atmospheric aberrations.

This paper will present the details of the photonic processor, analytical justification, and simulated as well as preliminary experimental results. The operation of the system with application to microwave array antennas, laser radar, and arbitrary waveform generation will be presented.

6572-09, Session 3

Chirp control via differential pumping of a monolithic passively mode locked quantum dot laser

K. C. Brown, B. Wysocki, M. L. Fanto, J. E. Malowicki, Air Force Research Lab.

A monolithic two section quantum dot semiconductor laser is differentially pumped creating nonuniform current injection in the gain region. We show that the type and amount of chirp in the output signal can be controlled using this differential pumping method, despite the fact the separately pumped gain regions are not electrically isolated in this device. Both negative (red-shift) and positive (blue shift) frequency chirps were observed during mode-locked operation and their effects on pulse duration and peak power are analyzed. In addition, it is demonstrated that mode locked operation under an expanded set of injection current and absorber bias voltage pairs are possible which were previously not available with single pad current injection.

6572-10, Session 3

Low noise, optical frequency stabilized, semiconductor-based frequency comb source for coherent communication and signal processing

F. J. Quinlan, S. Gee, S. Ozharar, P. J. Delfyett, Jr., College of Optics & Photonics/Univ. of Central Florida

A semiconductor based, 10.24 GHz repetition rate mode-locked laser with an OSNR \> 40 dB, optical frequency instability less than 1 MHz, linewidth less than 100 kHz and 7.5 fs of timing jitter (1 Hz - 100 MHz) is demonstrated. Estimations of the noise out to the Nyquist frequency lead to a total jitter (1 Hz - 5.12 GHz) under 30 fs. The introduction of dispersion compensating fiber into the laser cavity increased the optical bandwidth to 2 THz with a timing jitter of 11.4 fs (1 Hz - 100 MHz).

6572-11, Session 3

Ultrastable harmonically mode-locked erbium-doped waveguide laser

M. L. Fanto, J. E. Malowicki, R. K. Erdmann, B. Wysocki, T. McEwen, Air Force Research Lab.

Generation of stable pulses and a frequency stabilized optical comb are two key requirements for Fourier Based Arbitrary Waveform Generation (AWG) techniques. The longitudinal mode spacing of the laser must remain as stable as possible to permit effective isolation and processing of the modes for waveform synthesis. The short and long term temporal stability ultimately limit the system's precision as well as its operability in fielded systems. A packaged erbium-doped waveguide provided a highly compact gain medium for the harmonically mode-locked laser design. Stability was achieved by use of an intracavity etalon for frequency stabilization of the optical comb, a Pound-Drever-Hall (PDH) method, and an active bias feedback loop for low frequency noise suppression. The temperature was controlled to limit cavity length variation, and the contribution to stability of each method is quantitatively assessed. The system's stable operating time was increased from hours to days, and the timing jitter is demonstrated to be lower than that of commercially available erbium-doped fiber laser (EDFL) systems. Applications to metrology, optical signal synthesis, and Laser Radar are briefly discussed.

6572-12, Session 3

High stability, PLC-based broadband Er-ASE sources for integrated inertial navigation devices

S. V. Frolov, J. Shmulovich, A. J. Bruce, Inplane Photonics, Inc.

No abstract available

6572-13, Session 4

Multimode fibered photodetectors for high-power high-speed applications beyond 10 Gb/s

R. L. Howard, 7th Edge, LLC; A. M. Joshi, D. A. Becker, Discovery Semiconductors, Inc.

Multimode fiber collects more light without sacrificing speed or sensitivity in applications requiring up to 4o GHz optical bandwidth. The combination of a top illuminated planar InGaAs PIN diode with laser optimized multimode fiber, 50 or 62.5 um core, are finding new applications which require high speed and high optical power. We present data to characterize MMF photodetectors for applications in Free Space Optics, LIDAR, Optical A/D, Optical Backplane, and directly modulated VCSEL Laser development.

6572-14, Session 4

FOCUS: toward a high-gain and high-speed single photon detector

H. Mohseni, O. G. Memis, S. Kong, A. Katsnelson, Northwestern Univ.; S. Zhang, N. Jin, I. Adesida, Univ. of Illinois at Urbana-Champaign

We present the latest performance of our novel Focalized Carrier Augmented Sensor (FOCUS). The principal operation of this device is inspired from the eye's rod cell, and involves compression of photo-generated charges into a nano-meter size injector. The device is based on InP material system, and is processed using conventional e-beam and photolithography, dry-etching, metallization and planarization techniques. The large change of potential that is resulted from the condensed charge in the nano-injector leads to a significant change of the injected current. Therefore, the device shows a very high gain at low bias values of around 1 volt. Unlike avalanche photodiodes, the absence of the bi-carrier gain eliminates excess noise in FOCUS, and the device shows shot-noise limited performance. Also, the absence of avalanche multiplication makes the recovery time of FOCUS much faster than the avalanche photodiodes. We could measure an instrument limited recovery time of a few nanoseconds that is more than three orders of magnitude shorter than conventional avalanche single photon detectors.

6572-15, Session 4

InGaAsP avalanche photodetectors for non-gated 1.06 um photon-counting receivers

M. A. Itzler, X. Jiang, R. Ben-Michael, K. Slomkowski, Princeton Lightwave Inc.; M. A. Krainak, S. Wu, X. Sun, NASA Goddard Space Flight Ctr.

The efficient detection of single photons at 1.06 um is of considerable interest for lidar/ladar systems designed for remote sensing and ranging as well as for free-space optical transmission in photon-starved applications. However, silicon-based single photon avalanche diodes (SPADs) used at shorter wavelengths have very low single photon detection efficiency (~1 - 2%) at 1.06 um, while InP/InGaAs SPADs designed for telecommunications wavelengths near 1.5 um exhibit dark count rates that generally inhibit non-gated (free-running) operation. To bridge this "single photon detection gap" for wavelengths just beyond 1 um, we have developed high performance, large area (80 - 200 um diameter) InP-based InGaAsP quaternary absorber SPADs optimized for operation at 1.06 um and based on a highly reliable planar geometry avalanche photodiode structure. We will show that dark count rates are sufficiently low to allow for non-gated operation while achieving detection efficiencies far surpassing those found for Si SPADs. At a detection efficiency of 10%, 80 um diameter devices exhibit dark count rates below 1000 Hz and photon counting rates exceeding 1 MHz when operated at -40 C. Significantly higher detection efficiencies (30 - 50%) are achievable with acceptable tradeoffs in dark count rate. In this paper, we will also discuss performance modeling for these devices and compare their behavior with longer wavelength (~1.5 um) InP-based InGaAs ternary absorber SPADs fabricated on a related device design platform.

6572-16, Session 4

Linear-mode single photon counting APD arrays with subnanosecond, afterpulse free performance for ladar, spectroscopy & QKD applications

L. A. Aina, A. M. Fathimulla, H. S. Hier, M. Lecates, R. Dwarkin, D. Johnson, Epitaxial Technologies, LLC; S. Babu, NASA Goddard Space Flight Ctr.; J. J. Foshee, Air Force Research Lab.

Long range ladar, spectroscopy and quantum key distribution systems require single photon photoreceivers with subnanosecond and real time performance free of afterpulsing to meet the stringent requirements for long range, high count efficiency and high sensitivity. Currently available single photon detectors are either incapable of subnanosecond photon counting, have low quantum efficiency and/or have poor reliability. For example, Geiger mode APDs can at best count single photons in long pulse durations and are not capable of multiple counts between resets. In addition, other types of photoreceivers, have the drawback of relatively large size, weight and power, high deployment costs and poor reliability, which make them unsuitable for DoD platforms such as UAVs and missiles.

Epitaxial Technologies has developed a single photon counting photoreceiver that can operate in the linear mode to avoid the drawbacks of Geiger mode detectors. The Company's linear single photon counting photoreceiver array technology is based on cascading optical amplifiers on-chip with APDs to enable single photon capability below the APD breakdown voltage through ultra-low noise gain and preamplification. We have already demonstrated components for this photoreceiver that when implemented will have single photon sensitivities for subnanosecond pulses with high photon counting efficiency and without afterpulsing at 1064 and 1550-nm.

This paper will describe the implementation and the characteristics of the photoreceiver . Details, including system concepts, photoreceiver architecture, design, implementation, and performance data will be presented. Application of this technology to various DoD and NASA programs, as well as to commercial systems will also be discussed.

6572-17, Session 4

Multipurpose sensor fusing near infrared, visible, and communications wavelengths in a single camera

J. E. Nichter, Air Force Research Lab.; B. M. Onat, Goodrich Corp.

A multipurpose sensor that covers the visible wavelengths as well as the near infrared and communications wavelengths fusing wavelength functions in a single camera. The imagery can be used for Optical Communications, LIDAR/LADAR, and homeland defense. Daytime operation (through fog) and ambient night glow in the SWIR enables passive night vision imaging and active illumination at 1.55 µm is COVERT to night vision goggles (NVGs), yet the camera is sensitive to NVG illuminator wavelengths (~ 850 nm)

The short-wave infrared (SWIR)/visible camera comprised of a 640 X 512 InGaAs photodiode array (PDA) on a 25 µm pitch, hybridized to a Capacitive Transimpedance Amplifier (CTIA) read-out integrated circuit (ROIC), capable of range-gated imaging applications with a minimum integration time approximately 0.5 * S, high-speed imaging, staring-mode readout, and windowing from the full 320x256 down to 4x4 pixels The PDA substrate was removed via a unique processing technique, adding sensitivity to visible wavelengths in addition to the SWIR. The very short integration times can be used for range-gated imaging, allowing objects in a very tight range of interest to be viewed.

ROIC is mated with an InGaAs array that has been substrate removed for visible and short-wave infrared response. The ROIC design uses a CTIA with two selectable integration capacitors in each pixel - one very small (10 fF) and one of moderate size (100 fF). This allows the camera to operate in bright light as well as dark conditions.

6572-18, Session 5

MIT/LL development of broadband linear frequency chirp for high-resolution ladar

K. W. Holman, Massachusetts Institute of Technology

No abstract available

6572-19, Session 5

Frequency shifted optical pulses for range detection

S. Ozharar, S. Gee, F. J. Quinlan, P. J. Delfyett, Jr., College of Optics & Photonics/Univ. of Central Florida

Frequency shifted optical pulses are generated both via a composite cavity structure in a fiberized semiconductor optical amplifier ring laser and via a frequency shifting loop outside the laser cavity. The technique is similar to rational harmonic mode-locking, however it is based on cavity detuning rather than frequency detuning. These frequency shifted pulses are ideal for range detection applications since their interference results in a range dependent RF signal.

6572-20, Session 6

Advances in PLC technology for highly integrated photonic components in avionic and space network

J. Shmulovich, S. V. Frolov, A. J. Bruce, Inplane Photonics, Inc.

No abstract available

6572-21, Session 6

Fabrication and testing of laser communication terminals for aircraft

J. A. Cunningham, D. Foulke, T. Goode, D. Baber, M. E. Gangl, M. Fletcher, D. Hopf, D. S. Fisher, D. S. Grinch, D. Jeri, ITT Industries

Laser communication terminals have been developed which can be integrated into an aircraft or used in a ground station for transmitting 2.5 Gbps data between aircraft or from an aircraft to ground. The terminals were built under the Air Force Research Laboratory's EO Sensor Technology & Evaluation Research (ESTER) program. System design allows for link ranges greater than 100 km for aircraft at altitudes of 30,000 ft or greater. The terminals operate full duplex and interface to third party equipment via industry standard optical or electrical gigabit Ethernet or through a custom interface. A gimbal houses the free space optics hardware and is mounted externally to the aircraft. Electronics and laser modules are located internal to the airframe at a distance of up to 30 feet from the gimbal. GPS, an integrated INS and a laser-beacon are used for pointing and tracking.

Progress on the construction and integration of this system will be presented in this paper including the results of three field tests conducted during 2006.

6572-22, Session 6

Highly-integrated, VCSEL-based optoelectronics for fault-tolerant, self-routing optical networks

P. S. Guilfoyle, D. A. Louderback, K. Yang, K. M. Patel, X. Jin, J. Cheng, OptiComp Corp.

The demand for bandwidth and interconnectivity in aerospace and other defense networks and systems continues to expand. To meet this demand while still satisfying the unique requirements of these systems, innovative approaches are needed. For future networks to meet these goals, they will need to have high bandwidths that are scalable to the requirements of particular applications. In addition, the networks need to be very fault tolerant, protocol independent, non-blocking, low latency, and have low power consumption and small size. OptiComp Corporation has developed a unique network architecture where the hardware is distributed across the network, allowing the network to be self routing and highly fault tolerant. This network architecture is enabled by OptiComp's integrated optoelectronic technologies including waveguide coupled VCSELs and detectors, compact WDM, SOAs, and hybrid integration.

Waveguide grating couplers that enable a VCSEL to be coupled bidirectionally into an internal waveguide and allow a portion of the light in a waveguide to be tapped off to a detector comprise the core of OptiComp's integrated optoelectronics. This on-chip coupling into and out of a waveguide enables coarse WDM multiplexing and demultiplexing to be accomplished in a very small area with no additional packaging, making the structure more compact and rugged. Waveguide coupled device results will be presented, including high-speed data transmission between waveguide coupled VCSELs and detectors. Preliminary results on waveguide coupled WDM components will also be discussed. In addition to the enabling components, the implementation of the network architecture will also be presented.

6572-23, Session 7

A 1x3 optical switch by carrier induced beam-steering on InP

D. May-Arrioja, N. Bickel, P. LiKamWa, College of Optics & Photonics/Univ. of Central Florida

Local area zinc diffusion is used to precisely define the locations and depth of p-n junctions through which electrical currents are injected in a planar multiple quantum well waveguide structure. These electrical currents are used to confine an optical beam into a guided mode that is then steered onto one of three single mode waveguides. The total current needed to perform the optical beam steering is about 20mA and the cross-talk between the output waveguides is better than -17dB. The device operated under these conditions over a wavelength range of 50nm centered around a wavelength of 1565nm. The average on-chip insertion loss from input waveguide to output waveguide was 3.3dB when the optical beam was steered to the center output waveguide and 3.6dB when the beam was guided one of the edge output waveguides.

6572-24, Session 7

Programmable fiber-optic splitters using distributed optical MEMS

N. A. Riza, S. A. Reza, College of Optics & Photonics/Univ. of Central Florida

To the best of our knowledge, for the first time, programmable fiber-optic splitters are demonstrated using a compact distributed optical MEMS and low loss fiber-optics. This design enables precise power splitting ratios and low loss designs. Various proof-of-concept splitters are demonstrated including 50:50 and 90:10 tap ratios. Both splitters can have broad optical bandwidths and fast reset times.

6572-25, Session 7

Non-contact no-moving parts surface height measurement sensor using liquid crystal optics

N. A. Riza, M. A. Sheikh, College of Optics & Photonics/Univ. of Central Florida

Non-contact height or profile sensors are important when designing critical optical components. To the best of our knowledge, for the first time, this paper reports on an analog liquid crystal lens-based axial scanning confocal microscope that is demonstrated as a continuous range optical height measurement sensor used to characterize optical waveguide chips.

6572-26, Session 7

Simulation and analysis of ultrafast laser pulse induced plasma generation in dielectric materials

J. R. Gulley, S. W. Winkler, W. M. Dennis, The Univ. of Georgia

Recent experiments on optical damage by ultrashort laser pulses have demonstrated that the temporal pulse-shape can dramatically influence plasma generation in fused silica and sapphire. In this work a modified 3-D nonlinear Schrödinger equation for the pulse propagation coupled to a rate equation for the plasma density in the dielectric material is used to simulate pulse propagation and plasma formation in a range of dielectric materials. We use these simulations to analyze the influence of pulse-width, pulse-shape and beam geometry on the formation of the electron plasma and hence damage in the bulk material. In particular, when possible, we simulate the effect of pulses reconstructed from experimental data. It is expected that a better understanding of the dynamics of laser-induced plasma generation will enable the accurate simulation of optical damage in a variety of dielectrics, ultimately leading to an enhanced control of optical damage to real materials and optical devices.

6572-27, Poster Session

Pulse shape effects on the measurement of temperature using a Brillouin-based optical fiber sensor

C. A. Galindez, A. Cobo, O. M. Conde, F. J. Madruga, J. M. López-Higuera, Univ. of Cantabria (Spain)

Distributed fiber sensing based on Brillouin gain scattering (BGS) principle is a useful way to develop devices capable to measure temperature or strain in optical fibers. A device or a new configuration that could achieve a larger distance and/or a better spatial resolution is a topic of special interest in the distributed fiber sensing field. Due to this situation, in this paper it is presented the influence of the probe-pulse shape in the interaction between the pulsed light and the continuous wave laser in a pump-probe system with the purpose of improving the spatial resolution of the measurement without losing stability in the BGS measured. It is also showed how the backscattering Brillouin gain is affected by inducing variations on the final value of the BGS intensity measurements. This effect is illustrated by using an experimental set up based on the Brillouin optical time-domain analysis (BOTDA). Theoretical analysis of the probe pulse in the Brillouin shift and intensity value using triangular, sinusoidal and saw tooth shapes around the medium phonon lifetime (~10ns) are presented; experimental results and possible applications are also explained.

6572-28, Poster Session

Characterization of new thermo-responsive hydrogels for optical sensing applications

J. Rueda, K. Contreras, R. Coello, Pontificia Univ. Catolica del Peru (Peru); M. Lomer, Univ. de Cantabria (Spain); H. Komber, S. Zschoche, B. Voit, Leibniz-Institut für Polymerforschung Dresdene e.V. (Germany)

We report the use of new hydrogels based on poly-N-isopropylacrilamide and MeOXA in order to measure temperature using optical transmittance. We have obtained thermo-responsive hydrogels based on the radical copolymerization of N-isopropylacrylamide (NIPAAm) and bis-macromonomers of 2-methyl-2-oxazoline (MeOXA). The hydrogels show conformational transitions at defined temperatures, which are a function of the molar ratio NIPAAm / MeOXA inside of the hydrogel. The temperatures of transition have been determined by means of 1H NMR spectroscopy and by turbidity measurements using an optical setup with optical fibers and a diode laser. We show first experimental results and we discuss some future applications such as an optical switch or a device for optical sensing.

6572-29, Poster Session

Singlemode photonic crystal fiber for the middle infrared

L. N. Butvina, O. V. Sereda, E. M. Dianov, General Physics Institute (Russia); N. V. Lichkova, V. N. Zagorodnev, Institute of Microelectronics Technology (Russia)

We report the design, fabrication and optical characterization of a microstructured crystalline optical fiber from silver halide. The fiber was extruded from a preform with 18 inserted rods of lower refractive index that form two ring structure in a hexagonal pattern. The fiber core size was approximately 79 µm. Both experimental and theoretical evidences are presented to establish that the fiber is effectively singlemode at wavelength 10.6 µm with numerical aperture NA = 0.16. The near field and far field mode distributions showed no evidence of the structure associated with higher-order modes. Optical losses measured by cut-back method were ~ 2 dB/m . Crystalline microstructured optical fibers offer key advantages over step-index optical fibers from silver halide crystals because they may be designed polarization-maintaining and with large mode field area. Silver halide crystals have the wide transmission range of wavelengths 2-20 µm, so microstructured crystalline fibers have strong potential for power delivery of CO2 and quantum cascade lasers (QCL) to inaccessible places giving an opportunity to develop laser-based infrared sensor systems that will have improved performance with reduced weight, volume and power consumption. There is also a promising possibility of application of microstructured crystalline fibers as effective modal wavefront filters with broadband single-mode behavior in 4-20 µm.

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6573-35, Poster Session

Quantum properties that are extended in time

J. Tollaksen, George Mason Univ.

This article focuses on “time-extended” properties that quantum mechanics represents as existing at a given moment, but which cannot be measured at a given moment.

Several novel examples are presented in which energy cannot be measured in a short time. The essence of these examples is an attempt to measure the momenta (or the energy) of an ideal quantum clock by having an interaction that lasts only a short time, where this short time is defined with respect to the internal time which is conjugate to this momenta. However, this momenta and this time cannot both be definite at once. Nevertheless, the momenta can be definite at a definite external parameter time, rather than this internal time. From the internal perspective, however, it is shown that the energy cannot be defined at a given internal time and therefore, this aspect of “time-extension” is completely quantum in origin, unlike the classical aspect of “energy is frequency.”

An additional consequence of time extended properties is that the uncertainty is increased for the internal time before and after the energy measurement. This suggests that the complementarity between energy and time is deeper than the notion that precise measurements of energy take a long time.

Going beyond the “negative” statements about what cannot be measured (which characterize most of the discussions of the energy-time uncertainty relation), a positive aspect of Delta E Delta t \> 1 is demonstrated in a closed system based on causality. This positive aspect is related to a general approach for discovering efficient quantum algorithms by optimizing paths in Hilbert Space.

6573-38, Poster Session

Speaking of sensing in the language of quantum mechanics

J. M. Myers, Harvard Univ.

Currently there is interest in the possibility of using quantum-mechanically entangled light to enhance the spatial resolution of remote sensors. In response to this interest, this talk reviews some applications of equations in quantum-mechanical form to the design of sensors and related systems. I distinguish mathematical models as mathematical formulas, whether quantum-mechanical or classical, from experiments with devices such as lasers and light detectors. After outlining the two known ways to connect quantum models to experiments (one statistical-mechanical, the other by way of probabilities) I sketch:

(1) an approximate way to translate from equations of classical electromagnetism to the quantum language of photons and detection probabilities;

(3) some rough-cut mathematical models of interferometers that exploit probabilities of coincidences in light detections, with applications to sensing;

(4) quantum-mechanically suggested possibilities and limits with respect to enhancing both positional accuracy and spatial resolution;

(5) remarks on the relation of rough-cut models to other models that account better for experimental challenges that surely arise when one tries to implement designs inspired by the rough-cut models;

(6) a discussion of a recently proved universal gap between, on one hand, quantum-mechanical models composed of equations and, on the other hand, experiments with devices, with consequent opportunities for a designer to invent.

6573-01, Session 1

Coherence and entanglement in two-qubit dynamics: Interplay of the induced exchange interaction and quantum noise due to thermal bosonic environment

V. Privman, D. Solenov, Clarkson Univ.

We summarize our recent results for the induced exchange interaction due to thermal bosonic environment (bath) which also generates quantum noise. We demonstrate that the induced interaction can be used to manipulate and create entanglement over time scales sufficiently large for controlling the two-qubit system for quantum computing gate applications, though ultimately, for large times, the noise effects will dominate.

6573-02, Session 1

Recent advances in quantum computing

G. N. Gilbert, M. Hamrick, Y. Weinstein, J. Thayer, The MITRE Corp.

In this talk we will present the results of recent research in two principal areas: (1) our theoretical work on fundamental problems associated to achieving fault tolerant quantum computation, taking into account realistic interactions between the quantum computer and its environment, and (2) our experimental work on the practical construction of photonic clusters for graph state-based quantum computation.

6573-03, Session 1

Spatial optimization of the classically controlled ion-motion interface in a multiplexed ion-trap quantum computer

T. S. Metodi, Univ. of California/Davis; N. Isailovic, Univ. of California/Berkeley; D. D. Thaker, Univ. of California/Davis; M. Whitney, Y. Patel, J. D. Kubiatowicz, Univ. of California/Berkeley; F. T. Chong, Univ. of California/Santa Barbara

One of the central challenges that remains for the realization of a large-scale ion trap quantum computer is the modeling and engineering of the interfaces between the large number of physical ions (qubit containers) in the computer and the classical apparatus that controls them. A critical high-density interface is the ion-motion-path, where an electric signal to the electrodes that trap ions controls the ballistic motion of the individual ions and hence the transport of quantum information across the chip. Large-scale ion trap geometries are composed of millions of ions trapped in spatially multiplexed trap arrays and may not be able to provide the desired density and access of the classical control circuitry which orchestrates the complex pulse sequences needed to move each ion. In this paper we use traditional compiler-based techniques to model the scheduling of a multiplexed ion trap design to better match the density of the control electronics with the needed ion density defined as ions-per-unit-area for the individual components of a large-scale chip. More specifically, we adapt the existing Quantum Physical Operations Scheduler (QPOS) and build a library of maximally parallelized ion-motion patterns required for the functionality of the individual chip components such as memory units that employ concatenated quantum error correcting codes and computational units where logical operations and teleportation are performed. The motion path library is constructed such that the number of different voltage pulses is minimized and voltages are distributed in a programmed manner such that density constraints on the classical control circuitry are minimized. Such an optimization approach allows our scheduling algorithm to aid the design of dense ion-trap structures with close to minimal classical control overhead for any given quantum circuit including memory components that require complex error correction procedures.

6573-04, Session 1

Scattering theory in relation to quantum computing

J. M. Myers, T. T. Wu, Harvard Univ.

Most of the literature on quantum computing assumes the capacity to apply a chosen sequence of unitary transformations to the state of a quantum register. As has been widely recognized, this “application of a unitary transformation” requires an external influence. In this report we relate the physics of external influences to the well stablished framework of scattering problems. Scattering of fields or particles from a single-qubit quantum register is discussed, and special limiting cases are highlighted, in which scattering indeed results in a unitary transformation of the register. Implications for “transformation-induced decoherence” are developed.

6573-05, Session 2

Quantum computing in control and optimization

V. A. Yatsenko III, Institute of Space Research (Ukraine); P. M. Pardalos, D. Vassiloyannis, Univ. of Florida

This paper deals with a progress made in the optimal control of quantum systems. It concentrates on applying the geometric technique in order to investigate a finite control problem of a two-level quantum system, resonance control of a three-level system, simulation of bilinear quantum control systems, and optimal control using the Bellman principle. We show that a quantum object described by the Schredinger equation can be controlled in an optimal way by electromagnetic modes. We also demonstrate an application of these techniques and an algebra-geometric approach to the study of dynamic processes in nonlinear systems.

6573-06, Session 2

Topological quantum scheme based on quantum walk

A. C. Kwan, The Graduate Ctr./CUNY; X. Li, City Univ. of New York/ Technology College; L. W. Leung, The City Univ. of New York

Topological quantum computation provides efficiency with fault-tolerant and error-correction to overcome decoherence problem. Here we investigate a class of topological quantum computation device. We discuss a method of constructing topological quantum scheme based on quantum walk for the state space.

6573-07, Session 2

Optimization of algorithmic cooling for NMR quantum computers

A. Kaltchenko, Wilfrid Laurier Univ. (Canada)

BACKGROUND:

The scaling[1] of NMR ensemble computers is currently one of the main obstacles to building larger-scale quantum computing devices. To achieve scalability, one needs a large number of highly polarized spins in liquid nuclear-spin systems at finite temperature. In quantum computing terminology, such spin-half states are (almost) pure qubit states. Producing highly polarized spins (almost pure qubit states) out of non-polarized spins (non-pure qubit states) is sometimes called “purification”. From a thermodynamic point of view, purification can be viewed as cooling spins to a very low temperature.

PREVIOUS RESULTS:

A compression-based algorithmic cooling (via polarization heat bath) was proposed in [1] and implemented in [2]. A compression subroutine used in [1,2] is capable of producing m pure qubits out of n non-pure qubits, where m is upper-bounded by the expression n*[1 - H(1/2 +eps/ 2)] . Here H(.) is the binary entropy function, and eps arises from the qubits’ density matrix as follows. The qubit state is given by a diagonal 2x2 matrix with the diagonal elements (1+eps)/2 and (1-eps)/2.

The improved compression subroutine was introduced in [3] and a tradeoff between the number of cooled spins and the closeness of their quantum state to the ideal pure state was studied. The main result of [3] was a lower bound on the probability of cooled spins to be pure states for large n.

OUR CONTRIBUTION:

In this work, we extend the results of [3] as follows. First, we obtain the probability distribution of cooled spins as a function of n, m, and eps for all, not necessarily large, n. Second, we analyze how the mismatch the algorithm’s computational basis and the actual eigenbasis of the qubits’ density matrix will affect the cooling (purification) performance.

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6573-08, Session 2

Quantum lattice-gas simulation of Bose-Einstein condensates governed by the Gross-Pitaevskii equation

J. Yepez, Air Force Research Lab.

A variety of physically relevant quantum lattice gas systems have been recently developed by us, and these systems have emergent nonlinear effective field theories governing the time-dependent dynamical behavior of the long wavelength modes in the quantum system. Satisfying the dual purposes of computational physics and quantum computation, these numerical quantum algorithms are unitary models useful for numerically predicting the time-dependent solutions of nonlinear partial differential equations, including the Korteveg de-Vries (KdV) equation, a reduced set of magnetohydrodynamic (MHD) equations, and various forms of the nonlinear Schroedinger (NLS) equation, including the Manakov equations for optical solitons and now the Gross-Pitaeskii (GP) equation for Bose-Einstein condensates (BECs). Here, the quantum lattice gas algorithm is demonstrated to be a practical model of the GP equation for cold atomic gases in the BEC ground state. In our quantum lattice-gas algorithm, the quantum wave function of a many-body system of quantum particles is resolved on a computational grid (usually a Bravais lattice). The finite grid size of the lattice provides a cut-off regulation to the quantum theory, stabilizing the model by removing high k-modes. The evolution operator governing the time-dependent behavior of the wave function is cast as the product of three unitary operators locally applied in time-step fashion: (1) a homogeneous stream operator for the site-to-site hopping of the particles, (2) a homogeneous collision operator for the on-site particle-particle interactions, and (3) an inhomogeneous gauge operator for particle-field interactions. With the first two spatially independent (homogeneously applied) stream and collide operators alone, we recover linear quantum theories, both non-relativistic and relativistic theories. The spatially dependent (inhomogeneously applied) gauge operation allows us to go much further to model nonlinear quantum systems: many-body dynamics in an external potential and an internally generated potential. Consequently, we find the quantum lattice gas algorithm is well suited to modeling the many-body physics of atomic BECs. An external magnetic periodic trapping scalar potential is modeled as a gauge rotation fixed to each lattice site whereas the internal nonlinear mean-field scalar potential, characteristic of magnetically trapped alkali vapors, is modeled as a gauge rotation dependent on the local value of the ground state wave function, a mean-field treatment. Previously, we have demonstrated the quantum algorithm in 2+1 dimensions. In this paper, we describe the quantum algorithm in 3+1 dimensions and demonstrate its numerical accuracy and practicality by comparing numerical predictions in both 2+1 dimensions and 3+1 dimensions to analytical predictions for BECs governed by the GP equation.

6573-09, Session 2

Finite temperature quantum entanglement

D. Ghoshal, R. B. Gomez, George Mason Univ.; M. O. Lanzagorta, Naval Research Lab.; J. K. Uhlmann, Univ. of Missouri/Columbia

Some of our previous research showed some interesting results regarding the effect of non-zero temperature on a specified quantum computation. For example, our analysis revealed that more Grover iterations are required to amplify the amplitude of the solution in a quantum search problem when the system is found at some finite temperature. We will present a further study on the effects of temperature on quantum entanglement using a finite temperature field theoretical description. Such a framework could prove to be useful for the understanding of computational dynamics inside a quantum computer. Other issues that we will address in our discussion include analytical descriptions of the effects of the temperature in the Von Newman entropy as a measure of entanglement.

6573-10, Session 3

Quantum algorithm for partial search

V. E. Korepin, Stony Brook Univ.

Searching and sorting algorithms enters as a subroutine in many important algorithms. Quantum algorithm can find a target item in a database faster than any classical algorithm. One can trade accuracy for speed and find a part of the database (a block) containing the target item even faster, this is partial search. An example is the following: exact address of the target item is given by a sequence of many bits, but we need to know only some of them. More generally partial search considers the following problem: a database is separated into several { blocks}. We want to find a block with the target item, not the target item itself. Partial search was introduced by Mark Heiligman. A partial search algorithm was recently suggested by Grover and Radhakrishnan, it works faster then classical partial search. The author optimized it. Complexity of a search algorithm is measured by number of queries to the oracle. The author suggests a new version of Grover-Radhakrishnan algorithm which uses minimal number of queries to the oracle. The author also designed partial search in a database with several target items. The algorithm can run on the same hardware which is used for the usual Grover algorithm.

6573-12, Session 3

Quantum algorithms for optimal graph traversals problems

S. Doern, Univ. Ulm (Germany)

Quantum algorithms have the potential to demonstrate that for some problems quantum is more efficiently than classical computation. The study of the quantum complexity for graph problems is a new area in quantum computing. Only for a few graph problems quantum algorithms are known. The first optimal quantum algorithms for graph problems were presented by Duerr et al. (2004) for minimum spanning tree, graph connectivity, strong graph connectivity and for the single source shortest paths problem. Magniez et al. (2005) constructed a quantum query algorithm for finding a triangle in a graph. Ambainis and Spalek (2006) presented some polynomial time quantum algorithms for computing a maximum matching in a bipartite graph and for the network flow problem. We study the complexity of algorithms for graph traversals problems on quantum computers. More precise, we look at eulerian tour, postman tour, hamiltonian tour, traveling salesman problem and project scheduling. We present quantum algorithms and quantum lower bounds for these problems. Our results improve the best classical algorithms for the corresponding problems. For the proofs of our results, we using several techniques: Grover search, quantum walks and the quantum running time analysis of classical algorithms. The regarded graph traversales problem have many important applications in graph theory. Our quantum algorithms can be used as a building blocks for other quantum graph algorithms.

6573-13, Session 3

Two-way quantum finite automata with improved state complexity

F. M. Atak, C. Say, Bogaziçi Univ. (Turkey)

We propose a new technique to enhance the language recognition probabilities of 2QFAs. This method allows the construction of machines recognizing a language with bounded error, given an algorithm whose error is not bounded away from 1/2 for recognizing that language. A sample construction for such a case is inspected in detail. Using this technique, we construct a 2QFA with equal error probability and better state complexity compared to a well-known 2QFA in the literature for the same language.

6573-14, Session 3

Quantum query algorithms for certain functions and general algorithm construction techniques

A. Dubrovska, Latvijas Univ. (Latvia)

Quantum algorithms can be analyzed in a query model to compute Boolean functions where input is given by a black box, but the aim is to compute function value for arbitrary input using as few queries as possible.

Many authors have studied complexity of quantum query algorithms and there are a lot of theoretical results regarding various complexity bounds; unfortunately, there still are very few examples of quantum algorithms provided for specific Boolean functions to illustrate theoretical evaluation of the complexity.

The main aim of our research was to find new impressive algorithms and develop general algorithm construction techniques.

We have started from 3 and 4 variable functions and succeeded in utilizing quantum parallelism and interference to obtain a gap of 3 vs. 2 and 4 vs. 2 queries between classical deterministic and quantum exact algorithm complexity. Next we used the power of symmetry to extend results to two sets of functions S3 and S4, where for each function we are able to demonstrate complete exact(!) quantum query algorithm which saves the same 1 and 2 queries comparing to best possible classical algorithm.

To obtain next result we utilized quantum parallelism once again and received another two sets of 6-variable functions (16 functions in each), where each function can be computed by quantum algorithm with probability 3/4 using only 2 queries. Next result - set of functions with classical query complexity 8, but we can compute them in quantum settings with the same probability 3/4 and 2 questions.

Finally, we formulate several properties of quantum query algorithms and introduce general ‘algorithm transformation’ algorithms, which allow to construct efficient algorithms with bounded-error for complex functions using existing exact algorithms for sub-functions.

6573-15, Session 3

Information theoretic analysis of the Grover algorithm using generalized statistics

R. C. Venkatesan, Systems Research Corp. (India)

The Grover algorithm is studied within the framework of the generalized (nonextensive) statistics theory of Tsallis. The Grover algorithm employs two kind of unitary operators to operate on the joint state of the target and the computer. These are the oracle and non-oracle (inversion about the means) operators. All operators, oracle and non-oracle, preserve the entropy (both extensive and nonextensive) of the joint state. Information transfer in the Grover iteration is primarily a consequence of oracle calls on the computer state. Specifically, identifying the target is posed as a problem of determining the unitary operators that have the ability to transfer information from the target state to the computer state. This is accomplished via the formulation of an eigenvalue problem, utilizing the Fano inequality and the Holevo bound, expressed within the framework of generalized statistics. The results that are obtained are two-fold. First, the “evolution” of the genera lized entropy and mutual information with respect to the progression of the Grover iteration are established. Next, the rate of entanglement is related to the progression of the Grover iteration.

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6573-16, Session 4

Quantum simulator review

E. M. Bednar, Air Force Research Lab.

Quantum information processing's objective is to utilize revolutionary computing capability based on harnessing the paradigm shift offered by quantum computing to solve classically hard and computationally challenging problems. Some of our computationally challenging problems of interest include the promises for rapid image processing, rapid optimization of logistics, protecting information, secure distributed simulation, and massively parallel computation. The implementation of quantum computers is difficult to realize due to poor scalability and great presence of errors. Therefore, we supported the development of Quantum eXpress and QuIDD Pro, two quantum computer simulators running on classical computers for the development and testing of new quantum algorithms and processes. This paper contrasts different methods used by these two quantum computing simulators. Both simulators are reviewed, highlighting each simulator's background, interface, and special features. Also, a demonstration on how to implement current quantum algorithms on each simulator is included. This paper concludes with an analysis and comments on both simulators.

6573-17, Session 4

Multiscale quantum optical networks

G. A. Jaroszkiewicz, The Univ. of Nottingham (United Kingdom)

We present a formalism in which quantum optics experiments of arbitrary complexity are described in terms of time-dependent networks of quantum bits, each qubit representing an elementary information gateway. The emphasis here is on the signal properties of the apparatus, rather than on the photons being observed. The quantum states of the theory, the labstates, represent the observer's description of the apparatus rather than the photons. This gives a different conceptual interpretation of quantum processes. The formalism gives an efficient quantum register description strongly related to the formalism of quantum computation. Experiments conventionally described by the PVM and POVM formalisms are treated in identical terms.

There are several advantages in this formalism, one of which is that it provides an efficient modular approach to quantum optics experiments. Quantum optics experiments of arbitrary complexity can be systematically simulated by series of qubit networks connected in series and/or in parallel. We will discuss the possibility of encoding our formalism into a computer algebra package such as MAPLE, which should provide a method of performing quantum calculations for quantum optics circuits of unlimited size and unbounded complexity.

6573-19, Session 4

Recent MITRE research in quantum sensors

G. N. Gilbert, M. Hamrick, Y. Weinstein, The MITRE Corp.

Research carried out over the past few years has indicated the possibility of realizing significant advantages in sensing technology through the use of non-classical, entangled light, as opposed to classical light, in the illumination of prospective targets. One such advantage arises in the possibility of achieving image resolution that is superior to that of the standard Rayleigh limit. In this talk we will present recent experimental and theoretical results from MITRE's research in quantum sensors, with emphasis on practical applications.

6573-33, Session 4

Non-statistical weak measurements

J. Tollaksen, George Mason Univ.

Weak values are the outcomes of weak measurements and were discovered by studying the time-symmetric aspects of quantum mechanics. This resulted in rich new areas of physics such as the quantum random walk, new approaches to quantum cryptography and new resources for quantum information. In this article, new non-statistical aspects of weak measurements are introduced including the most general way to obtain an ensemble on a single system but over time. I.e. a single system is pre-selected, a weak measurement is performed, a complementary post-selection is performed and then another weak measurement is performed (using the same device as in the first weak measurement). When this is repeated on the same single system, then the measuring device can robustly yield eccentric weak values that are outside the range of eigenvalues. Contary to past results, this outcome is not rare, suggesting that weak values are a property of every individual pre-and-post-selected system. Finally, it is shown how generic electromagnetic interactions are themselves weak measurements and thus automatically record these eccentric weak values.

6573-20, Session 5

On the security of the Y-00 or alpha-eta protocol

H. P. Yuen, R. Nair, Northwestern Univ.

We review the basic security framework for analyzing the data and key security of the Y-00 or alpha-eta quantum cryptographic protocol for direct encryption, and also for key generation. For each of these two cryptographic functions, we compare the advantages and disadvantages of Y-00 with respect to standard cryptographic protocols and other quantum cryptographic protocols such as BB84. It will be emphasized that meaningful quantitative security guarantee of any kind cannot yet be obtained in any protocol in a realistic implementation.

6573-21, Session 5

POVM and PV measurement in QKD

H. E. Brandt, Army Research Lab.

I first review positive-operator and projection valued measures in quantum mechanics, and then address a few applications in quantum key distribution (QKD). The positive operator valued measure (POVM) is useful in the design of a quantum key receiver [1], [2]. The projection valued (PV) measure is useful in the design of QKD eavesdropping devices [3]-[5]. In this case the measurement determines correlations with the measurements made by the legitimate receiver and therewith the maximum information gain by the probe. It is essntial to know the latter for privacy amplification.

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6573-23, Session 5

The security and efficiency of continuous variable quantum communication

K. Tang, X. Zhang, The Graduate Ctr./CUNY

The security of quantum cryptography (QC) are based on the laws of quantum mechanics and has been proved unconditional secure and detectable to eavesdropping. Quantum Key Distribution (QKD) schema which based on discrete variable has the difficulty in generating and detecting of single photon, so it is hard to acquire high speed communication. In this paper, we discussed the enhancement of efficiency of using continuous variable Einstein-Podolsky-Rosen (EPR) pairs in quantum secure communication, as well the security against the eavesdropping.

6573-24, Session 5

Fisher-Schrödinger models for statistical encryption of covert information

R. C. Venkatesan, Systems Research Corp. (India)

A systematic strategy to secure covert information (code) via unitary projections into the null spaces of ill-conditioned eigenstructures of a hierarchy of host statistical distributions, inferred from incomplete constraints, is presented. The security of the encryption/decryption strategy is based on the extreme instability of the encoding process. The host pdf's are inferred using the Fisher information as the measure of uncertainty.

The process of achieving encryption of covert information with the aid of unitary projections extends previous work in this area [1, 2]. The host density reconstruction is governed by a time independent Schrödinger-like equation (TISLE). The TISLE possesses an empirical pseudo-potential characterized by Lagrange multipliers, that are determined from a Fisher game. The hierarchy of statistical hosts correspond to multiple energy states of the TISLE, when solved as an eigenvalue problem.

The above extensive model is extended to the case of Tsallis nonextensive statistics, where the governing equation is a nonextensive TISLE. A methodology to amalgamate the statistical encryption models with a quantum mechanical connotation with existing quantum key distribution protocols, in order to achieve a self-consistent hybrid statistical/quantum mechanical crypto-system using a shared key concept, is described for both symmetric and asymmetric cryptography. Numerical examples exemplify the efficacy of the models.

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6573-25, Session 6

Quantum technology and cryptology for information security

S. Naqvi, Ctr. of Excellence in Information and Communication Technologies (Belgium); M. Riguidel, École Nationale Supérieure des Télécommunications (France)

Cryptology and information security are set to play a more prominent role in the near future. In this regard, quantum communication and cryptography offer new opportunities to tackle ICT security. Quantum Information Processing and Communication (QIPC) is a scientific field where new conceptual foundations and techniques are being developed. They promise to play an important role in the future of information Security. It is thus essential to have a cross-fertilizing development between quantum technology and cryptology in order to address the security challenges of the emerging quantum era.

In this article, we discuss the impact of quantum technology on the current as well as future crypto-techniques. We then analyse the assumptions on which quantum computers may operate. Then we present our vision for the distribution of security attributes using a novel form of trust based on Heisenberg's uncertainty; and, building highly secure quantum networks based on the clear transmission of single photons and/or bundles of photons able to withstand unauthorized reading as a result of secure protocols based on the observations of quantum mechanics. We argue how quantum cryptographic systems need to be developed that can take advantage of the laws of physics to provide long-term security based on solid assumptions. This requires a structured integration effort to deploy quantum technologies within the existing security infrastructure. Finally, we conclude that classical cryptographic techniques need to be redesigned and upgraded in view of the growing threat of cryptanalytic attacks posed by quantum information processing devices leading to the development of post-quantum cryptography.

NB: This research is supported by the European Commission funded project SECOQC (Secure Communication based on Quantum Cryptography) under reference number IST-2002-506813. The overall objectives of the SECOQC project are to specify, design, and validate the feasibility of an open, Quantum Key Distribution infrastructure dedicated to secure communication as well as to fully develop the basic enabling technology. Project webpage is located at www.secoqc.net

6573-26, Session 6

Demonstration of a six-user quantum key distribution network on a bus architecture

P. D. Kumavor, A. C. Beal, L. Lu, E. J. Donkor, B. C. Wang, Univ. of Connecticut

We demonstrate the implementation and operation of a multi-user QKD system using a bus topology that spans a total distance of 31 km of standard telecom-grade optical fiber. The QKD system is based on the two-way auto-compensating scheme and employs the BB84 protocol to allow a network server to establish a secure encryption key with five other users on the network at a time. The values of the quantum keys sent by the network server are encoded onto the phase states of highly attenuated pulses, with mean photon number 0.1. These pulses are generated by modulating a wavelength-tunable continuous wave (CW) laser light using an electro-optic modulator, and detected using avalanche single photon detectors cooled to a temperature of -55 oC and operating in the Geiger mode. Every user on the network is allocated a unique address wavelength channel in the C-band region for communication with the network server. Commercial add/drop multiplexer modules (OADM) perform the necessary photon routing to the users. These modules transmit photons with the matching wavelength to the intended recipient and reflects photons at all other wavelengths onward along the fiber. In this way, the network server is able to selectively address each user on the network. The measured quantum bit error rate and sifted key rate values are in good agreement with theory.

6573-27, Session 6

A simple secure quantum authorization scheme

X. Zhang, X. Xu, K. Tang, A. C. Kwan, The Graduate Ctr./CUNY; X. Li, City Univ. of New York/Technology College; M. M. Anshel, City College/CUNY

Based on quantum mechanics we present a simple authorization scheme: Quauth. The description of the scheme is given in details. The authorization is accomplished through a quantum channel by one way communication. We show that eavesdropper gets no information about key no matter how many times s/he is listening on the channel. The scheme is robust against both the passive and active attacks. By induction we prove that the scheme is information theoretically secure.

6573-28, Session 6

Quantum entanglement assisted key distribution

K. Tang, The Graduate Ctr./CUNY; P. Ji, John Jay College; X. Zhang, The Graduate Ctr./CUNY

Quantum correlations or entanglement is a basic ingredient for many applications of quantum information theory. One important application that exploits the correlation nature of entangled photon states is quantum key distribution, which is proven unbreakable in principle and provides the highest possible security that is impossible in classical information theory. However, generating entangled photon pairs is not a simple task — only approximately one out of a million pump photons decay into a signal and idler photon pair. This low rate of entangled photon pairs is further reduced by the overhead required in order for the rectification of the inevitable errors due to channel imperfections or caused by potential eavesdroppers. As a consequence, quantum key distribution suffers from a low bit rate, which is in the order of hundreds to thousands bits per second or below. On the other hand, the classical public key distribution does not impose a tight limit on the transmission rate. However, it is subject to the risks of eavesdroppers sitting in the middle of the insecure channel. In this paper, we propose a hybrid key distribution method which uses public key distribution method to generate a raw key, and then uses entanglement assisted communication to modify the raw key by inserting a number of quantum bits in the raw key. Building upon the foundation of the unconditional security of quantum key distribution, we use the privacy amplification to make the affection of inserted bits expand to a whole key. Our quantum entanglement assisted key distribution scheme greatly improves the efficiency of key distribution while without compromising the level of security achievable by quantum cryptography.

6573-29, Session 7

Quantum algorithms for topological quantum computing

S. J. Lomonaco, Jr., Univ. of Maryland/Baltimore County; L. H. Kauffman, Univ. of Illinois/Chicago

We will discuss a number of quantum algorithms for topological quantum computing.

6573-30, Session 7

Spin networks, knots, and quantum algorithms

L. H. Kauffman, Univ. of Illinois/Chicago; S. J. Lomonaco, Jr., Univ. of Maryland/Baltimore County

This talk will review quantum information theory

in the light of the Cramer transactional interpretation of quantum mechanics. We will discuss this in categorical and algebraic terms using a matrix-diagrammatic approach that includes our previous work on telelportation, anyonic quantum computing and on quantum knots.

6573-31, Session 7

Two qutrits universal quantum gates from nine dimensional solutions of Yang-Baxter equation

J. F. Ospina, Univ. EAFIT (Colombia)

Recently Kauffman and Lomonaco have introduced the Yang-Baxter equations in the realm of the topological quantum computation. From these equations the mentioned authors are able to obtain universal quantum gates for systems of two qubits. In this line, H. Dye was able to obtain the full classification of the four dimensional unitary solutions of the Yang-Baxter equation.

A very interesting open question consists in to consider the case of nine dimensional unitary solutions of the Yang-Baxter equation and to derive from them universal quantum gates for systems of two qutrits. This is the object of the present work. We will collect certain nine dimensional unitary solutions of the YBE, extracted from various contexts such as quantum doubles for finite groups(dihedral group, symmetry group, alternate group), quandles and racks. From these solutions we derive two qtrits universal quantum gates. These gates can be implemented on anyon systems with finite dynamical algebras. Finally some remarks about Yang-baxterization are realized.

6573-32, Session 7

A quantum state discrimination martingale

M. R. Frey, Bucknell Univ.

A quantity with the properties of a martingale is identified for conclusive Bayesian discrimination of two quantum states subjected to a sequence of optimal weak measurements. This martingale is solely a function of the two system states and their respective probabilities at the time of each measurement, and it directly determines the evolving probability of discrimination error. Also, it is constant if and only if the states are pure. For strictly mixed states the martingle is invariant only in an average sense, with the consequence that, with some probability, the realized discrimination error probability conditioned on prior measurements may be less than the optimal Helstrom error probability. So for mixed states conditionally superoptimal discrimination is possible. This is illustrated numerically in an example.

6573-34, Poster Session

Quantum repeaters: fundamental and future

Y. Li, Y. Liu, J. Ye, Huazhong Univ. of Science and Technology (China); Q. Zhou, China Aerospace Science & Industry Corp. (China)

An overview of the quantum repeater techniques based on entanglement distillation and swapping is provided. Beginning with a brief history and the basic concept of the quantum repeaters, the article primarily focuses on the description of the communication model based on the quantum repeater techniques, which mainly consists of two fundamental modules — entanglement distillation and swapping. The realizations of entanglement distillation are discussed, including Berstein's procrustean method, entanglement concentration, CNOT-purification method, etc. The schemes of implementing swapping, which include swapping based on Bell-state measurement and swapping in cavity QED, are also introduced. Then a comparison between these realizations and evaluations on them are presented. At last, the article discusses the existed experimental schemes of quantum repeaters, and documents some remaining problems and emerging trends in this field, especially the usage of quantum repeaters in national defense and security in the future.

6573-36, Poster Session

Quantum entanglement, weak measurements and weak values

D. Ghoshal, George Mason Univ.

It is known that as a resource, quantum entanglement along with quantum superposition, quantum parallelism and quantum measurement provide enormous power to the quantum information processing and quantum communication. Very different roles and issues of entanglement are already studied by various researchers with exciting outcome. We focus our research on one particular area where we see that quantum weak measurements exhibit particles to be entangled in unusual manner. Here weak measurements are considered between preselected and postselected states and the preselected state is entangled. Understanding such entangled state is important and based upon our understanding we try to explore and extend our views on quantum entanglement from the perspective of weak measurements and weak values.

6573-37, Poster Session

Properties and application of nondeterministic quantum query algorithms

A. Dubrovska, Latvijas Univ. (Latvia)

Many quantum algorithms can be analyzed in a query model to compute Boolean functions where input is given by a black box. Like in classical version of decision trees, different kinds of quantum query algorithms are possible - exact, zero-error, bounded-error and even nondeterministic. In this paper we study the latter class of algorithms. We introduce the fresh notion in addition to already studied nondeterministic algorithms and introduce dual nondeterministic quantum query algorithms. We examine properties of such algorithms and prove relations with exact and nondeterministic quantum query algorithm complexity. As a result and as an example of application of discovered properties we show a gap of n vs. 2 for classical deterministic and dual nondeterministic quantum query complexity for a Boolean function.

Conf. 6574: Optical Pattern Recognition XVIII

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6574-01, Session 1

SAR classification and confuser and clutter rejection tests on MSTAR ten-class data using Minace filters

R. Patnaik, D. P. Casasent, Carnegie Mellon Univ.

In our previous SAR ATR work, we used a subset of the MSTAR (Moving and Stationary Target Acquisition and Recognition) public database for the benchmark three-class problem and we addressed confuser and clutter rejection. We demonstrated that the test results using our minimum noise and correlation energy (MINACE) filter-based classifier were better than all prior work. In this paper, we address classification and rejection tests on the more challenging MSTAR ten-class public database. To handle the full 360° range of aspect view in MSTAR data, we use a set of Minace filters for each object; each filter should recognize the object (and its variants) in some angular range. We use fewer DIFs per object than prior work did. We use our autoMinace algorithm that uses a training and a validation set to select the Minace filter parameter c (which selects emphasis on recognition or discrimination) and to select the training set images to be included in the filter, so that the filter can achieve both good recognition and good confuser and clutter rejection performance. No confuser, clutter, or test set data are present in the training or the validation set. In tests, we do not assume that the test input's pose is known (as most prior work does), since pose estimation of SAR objects has a large margin of error; we address tests with proper use of SAR pose estimates in MSTAR recognition. We address the use of multi-look SAR data to improve performance. We also consider initial work on the use of generic macro classes such as tanks vs. APCs vs. trucks or wheeled vs. tracked vehicles.

6574-02, Session 1

Track and trap in 3D

J. Glückstad, Risø National Lab. (Denmark)

In the beginning of the 21st century it was realized that versatile and general manipulation of molecules and particles is possible by using specially tailored three-dimensional crystal-like structures of light. Such sculpted light patterns have unprecedented potential for manipulating mesoscopic objects and have already been successfully used to organize small particles, including microbial cells, in desired patterns and to sort samples of particles according to their size to mention but a few applications [1].

3D light structures can be created by modulating the spatial phase and polarization properties of the laser light. A particularly promising technique is the Generalized Phase Contrast (GPC) method invented and patented at Risø National Laboratory [2]. Based on the combination of programmable spatial light modulator devices and an advanced graphical user-interface the GPC-method enables real-time, interactive and arbitrary control over the dynamics and geometry of synthesized light patterns. Recent experiments have shown that GPC-driven micro-manipulation provides a unique technology platform for fully user-guided assembly of a plurality of particles in a plane, control of particle stacking along the beam axis, manipulation of multiple hollow beads, and the organization of living cells into three-dimensional colloidal structures [3,4]. These demonstrations illustrate that GPC-driven micro-manipulation can be utilized not only for the improved synthesis of functional microstructures but also for non-contact and parallel actuation [5] crucial for sophisticated opto- and micro-fluidic based lab-on-a-chip systems [6,7].

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6574-03, Session 1

Recent results of integrated sensing and processing with hyperspectral imager

R. R. Muise, A. Mahalanobis, Lockheed Martin Missiles and Fire Control

In this paper we present an information sensing system which integrates sensing and processing resulting in the direct collection of data which is relevant to the exploitation application. Broadly, integrated sensing and processing (ISP) considers algorithms that are integrated with the collection of data. We demonstrate an ISP system which utilizes a near Infrared (NIR) Hadamard multiplexing imaging sensor. This prototype sensor incorporates a digital mirror array (DMA) device in order to realize a Hadamard multiplexed imaging system. Specific Hadamard codes can be sent to the sensor to realize inner products of the underlying scene rather than the scene itself. The developed ISP algorithm incorporates the exploitation tasks into the sensing by computing an ATR metric which directs the sensor to collect only the information relevant to the ATR problem. The result is a multiple resolution hyperspectral cube with full resolution where targets are present and less than full resolution where there are no targets. We demonstrate this algorithm fully integrated with the sensor and running in real time on a test case to demonstrate feasibility.

6574-04, Session 2

System issues of developing grayscale optical correlator for ATR applications

T. -. Chao, T. T. Lu, Jet Propulsion Lab.

No abstract available

6574-05, Session 2

A hybrid digital-optical correlator for automatic target recognition

A. K. Gupta, Instruments Research and Development Establishment (India)

Optical information processing techniques for pattern recognition have generated considerable amount of interest in the optics community for the last few decades. An optical correlator is being considered as an extremely useful and important resource available to military personnel and operations in the areas of surveillance and targeting.

Recently, we proposed a WaveMACH (wavelet-modified maximum average correlation height) filter for in-plane and out-of-plane rotation invariance. Use of wavelet transform improves performance of the MACH filter by reducing the number of filters required for identifying a rotated target and enhances the correlation peak intensity significantly. The output of a hybrid digital-optical correlator contains two autocorrelation peaks and a strong dc. Using a chirp function with the WaveMACH filter, the correlation signals are focused in three different planes. Thus placing a peak capturing CCD camera at a particular plane, the desired correlation peak is recorded, discarding the strong dc and other autocorrelation peak. SNR was calculated as a metric of goodness of the proposed filter. The influence of perturbations in hybrid digital-optical correlator has also been studied. Perturbations include, effect of occlusion on input target, effect of additive and multiplicative noise and their combined effect on input target, and effect of occlusion of product function (a function obtained after multiplication of input

target's Fourier spectrum with presynthesized filter) to be optically processed for obtaining the correlation outputs.

The present paper reviews investigations on the hybrid digital-optical correlation scheme with special reference to the work carried out at the Photonics Division, IRDE Dehradun.

6574-06, Session 2

Pattern recognition in hyperspectral imagery using Gaussian filter with post-processing

M. S. Alam, Univ. of South Alabama; M. N. Islam, Univ. of West Florida; A. Bal, Istanbul Univ. (Turkey)

Pattern recognition in hyperspectral imagery often suffers from a number of limitations, which includes computation complexity, false alarms and missing targets. The major reason behind these problems is that the spectra obtained by hyperspectral sensors do not produce a deterministic signature, because the spectra observed from samples of the same material may vary due to variations in the material surface, atmospheric conditions and other related reasons. In addition, the presence of noise in the input scene may complicate the situation further. Therefore, the main objective of pattern recognition in hyperspectral imagery is to maximize the probability of detection and at the same time minimize the probability of generating false alarms. Though several detection algorithms have been proposed in the literature, but most of them are observed to be inefficient in meeting the objective requirement mentioned above. This paper presents a novel detection algorithm which is fast and simple in architecture. The algorithm involves a Gaussian filter to process the target signature as well as the unknown signature from the input scene. A post-processing step is also included after performing correlation to detect the target pixels. Computer simulation results show that the algorithm can successfully detect all the targets present in the input scene without any significant false alarm.

6574-07, Session 3

A new SVM for distorted IR object tracking and recognition

Y. F. Wang, D. Casasent, Carnegie Mellon Univ.

In this paper, we apply our new SVRDM (support vector representation and discrimination machine) classifier to address ATR tracking and recognition problems. The SVRDM classifier has good generalization (like the standard SVM does), and it has the added property of a good rejection ability. In other words, it not only gives very promising recognition results on the true target classes, it is also able to reject other unseen non-target input. In ATR recognition applications, we are dealing with a multi-class classification problem, and the targets are present at the same range and depression angle, but may be present in different thermal states and aspect views. When the number of target classes is large, the multi-class classification problem with thermal state and aspect view variations becomes challenging. We apply our hierarchical SVRDM classifier to address this recognition problem.

In ATR tracking, the object is not only present with thermal and aspect view angle variations, its size (range) also changes as the sensor approaches the target, and depression angle variations can exist. Therefore, it is important and realistic to know how our SVRDM handles these variations. We varied the number of aspect view training images, and we trained our SVRDMs at different sets of ranges, depression angles, etc. to evaluate the effects of them. Thus, our results are most unique and worthwhile but are not easily compared to prior work. Recognition, rejection and tracking test results are presented on both simulated and real infra-red (IR) data.

6574-08, Session 3

Building robust appearance models using on-line feature selection

R. B. Porter, R. C. Loveland, E. Rosten, Los Alamos National Lab.

In many tracking applications, adapting the target appearance model over time can improve performance. This approach has found widest application in high frame rate video applications where latent variables, related to the objects appearance (e.g., orientation and pose), vary slowly from one frame to the next. In these cases the appearance model and the tracking system are tightly integrated, and latent variables are often included as part of the tracking system's dynamic model. In this paper we describe our efforts to track cars in low frame rate data (1 frame / second), acquired from a highly unstable airborne platform. Due to the low frame rate, and poor image quality, the appearance of a particular vehicle varies greatly from one frame to the next. This leads us to a different problem: how can we build the best appearance model from all instances of a vehicle we have seen so far. The best appearance model should maximize the future performance of the tracking system, and maximize the chances of reacquiring the vehicle once it leaves the field of view. We propose an online feature selection approach to this problem and investigate the performance and computational trade-offs with a real-world dataset.

6574-09, Session 3

Fully invariant multiple object recognition and tracking using MACH and Kalman filters

P. Bone, Univ. of Sussex at Brighton (United Kingdom)

A method of recognising and tracking multiple solid objects in video sequences despite any kind of perspective distortion is demonstrated. Moving objects are initially segmented from the scene using a background subtraction method to minimize the search area of the filter. A variation on the Maximum Average Correlation Height (MACH) filter is used to create invariance to orientation while giving high tolerance to background clutter and noise. A log r-θ mapping is employed to give invariance to in-plane rotation and scale by transforming rotation and scale variations of the target object into vertical and horizontal shifts. The MACH filter is trained on the log r-θ map of the target for a range of orientations and applied sequentially over the regions of movement in successive video frames to test for target objects. A Kalman filter is employed to continuously track the target objects over successive frames, which has enabled the system to track multiple targets despite temporary occlusion or intersection.

6574-11, Session 3

Advanced correlation filter methods for SHARP ATR

P. Topiwala, FastVDO LLC; D. P. Casasent, Carnegie Mellon Univ.; A. V. Nehemiah, FastVDO LLC

A electro-optic (EO) and infrared (IR) automatic target recognition (ATR) system based on the minimum noise and correlation energy (MINACE) distortion invariant filter (DIF) is presented. The system uses exceptionally high resolution EO and IR data obtained from the Shared Reconnaissance Pod (SHARP). Excellent detection results are obtained. Furthermore, the selection of a key parameter - the MINACE filter parameter c - is fully automated using a training and validation set. We also present a set of correlation plane post processing methods to reduce false alarms and improve detection accuracies. The system is evaluated using multi-sensor imagery acquired using the SHARP sensor suite, the detection (PD) and false alarm (PFA) scores are presented for the problem of detecting aircrafts in the high resolution imagery. The scale and orientation of the targets are not assumed to be known, thus making the problem more realistic.

6574-12, Session 4

Super-resolution reconstruction of hyperspectral images

M. I. Elbakary, M. S. Alam, Univ. of South Alabama

Hyperspectral imagery are used for a wide variety of military and commercial applications, including target detection, tacking, agricultural monitoring and natural resources exploration. The reason of importance of hyperspectral images is the fact that the hyperspectral imagery reveals spectral information about the scene that are not obtainable by single band. Unfortunately, many factors such as sensor noise and atmospheric scattering degrade the spatial quality of these images. Recently, many algorithms are introduced in the literature to improve the

resolution compared to Price's algorithm results. In this paper, Price's algorithm is revisited to improve the results compared with the traditional algorithm. The proposed method is dedicated to produce high resolution bands from low resolution bands that are strongly correlated to the corresponding high resolution panchromatic image. The proposed method is based on using the local correlation instead of using the global correlation to improve the estimated interpolation in the constructed high resolution. Using the local correlation significantly improved the results compare to the results of the traditional algorithm. The local correlation is achieved in small windows with predefined size across the low resolution image. In addition, in this paper numerous studies are conducted to compare the effect of the chosen window size in the image quality. Many experiments are conducted using real life hyperspectral imagery to evaluate the proposed algorithm and to demonstrate the efficacy of the algorithm.

6574-13, Session 4

Dynamic range compression deconvolution using A-law and μ-law algorithms

B. Haji-saeed, S. K. Sengupta, W. D. Goodhue, Univ. of Massachusetts/Lowell; J. Khoury, C. L. Woods, Air Force Research Lab.; J. Kierstead, Solid State Scientific Corp.

In this paper the A-law/μ-law Dynamic Range Compression algorithm used in telecommunication systems is proposed for the first time for nonlinear Dynamic Range Compression image deconvolution. In the proposed setup, a joint image of the blurred input information and the blur impulse response are jointly Fourier transformed via a lens to a CCD camera which acts as a square-law receiver. The output from the CCD camera is sent to the A-law/μ-law digital or analog receiver. After nonlinear A-law/μ-law Dynamic Range compression deconvolution the output is sent to an SLM and then the output from the SLM is Fourier transformed via a lens to produce an edge-enhanced version of the corrected image and its conjugate. The output then can be lowpass filtered to recover the gray level image. The CCD camera is responsible for mixing the Fourier transforms of the impulse response and the distorted image to compensate for the phase distortion and then the A-law/μ-law nonlinear transformation is responsible for enhancing both the high frequencies and the signal to noise ratio. The proposed technique is supported by computer simulation.

6574-14, Session 4

A neural network identification system for space-borne GCMS pattern recognition

T. T. Lu, T. -. Chao, J. Macaskill, M. Girard, M. R. Darrach, Jet Propulsion Lab.

No abstract available

6574-15, Session 4

Machine intelligence-based decision-support (Mind) for automatic anomaly detection

N. R. Prasad, New Mexico State Univ.; T. T. Lu, Jet Propulsion Lab.

No abstract available

6574-16, Session 4

Distributed sensor network control for power and bandwidth allocation in large sensor networks

A. Talukder, A. Panangadan, Univ. of Southern California

No abstract available

6574-17, Poster Session

IR classification and rejection tests on Comanche data using Minace filters

D. P. Casasent, R. Patnaik, Carnegie Mellon Univ.

This paper presents our IR automatic target recognition (ATR) work on the Comanche database using the minimum noise and correlation energy (MINACE) distortion-invariant filter (DIF). The Comanche database contains real IR data of eight targets with aspect view and thermal state variations. We consider recognition of six of these targets and we consider rejecting two targets (confusers) and clutter. To handle the full 360° range of aspect view in Comanche data, we use a set of Minace filters for each object; each filter should recognize the object in some angular range. We use our autoMinace algorithm that uses a training and a validation set to select the Minace filter parameter c (which selects emphasis on recognition or discrimination) and to select the training set images to be included in the filter, so that the filter can achieve both good recognition and good confuser and clutter rejection performance. No confuser, clutter, or test set data are present in the training or the validation set. Use of the peak-to-correlation energy (PCE) ratio is found to perform better than the correlation peak height metric. The use of circular versus linear correlations is addressed; circular correlations require less storage and fewer online computations and are thus preferable. We also present results using CMO preprocessed data; CMO (close-minus-open) is our segmentation noise reduction preprocessing algorithm.

6574-18, Poster Session

Real-time multisensor-based vehicle detection using MINACE filters

A. V. Nehemiah, P. Topiwala, FastVDO LLC

A method to detect vehicles (cars, trucks etc) in electro-optic (EO) and infrared (IR) imagery is presented. We present the use of the minimum noise and correlation (MINACE) distortion invariant filter (DIF) for this problem. Excellent detection performance is demonstrated. Furthermore, the selection of a key parameter - the MINACE filter parameter c - is fully automated using a training and validation set. We also present a new method to segment training data based on object scale to make the system scale invariant. A new set of correlation plane post processing methods that improve detection accuracies and reduce false alarms are presented. The system is tested on real life imagery of traffic in parking lots and roads obtained using a multi-sensor EO/IR platform.

6574-20, Poster Session

Input scene restoration in pattern recognition correlator based on digital photo camera

S. N. Starikov, N. N. Balan, M. V. Konnik, V. G. Rodin, I. V. Solyakin, E. A. Shapkarina, Moscow Engineering Physics Institute (Russia)

Diffraction image correlator based on commercial digital SLR photo camera was reported earlier. The correlator was proposed for recognition of external scenes illuminated by quasimonochromatic spatially incoherent light. The correlator hardware consists of digital camera with plugged in optical correlation filter unit and control computer. The kinoform used as correlation filter is placed in a free space of the SLR camera body between the interchangeable camera lens and the swing mirror. On the other hand, this correlator can be considered as a hybrid optical-digital imaging system with wavefront coding. It allows not only to recognize objects in input scene but to restore, if needed, the whole image of input scene from correlation signals distribution registered by SLR camera sensor. Linear methods for image reconstruction in the correlator are discussed. The experimental setup of the correlator and experimental results on images recognition and input scenes restoration are presented.

6574-25, Poster Session

Position estimation and driving of an autonomous vehicle by monocular vision

J. C. Hanan, P. Kayathi, Oklahoma State Univ.; C. L. Hughlett, Zion Labs. Inc.

Recognition error is often situation dependent. Variables including the sampling rate, object complexity, energy content, clutter, and noise, all play a role in limiting the precision of recognition. For a stationary camera, discrete subjects are typically tracked in motion while the background remains constant. For the rover situation, the background is in motion and may be characterized to provide visual cues on rover travel such as rate, pitch, roll, and distance to objects of interest or hazards. Objects in the scene may be used as landmarks, or waypoints, for such estimations. As the objects are approached, their scale increases and their orientation may change. In addition, particularly on rough terrain, these orientation and scale changes may be unpredictable. Thus, without predicting the motion of landmarks, a general estimation of confidence in the position of the waypoints and therefore the position of the rover may be calculated based on the tracking algorithm. Here, automatic adaptive tracking in real-time for target recognition provided autonomous control of a moving platform. The motion platform consists of an autonomous rover test-bed for vision based guidance and navigation. Methods were implemented to monitor tracking error and ensure a safe, accurate arrival at the intended science target. Many methods are situation independent relying only on the confidence error response of the target recognition algorithm. Other methods take advantage of the scenario of combined motion and tracking. In either case, only a single calibrated camera was needed for position estimation. Results from real-time autonomous driving tests on the JPL simulated Mars yard are presented.

6574-21, Poster Session

Face recognition for building access control

C. L. Woods, J. Khoury, P. Crabtree, Air Force Research Lab.

We compare facial biometric performance recognition for building access control with cooperative subjects using two image datasets. Two template equalization techniques are evaluated and compared. Preliminary results indicate promising performance.

6574-22, Poster Session

Object detection in hyperspectral imagery using K-means clustering algorithm with pre-processing

M. S. Aslan, M. S. Alam, M. I. Elbakary, Univ. of South Alabama

K-means clustering method has been employed in different applications of data analysis. This paper develops a target detection system using the k-means algorithm including a preprocessing step based on the Euclidean distance. The pre-processing step reduces the computational complexity of the k-means algorithm in case of hyperspectral imagery. After reducing the set of pixels in the background from the data by using the pre-processing step, k-means algorithm is employed to determine the clusters in rest of the image data cube. Having obtained the clustered data, the objects of interest can easily be detected using the known target signature. The proposed clustering algorithm is successfully applied to the real life hyperspectral data sets where the objects of interest can efficiently be detected. The proposed scheme effectively reduces the convergence time of the k-mean algorithm compared to that required by the traditional k-means algorithm.

6574-23, Poster Session

Experimental estimation of the recognition reliability in the optical pattern recognition systems

V. L. Perju, Technical Univ. of Moldova (Moldova)

One of the important questions in optical pattern recognition represents the estimation of the objects recognition reliability.

In this article it is described a method of the recognition reliability estimation in the optical pattern recognition systems. This method is based on minimal differences of the similarity measures, which permits to execute the evaluation of the objects correct classification probabilities. On the base of this method there are carried out the experimental estimation of the objects recognition reliability.

At the first stage it was checked the hypothesis about the law of similarity measures differences distribution according to two criteria: on the base of experimental data was built a normal theoretical curve which then was compared with experimental curve; for more careful checking of the hypothesis there was used the Pierson's criteria.

At the next stage there were calculated the reliabilities of the correct objects classification in the optical pattern recognition system based on the using of holographic filters.

He obtained results permitted to make the recommendation regarding the possibilities of utilization of the optical correlation systems for invariant pattern recognition.

6574-24, Poster Session

The intellectual processor on basis of 2nd order objects in restoration of images

I. A. Mardare, Technical Univ. of Moldova (Moldova)

All objects of environment are classified into groups of certain order. The 1-st order object represents some heterogeneity, which stands out this object against homogeneous background. The 2-nd order object is a result of transformation of 1-st order objects. Control operators I and F of 2-nd order object, applied to defective image , allow to eliminate defects.

The intellectual processor, having neural network as one of its elements, is used for restoration of stage consisting of several 1-st order objects and represents by itself the 2-nd order object .

When on input of image restoration system come two 1-st order objects and it is necessary to define the relation of domination and subordination between them, as well as presence of defects in them. Revealing of dominant and subordinate objects of a stage is made by definition of their complexity. Most complex object is the dominant object. The dominant object defines the contents of a stage and parameters of subordinated object. On basis of analysis of parameter values of objects and conclusion about conformity or disconformity of parameters values with true images of objects and is made. In case of disconformity control operators I and F are applied to defective images of objects and . Control operators I and F are founded by training of neural network. And the trained neural network allows to influence on set of object parameters, which don't corresponds to required values.

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Tuesday 10 April 2007

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6575-01, Session 1

A system to automatically track humans and vehicles with a PTZ camera

M. Lalonde, S. Foucher, L. Gagnon, CRIM (Canada); A. Janelle, VideoStream Technologies Inc. (Canada)

The aim of this work was to develop a software module as an add-on to a commercial pan-tilt-zoom surveillance camera that allows autonomous object detection, recognition and tracking in outdoor urban environment. The module can discriminate between various moving objects and identify the presence of pedestrians or vehicles, track them, and optionally zoom on them, all in near real-time.

The module is composed of three main components: (1) background modeling (2) blob management and (3) tracking. The first component maintains a background model that allows it to produce a probability map that gives the probability for a pixel to be part of the background. Group of "connected" pixels that have a low probability forms a blob of potential interest that is further analyzed. The blob management component involves many operations. Blobs are first segmented based on the probability map and further tracked on several frames. Each of theses blobs initiates a candidate trajectory. Blobs are characterized by their shape, color and motion and are labeled as pedestrian, vehicle or other. Blobs in successive frame are fused together if there are similar in shape and color. If no matching blob is found, a bootstrap filter is applied locally in order to find the foreground region the most coherent with the blob motion and color. Finally, if the bootstrap failed the blob is rejected. Blob position and label are smoothed over time to increase identification robustness. Blobs with incoherent motion are rejected as they most probably refer to noise or stationary objects (e.g. tree leaves moving in the wind). The output is a list of regions of interest containing information about the candidate objects (label, position, speed, confidence level on the detection, etc.). Finally, the third module component allows tracking specific object despites changes in camera point of view. Tracking uses a particle filtering approach based on color histogram information, with the reference signature provided by the blob management component.

The module was developed for and integrated into VideoStream Technologies' VST OneTrack system, an intelligent tracking product using PTZ cameras. The system includes an API that enables modifications to detection and tracking characteristics on-line during the operational mode.

6575-02, Session 1

Visual signal processing using fly-eye-based algorithm to detect the road edge

N. Truong, U.S. Army Tank-Automotive Research, Development and Engineering Ctr.; W. Agassounon, Physical Sciences Inc.

Soldiers incurred injuries or even lost their lives due to rollover while driving military vehicles. A recent report identified that the one cause of rollovers is the driver's inability to assess rollover threats, such as cliff, soft ground, water, or culvert on the passenger side of the vehicle due to the vehicle's width. To reduce the number of rollover accidents, a road edge detection and driver warning system is being developed to detect the rollover threats on the passenger side of the vehicle and warns the driver. This system utilizes a unique, ultra-fast image processing algorithm based on neurobiology of insect vision and the study of fly vision. The system consists of a camera system, a long-range, planar laser scanner, a processing module in which a biomimetic image processor detects edges present in the images in real-time, and a Graphical User Interface (GUI) which displays the current road image, detected boundaries, and road side terrain steepness.

6575-03, Session 1

A progressive de-skewing technique for document image analysis

D. Charalampidis, Univ. of New Orleans; J. Haralambides, Barry Univ.

Skew detection is an important pre-processing step for several document analysis algorithms, including those in the context of law enforcement and intelligence scenarios. In this work, we propose a fast method that estimates skew angles based on a local-to-global approach. Most existing techniques, based on connected component analysis, group together pixels in order to form small document objects. Then, a Hough based technique is used to estimate the skew angle. The connected components detection process introduces an undesired overhead. Nearest neighbor based techniques examine only local pixel groups, thus failing to achieve great skew accuracy. Projection based techniques create 1-D profiles by successively rotating the document within a range of angles. Detection can be accelerated considering coarse to fine rotations. However, rotation and projection may exhibit significant overheads. The proposed technique is characterized by both high processing speed and high skew estimation accuracy. First, local areas are analyzed for an initial skew estimation by building angle histograms between pairs of random points or blocks. Following a local region selection process, a single histogram is obtained. Initially estimated angles are progressively refined by examining image objects at increasingly larger distances. Special attention is given to multiple column documents to eliminate deskew inaccuracies due to text line misalignments across columns. Experimental results have shown that the proposed technique yields superior results in terms of estimation accuracy and speed compared to recently published techniques.

6575-04, Session 1

Applications of adaptive feature-specific imaging

J. Ke, P. K. Baheti, M. A. Neifeld, The Univ. of Arizona

Feature-specific imaging (FSI) refers to any imaging system that directly measures linear projections of an object irradiance distribution. Numerous reports of FSI (also called compressive imaging) using static projections can be found in the literature. In this paper we will present adaptive methods of FSI suitable for the applications of (a) image reconstruction and (b) target detection. Adaptive FSI for image reconstruction is based on principal component features. The adaptive algorithm employs an updated training set in order to determine the optimal projection vector after each measurement. Adaptive FSI for detection is based on a sequential hypothesis testing framework. The probability of each hypothesis is updated after each measurement and in turn defines a new optimal projection vector. Both of these new adaptive methods will be compared with static FSI as well as conventional imaging.

6575-07, Session 2

Power spectrum weighted edge analysis for target detection in images

H. V. Karvir, J. A. Skipper, Wright State Univ.

Edge extraction is a commonly used target detection tool. However, noisy images often yield broken edge lines that lead to missed detections, and extraneous lines that may contribute to false target detections. We present a sliding-block approach for target detection using power spectrum analysis. In general, a line in an edge image that corresponds to a given frequency band will be represented as a peak in the Fourier domain at a radius corresponding to that frequency, and direction corresponding to the orientation of the structure in the spatial domain. Knowing the line width and spacing, a band-pass filter is designed to extract the Fourier peaks corresponding to the target edge lines and suppress noise in the image. These peaks are then detected by amplitude thresholding. The frequency band width and the subsequent spatial filter mask size are variable parameters for detection of target objects of different sizes under known imaging geometries. Many military objects, such as trucks, tanks and missile launchers, produce definite signatures with parallel lines, and the algorithm proves to be ideal for detecting such objects. Moreover, shadow-casting objects generally provide sharp edges and are readily detected. The block operation procedure offers the advantages of significant reduction of noise influence, improved edge detection, faster processing speed and versatility to detect diverse objects of different sizes in the image. With Scud missile launcher replicas as target objects, the method has been successfully tested on terrain board test images under different backgrounds, illumination and imaging geometries with cameras of different spatial resolution and bit-depth.

6575-08, Session 2

A local variance-based filtering method for enhancement in super-resolution image reconstruction

N. Unaldi, V. K. Asari, Old Dominion Univ.

A frequency domain approach for registration and bicubic interpolation combined with a local variance based edge boosting technique for the reconstruction of an enhanced high resolution image from a set of low resolution images is proposed in this paper. Planar shifts and rotations in the low resolution images are determined by a phase correlation approach performed on the polar coordinate representations of their Fourier transforms. Appropriate low pass filtering is performed on the image set to eliminate aliasing effects. The pixels of the low resolution images are expressed in the coordinate frame of the reference image and the image values are interpolated on a regular high-resolution grid. The non-uniform interpolation technique which allows for the reconstruction of functions from samples taken at non-uniformly distributed locations has relatively low computational complexity. Since bicubic interpolation produces blurred edges due to its averaging effect, the edges of the reconstructed image are enhanced using a local variance based approach. The normalized variance image obtained using an optimized mask size is scaled and added to the reconstructed image. Performance of the proposed super-resolution algorithm is evaluated by conducting experiments on both synthetic and real image sets and the preliminary results are encouraging in terms of fidelity, smoothness and computation time.

6575-10, Session 2

Local adaptive contrast enhancement for color images

J. Dijk, J. G. M. Schavemaker, K. Schutte, TNO-FEL (Netherlands)

A camera or display usually has a smaller dynamic range than the human eye. For this reason, objects that can be detected by the naked eye may not be visible in recorded images. Lighting is an important factor; improper lighting impairs visibility of details or even entire objects. When a human is observing a scene with different kinds of lighting, such as shadows, he will need to see details in both the dark and light parts of the scene.

For grey value images such as IR imagery, algorithms have been developed in which the local contrast of the image is enhanced by using local adaptive techniques. In this paper we present how such algorithms can be adapted so that the details in color images are enhanced while retaining the color information. We propose to apply the contrast enhancement to the luminance channel of the color signal. The color coordinates of the signal remain the same.

This technique can for instance be used by humans monitoring movements of people on a display in order to signal suspicious behavior. To do this effectively, specific individuals should be as easy to recognize and track as possible. This requires optimal local contrast, and is sometimes much helped by color - for instance, when tracking a person who is wearing colored clothes. In such applications, enhanced local contrast in color images leads to more effective monitoring.

6575-29, Session 2

All source adaptive fusion for aided navigation in non-GPS environment

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There is a critical need to provide fully autonomous robust navigation capability in GPS denied environments. The field of computer vision has witnessed many approaches for computing ego-motion from optical flow measurements. Other approaches combine precision radar sensors with digital terrain elevation databases. NG-ISWR and Air Force Research Lab Munitions directorate (AFRL/MN) have developed an innovative approach to adaptively fuse in real-time all available navigation data such as inertial measuring unit, GPS, altimeters, star tracker, passive imaging sensor, and digital elevation database. The integration of passive imaging sensors has some important advantages. Foremost, the sensors are completely passive, and can operate in any environment.

The All Source Adaptive Fusion (ASAF) approach performs at levels which are difficult to attain with single non-integrated navigation sources. ASAF is a novel approach which offers the following principle advantages: 1) is a modular software solution which can be easily integrated into existing and future platforms; 2) combines in real-time various sources of information as they become available; 3) can reduce weapon targeting error and provides more accurate sensor position critical to the coherent processing of the Synthetic Aperture Radar Sensors; 4) provides passive Moving Target Indication (MTI); and 5) supports both structure-from-motion (SFM) and motion-from-structure (MFS), thus providing 3-D digital terrain mapping in the presence of GPS. The 3-D digital map can be generated using ASAF software hosted on multiple surveillance UAVs flying over urban areas to provide routing support for other platforms and 3-D mapping.

NG-ISWR and AFRL developed an end-to-end simulation test bed environment for testing the overall system performance against key performance parameters. The test bed encompasses a 6-DOF simulation, physics-based scene generation tools, a suite of optical flow software, Digital Terrain Elevation Data, IMU/GPS, baro-altimeter, and star tracker simulations, and a suite of 2-D and 3-¬D extended and unscented Kalman filters. The test bed software is modular, and can be reconfigured to work in real-time mode to receive real imagery and navigation data. The real-time software will be ported to a real-time processor as a part of a flying test bed on a Cessna Grand Caravan. In this paper NG-ISWR and AFRL will present the performance of ASAF using both simulated and acquired data.

6575-30, Session 2

Steganalysis feature improvement using expectation maximization

B. M. Rodriguez II, G. L. Peterson, Air Force Institute of Technology; S. S. Agaian, The Univ. of Texas at San Antonio

In this paper the presence of steganography is conducted using two spatial domain feature extraction methods, the features are generated from simple first order statistical characteristics of the image. One of the methods presented is RS Steganalysis which focuses on detection of least significant bit embedding within digital images and determines the amount of steganographic content (message length) with the use of a polynomial “classifier.” For the purpose of this paper the method was modified to generate features which separate the feature space between clean images and steganalysis embedded images. The second spatial domain feature extraction method focuses on the development of weighted multi pixel comparison within digital images which is used to generate features for determine if steganographic content exists or not. By generating features from RS Steganalysis, and weighted multi pixel comparison for use during classification, an improved detection of LSB modifications is shown.

The classification method used in this paper is Expectation Maximization (EM) which is typically used as a clustering method with a Gaussian probabilistic model. The focus of EM algorithm is that given unknown data values the distribution from samples can be used to determine an estimate for the posterior probability of belonging to a given cluster. This method can be considered as two maximum likelihood approaches used for mixture analysis. With the various orientations, shapes and sizes that data clusters represent in feature space the distribution is improved with the use of mixed models which represent the distribution. The first is the mixture approach which maximizes the likelihood over the mixture parameters. The second is by classification based on maximizing the likelihood over the mixture parameters and identifying the class of the mixture component origin for each exemplar. The classification is improved with the use of a Bayes classification technique which uses the posterior probability, covariance matrix and the mean of the distribution representing the cluster.

6575-11, Session 3

Image data representation for efficient optimization of objective criterion

R. Sundaram, Gannon Univ.

Computing architectures to process image data and optimize an objective criterion are identified. One such objective criterion is the energy in the error function. The data is partitioned and the error function is optimized in stages. Each stage consists of identifying an active partition and performing the optimization with the data in this partition. The other partitions of the data are inactive i.e. maintain their current values. The optimization progresses by switching between the currently active partition and the remaining inactive partitions. In this paper, sequential and parallel update procedures within the active partition are presented. These procedures are applied to retrieve image data from linearly degraded samples. In addition, the local gradient of the error functional is estimated from the observed image data using simple linear convolution operations. This optimization process is effective when the dimensions of the data and the number of partitions increase. The purpose of developing such data processing strategies is to emphasize the conservation of resources such as available bandwidth, computations, and storage in present day Web-based technologies and multimedia information transfer.

6575-13, Session 3

Fast orthogonal heap transforms: theory and application in cryptography

A. M. Grigoryan, R. N. Raghunath, The Univ. of Texas at San Antonio

In general, the existent linear unitary transforms, such as the Fourier, Hadamard, and cosine transforms, are defined by matrices with constant coefficients. The complete systems of basis functions for these transforms do not use many properties of signals and their peculiarities. Many signals are composed by sinusoidal waves, and the Fourier transform can thus be applied for signal representation in the frequency domain. However, it is difficult to imagine that simple rectangular waves or their linear combinations are represented by sinusoidal waves in reality. In the discrete time case, it is also difficult to assume that any N-point signal has been created by sinusoidal waves of N different frequencies. This paper presents a novel approach to compose discrete orthogonal and unitary transforms that are induced by specified signals, which are considered to be generators of the transforms. Properties and examples of such transforms, which we call discrete heap transforms are given. The transforms are fast, because of a simple form of decomposition of their matrices, and they can be applied for signals of any length. Fast algorithms of calculation of the direct and inverse heap transforms do not depend on the length of the processed signals. In this paper, we demonstrate the applications of the heap transforms for transformation, processing, and reconstruction of 1-D signals and 2-D images, as well as in the cryptography, when transforming the plaintext by very short keys. Different examples of generating transformation and designing their keys are considered.

6575-14, Session 3

Wavelet priors for multiframe image restoration

P. M. Shankar, M. A. Neifeld, The Univ. of Arizona

It is known that the distributions of wavelet coefficients of natural images at different scales and orientations can be approximated by generalized Gaussian probability density functions, or mixtures of Gaussian densities. We exploit this prior knowledge within a novel statistical framework for multi-frame image restoration based on the maximum aposteriori (MAP) algorithm. We describe an iterative algorithm for obtaining a high-fidelity object estimate from multiple warped, blurred, and noisy low-resolution images. We compare our new method with several other techniques including linear restoration, L1 minimization, and minimum total variation. Both performance and computational issues will be discussed.

6575-15, Session 3

Elastic image registration using subspace constraints

A. S. Elsafi, R. Zewail, N. Durdle, Univ. of Alberta (Canada)

Image registration is the process of aligning two images or more from different viewpoints, at different instances, or at different modalities. In particular, the main goal of image registration is to determine the deformation, i.e. the geometric transformation relating images to be aligned. Some of the recent approaches in image alignment employ local deformation models followed by global regularization procedures to reject improper translations. In this article, we propose a new framework that incorporates prior deformation knowledge in order to obtain smooth transformation maps. During the training phase, an elastic image registration procedure is used to obtain the deformation fields by modeling the nonrigid deformations as locally affine and globally smooth flow fields. Next, the estimated geometric transformation maps are used to obtain a prior deformation model using two subspace projection techniques. The first method is principle component analysis (PCA) which uses only second order statistics. The second method is independent component analysis which uses higher order statistics in order to generate the deformation basis. A smooth deformation is now guaranteed by projecting the locally affine transformation onto a subspace of allowed deformations. One advantage of our approach is in its ability to guarantee smoothness without the need for iterative regularization. The new algorithm was validated using two databases, the Amsterdam library of images (ALOI). Our experiments demonstrate promising results in terms of mean square error and with significant reduction in computational time.

6575-27, Session 3

Data mining within digital images

T. P. Donovan, Midwestern State Univ.

Previous papers have studied the relationship between a bit map digital image and a given object, called the search object. In particular, to signal that it is likely, or not likely, that the search object appears, at least partially, in the image. Edges in the search object and in the digital image are then represented as objects, in the object oriented programming sense. Each edge or segment of an edge is represented as a normalized Bezier cubic parameterized curve. The normalization process is intended to remove the effect of size in the edge or edge segment. If the edges match and their orientation is the same, then the system signals that the object is likely to appear in the image and the coordinates in the image of the object are returned. The functioning of the algorithm is not dependent on scaling, rotation, translation, or shading of the image. This paper attempts to use data mining techniques together with these representations of edges in a collection of images to try to establish time and space relationships between occurrences in the various images. These relationships could then be used to advantage in supplying information for defense, corporate, or law enforcement intelligence.

6575-16, Session 4

Task-specific information: an imaging system analysis tool

A. Ashok, P. K. Baheti, M. A. Neifeld, The Univ. of Arizona

We present a novel method for computing the information content of an image. We introduce the notion of task-specific information (TSI) in order to quantify imaging system performance for a given task. This new approach employs a recently-discovered relationship between the Shannon mutual-information and minimum estimation error. We demonstrate the utility of the TSI formulation by applying it to several familiar imaging systems including (a) geometric imagers, (b) diffraction-limited imagers, and (c) projective/compressive imagers. Imaging system TSI performance is analyzed for three tasks: (a) detection, (b) classification, and (c) localization.

6575-17, Session 4

Application of particle analysis to transmission electron microscopy (TEM)

J. S. DaPonte, T. J. Sadowski, C. Broadbridge, A. Lehman, D. Krishna, L. Marinella, P. Munhutu, M. Sawicki, Southern Connecticut State Univ.

Nanoparticles, particles with a diameter of 1-100 nanometers (nm), are of interest in many applications including device fabrication, quantum computing, and sensing because their size may give them properties that are very different from bulk materials. Further advancement of nanotechnology cannot be obtained without an increased understanding of nanoparticle properties such as size (diameter) and size distribution frequently evaluated using transmission electron microscopy (TEM). In the past, these parameters have been obtained from digitized TEM images by manually measuring and counting many of these nanoparticles, a task that is highly subjective and labor intensive.

More recently, computer imaging particle analysis has emerged as an objective alternative by counting and measuring objects in a binary image. This paper will describe the procedures used to preprocess a set of gray scale TEM images so that they could be correctly thresholded into binary images. This allows for a more accurate assessment of the size and frequency (size distribution) of nanoparticles. Several preprocessing methods including pseudo flat field correction, FFT band pass filtering and rolling ball background correction were investigated with the rolling ball algorithm yielding the best results. Examples of particle analysis will be presented for different types of materials and different magnifications. In addition, a method based on the results of particle analysis for identifying and removing small noise particles will be discussed. This filtering technique is based on identifying the location of small particles in the binary image and removing them without affecting the size of other larger particles.

6575-18, Session 4

An architecture for the efficient implementation of compressive sampling reconstruction algorithms in reconfigurable hardware

F. E. Ortiz, E. J. Kelmelis, EM Photonics, Inc.

According to the Shannon-Nyquist theory, the number of samples required to reconstruct a signal is proportional to its bandwidth. Recently, it has been shown that acceptable reconstructions are possible from a reduced number of random samples, a process known as compressive sampling. Taking advantage of this realization has radical impact on power consumption and communication bandwidth, crucial in applications based on small/mobile/unattended platforms such as UAVs and distributed sensor networks. Although the benefits of these compression techniques are self-evident, they require the solution of nonlinear signal processing algorithms, which limit applicability in portable and real-time systems. In particular, (1) the power consumption associated with the difficult computations offsets the power savings afforded by compressive sampling, and (2) limited computational power prevents these algorithms to maintain pace with the data-capturing sensors, resulting in undesirable data loss. FPGA based computers offer low power consumption and high computational capacity, providing a solution to both problems simultaneously. In this paper, we present an architecture that implements the algorithms central to compressive sampling in an FPGA environment. We start by studying the computational profile of the convex optimization algorithms used in compressive sampling. Then we present the design of a pixel pipeline suitable for FPGA implementation, able to compute these algorithms. Performance estimates will be given for this computational kernel, and, finally, real-time video compression will be used as a case study, in order to evaluate the benefits and shortcomings of an FPGA-based computer for the processing associated with compressive sampling.

6575-19, Session 4

Median predictor-based lossless video compression algorithm for IR image sequences

R. Saran, H. B. Srivastava, A. Kumar, Instruments Research and Development Establishment (India)

Lossless image compression has long been recognized as an important need for several applications such as medical imaging, storage of critical IR image sequences and remote sensing. In this paper, we propose a simple, fast and easy to realizable-on-hardware lossless video compression algorithm that is well suited for IR imageries. Context based median predictor is used for prediction of reference pixels. Three neighboring pixels are used as context for prediction. Interframe coding is performed by encoding the redundant pixels in an efficient way, using one bit code. Finally the arithmetic coder is used as entropy coding. The proposed algorithm is able to operate in image compression mode as well as video compression mode. The proposed MPLVC (Median Predictor based Lossless Video Compression) algorithm is compared with JPEG-LS (Joint Pictures Experts Group-Lossless) and FELICS (Fast and Efficient Lossless Image Compression System) for compression performance. The results demonstrate that proposed algorithm is superior in encoding rate with added advantage in simplicity and ease in realization on hardware.

6575-20, Session 4

BTC-based object tracking

V. K. Mittal, C. R. Patil, Bharat Electronics Ltd. (India)

In this paper, we propose a method to evaluate the correlation of objects in successive frames. Block Truncation coding (BTC) is applied on selected object of image frame and N-tuple pattern is formed. Minimum hamming distance in two-dimensional plane is computed which is used to evaluate the amount of correlation among the selected objects in successive frames. Peak correlation provides the object shift, which is used for object tracking. The method is compared with existing mean based correlation, and transform based correlation techniques. In addition, the algorithm can be implemented in real time.

6575-06, Poster Session

Objectively assessing underwater image quality for the purpose of automated restoration

W. Hou, A. D. Weidemann, Naval Research Lab.

In order to automatically enhance and restore images, especially those taken from underwater environments where scattering and absorption by the medium strongly influence the imaging results even within short distances, it is critical to have access to an objective measure of the quality of images obtained. This contribution presents an approach to measure the sharpness of an image based on the weighted gray-scale angle (GSA) of detected edges. Images are first decomposed by wavelet transform to remove random and part medium noises, to augment chances of true edge detection. Sharpness of each edge is then determined by means of regression to determine the slope between gray-scale values of edge pixels versus locations, which is the tangent of an angle based on grayscale. The overall sharpness of the image is the average of each measured GSAs, weighted by the ratio of the power of high frequency components of the image from the first level decomposition details, to the total power of the image. Adaptive determination of edge widths is facilitated by values associated with image noise variances. To further remove noise contamination, edge widths less than corresponding noise variances or regression requirement are discarded. Without losing generality while easily expandable, only horizontal edge widths are used in this study. Standard test images as well as those taken from field are used to be compared subjectively. Initial restoration results from field measured underwater images based on this approach and weakness of the metric are also presented and discussed.

6575-12, Poster Session

Image quality measure using a quadtree homogeneity analysis

E. P. Lam, ThalesRaytheonSystems

Image quality is needed to compare processed images with known reference images when there is a need to evaluate the effectiveness of an image processing application. Examples that require image quality are comparison of compressed/uncompressed image with known reference image, comparison of reconstructed image with reference image, and comparison of two images in time. Objective image quality is a difficult research area because there is no widely accepted measure.

Historically, image quality is quantified as the mean squared error (MSE) or peak signal to noise ratio (PSNR). MSE and PSNR are used because they are simple to calculate and there is no measure that is widely accepted in the image processing community. MSE and PSNR fail to take into account the human visual system, because they examine only pixel values. One needs to look at the “big picture” of determining what a close an image is when compared to a reference image. Structure of the image is important because this provides global information about image quality.

Quadtree is performed recursively until all regions are homogeneous or until number of maximum decomposition is reached. The homogeneous regions also contain information of the global structure of the image.

Edge extraction fails to detect noise. Quadtree performs more recursive decomposition because the regions are not as homogeneous with noise. Using edge extraction and quadtree gives a more robust image quality metric.

An image quality score is derived from edge extraction and quadtree analysis. The edge extraction examine if an image is blurred. If an image is blurred, the edges are smeared. This causes the number of edge pixels to increase.

Quadtree analysis uses the quadtree boundaries. Quadtree analysis divides an image into four equal-sized quadrants. If a quadrant is heterogeneous, it is divided into to four equal-sized quadrants. The division of quadrants is terminated when the set number of levels is reached or if a quadrant is homogeneous in pixel values. This requires a quadrant metric. Some examples of a quadrant metrics are variance and entropy measures.

This presentation demonstrates an image quality metric that examines the image structure rather than using pixels intensity values. We examine the overall structure of the reference image and the analysis image. This is done with edge extraction and quadtree decomposition. Edge extraction gives us the global structure information. It is these edges that compose objects in the image.

6575-21, Poster Session

Comparison of thresholding techniques on nanoparticle images

J. S. DaPonte, T. J. Sadowski, C. Broadbridge, D. Day, A. Lehman, D. Krishna, L. Marinella, P. Munhutu, M. Sawicki, Southern Connecticut State Univ.

Thresholding is an image processing procedure used to convert an image consisting of gray level pixels into a black and white binary image. One application of thresholding is particle analysis. Once foreground objects are separated from the background, a quantitative analysis that characterizes the number, size and shape of particles is obtained which can be of assistance when evaluating a series of nanoparticle samples.

Numerous thresholding techniques exist differing primarily in how they deal with variations in noise, illumination and contrast. In this paper, several popular thresholding algorithms are qualitatively and quantitatively evaluated on transmission electron microscopy (TEM) and atomic force microscopy (AFM) images. Initially, six thresholding algorithms were investigated: Otsu, Riddler-Calvard, Kittler, Entropy, Tsai and Maximum Likelihood. The Riddler-Calvard algorithm was not included in the quantitative analysis because it did not produce acceptable qualitative results for several of the images in the series.

Two quantitative measures were used to evaluate these algorithms. One is based on comparing object area and the other is based on diameter before and after thresholding. For AFM images the Kittler algorithm yielded the best results followed by the Entropy and Maximum Likelihood techniques. The Tsai algorithm yielded the top results for TEM images followed by the Entropy and Kittler methods.

6575-23, Poster Session

Visualized measurement instrument based on electrical capacitance tomography technique

D. Chen, Harbin Univ. of Science and Technology (China)

The subject investigated in this paper is oil-water two-phase flow. The mathematic model of the oil-water two-phase distribution information is established based on double integral infinitesimal principle. An ECT measurement system of 8-electrode oil-water two-phase flow is set up that is comprised of a measurement circuit with stray-capacitance-resistance and a 80C32 SCM, both of which control the measurement among the pole plates and the capture system. The image reconstruction for oil-water two-phase cross-sectional image and the calculating of oil-water two-phase water content can be accomplished by an adaptive threshold image reconstruction algorithm, and the precision of reconstruction is about 1%, which can meet the need of identification of flow regime for oil-water two-phase flow. Therefore, it offers a new method for the visualized measurement of oil-water two-phase flow parameters.

6575-25, Poster Session

An approach of key frame extraction based on rough set

T. Wang, W. Yu, L. Chen, Chongqing Univ. of Posts and Telecommunications (China)

A shot’s key frame is a picture or a few pictures which can represent main content of the shot. Key frame extraction technique is the foundation of video analysis and content-based retrieval. At present, most key frame techniques are based on original video streams. Obviously it is inefficient that the video data is analyzed after decoding compressed streams. In this paper, we analyze the motion information extracted from MPEG compressed streams and present an approach of key frame extraction based on Rough Set. Experimental results show that this approach is computationally simple and the key frame extracted can represent the visual content.

6575-26, Poster Session

Linear restoration methods for wavefront coded imaging system based on digital photo camera

S. N. Starikov, M. V. Konnik, E. A. Manykin, V. G. Rodin, Moscow Engineering Physics Institute (Russia)

Linear methods of image restoration in hybrid optical-digital imaging system based on commercial digital SLR photo camera are described. In the image formation scheme of the camera is inserted a kinoform as coding diffractive optical element. Relatively low signal to noise ratio of the image sensor and extended PSF of the kinoform are special features of considered system. The images generated by numerical simulation of optical coding, and files of the real coded images obtained by digital photo camera with kinoform were used for image restoration in experiments. It is shown that modified evolutionary method, which employs regularization by Tikhonov, is the optimum one among linear methods of restoration. As a regularization term the noise to signal ratio as function of spatial frequencies was used. The analysis of boundary areas of the image (for noise approximation) and the postprocessing included contouring on the basis of posterization were performed in addition to improve quality of the restoration. The results on digital restoration of optically coded images are presented, application of preprocessing for improvement of quality of restoration of the truncated images is discussed, and values of parameters of preprocessing are estimated.

6575-28, Poster Session

Image denoising based on a mixture of bivariate laplacian distributions with local parameters in complex wavelet domain

H. Rabbani, M. Vafadust, Amirkabir Univ. of Technology (Iran)

The performance of estimators, such as maximum a posteriori (MAP), is strongly dependent on the accuracy of the employed distribution for the noise-free data and the accuracy of the involving parameters. In this paper, we select a proper model for the distribution of wavelet coefficients and present a new image denoising algorithm. We model the wavelet coefficients in each subband with a mixture of bi-variate Laplacian probability density functions (pdfs) using local parameters for the mixture model. This model allows capturing the heavy-tailed nature of the coefficients and to exploit the interscale dependencies of the wavelet coeffici-ents. The empirically observed correlation between the co-efficient amplitudes are locally calculated and used in order to characterize the model. We propose a MAP estimator for image denoising using this mixture model and the estimated local parameters. Our simulation results reveal that the proposed method outperforms several existing methods both visually and in terms of peak-signalto-noise-ratio (PSNR).

6576-36, Poster Session

Independent vector analysis for real world speech processing

T. Lee, Univ. of California/San Diego

No abstract available

6576-09, Session 2

Improved denoising approach using higher-order statistics

S. P. Kozaitis, Florida Institute of Technology

We reduced noise in signals by first estimating the higher-order statistics of a signal, then denoising based on those statistics. This is an improvement over previous methods that have only classified wavelet coefficients as either mostly noise or mostly signal. We ultimately used a detection algorithm derived from higher-order statistics and determined how noisy a wavelet coefficient was. Our approach showed improved results when compared to more conventional methods.

6576-29, Session 2

Design and implementation of a support vector machine using an optoelectronic matrix-vector multiplier

J. Gimeno Sarciada, H. Lamela, M. González, M. Jiménez, M. Ruiz-Llata, Univ. Carlos III de Madrid (Spain)

3-D image processing detection and identification of special features in real time video images is considered to be a very difficult problem to solve, this is mainly due to the following reasons: the large amount of information to be processed in a very short time and the differences in the shapes and lighting for the different objects to be processed. In order to process effectively a high amount of generalization is required for the processor to recognize the same object under different circumstances. SVM [1] is a possible solution to these problems.

Support Vector Machines, SVM are a new promising model for neural networks. They have remarkable properties of generalization and speed. Their performance is higher compared to other more conventional neural networks. One of their advantages is that they seek to lower structural error instead of training error putting an upper limit on their generalization capabilities. SVM training is the equivalent to solving a quadratic programming problem with box inequality restrictions, where the number of variables equals the number of support vectors.

Anguita et all. [2] have shown how a recurrent network can be used to solve a quadratic programming problem for SVM learning. They also presented a hardware scheme for an electronic development based on a recurrent analogue circuit. The scheme in [2] has been implemented in an analogue circuit with 40 support vectors, showing that analogue quadratic programming has several problems, the main one being that most of the actual processing is done by digital machines forcing an analogue-digital conversion before using the data. However their main advantage is their high speed, parallel processing and lower power consumption. R. Genov and G. Cawenberghs [3] have developed a mixed architecture with analogue processing of a digital input and output this overcomes the disadvantages and uses the strengths of analogue programming.

In this work we propose a new scheme using an optoelectronic matrix-vector multiplier using an optical broadcast neural processor [4], [5] this allows us to speed up the process on a mixed architecture that uses fast speed neural processing [6].

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6576-42, Session 2

Unsupervised learning with mini free energy

L. Miao, H. Qi, The Univ. of Tennessee; H. H. Szu, Office of Naval Research

No abstract available

6576-48, Session 2

Learning, entropy, free energy underlying commonality

J. E. Gray, Naval Surface Warfare Ctr.; H. H. Szu, Office of Naval Research

No abstract available

6576-53, Session 2

Design of a cylindrical fiber-optic lens focusing passive dual-color irspectra and readout

K. A. Byrd, Howard Univ.; H. H. Szu, Office of Naval Research and Howard Univ.

Following our first design concept paper, we have further explored the potential of detection at both the Middle Infrared (Mid-IR) and Long Infrared (Long-IR) spectrum emitted through elevated growth stress of lower GI tract tumors by insertion of a Fiber-Optic cylindrical lens into the rectum and colon. Electrophysiology suggests that we study the electrical properties of both biological cells and tissues. One may do this by intracellular recording or extracellular recording. To effectively access the relationship of the sigmoid colon and rectum in humans, it is important to study the electrical and mechanical activiation (pressure); we do this by close examination of pacesetter and action potentials, detection of various lower GI tract arrhythmias and studying early developmental symptoms of the “angiogenesis effect”. Making use of non-sequential ray tracing software (ASAP 8.0.3 Complete + BIO), we seek to design a plastic lens of appropriate index of refraction for the focussing of Long-IR (8-12um) onto the axis and a Mid-IR (3-8um) on about 1/2 the radius of the cylindrical surface. Intensity (passive dual-color IR spectrograms) will be measured via this so-called “rectomoscopeTM” and correlated with various transcutaneous and invasive electrophysiological measurements.

6576-14, Session 3

Singular value decomposition (SVD)-based segmentation of multicomponent signals

S. Rajan, Defence Research and Development Canada (Canada); R. Doraiswami, Univ. of New Brunswick (Canada)

A novel methodology for segmentation of multi-component signals buried in additive white noise using singular value decomposition (SVD) in the joint time-frequency domain is proposed. The segmentation problem is formulated using the paradigm of binary statistical hypothesis testing. Using the Generalized Likelihood Ratio (GLR), the optimal test statistic is shown to be the sum of squares of the norm of the principal components of the signal in the joint time-frequency domain. The signal-to-noise ratio (SNR) of the dominant signal frequencies is assumed to be sufficiently high to determine the bandwidth of the signal components. This methodology may be applied in several areas of signal processing including wideband RF signals, radar signals, audio and speech signals, and biological signals. The proposed segmentation methodology is evaluated on speech and heart sound signals.

To illustrate our approach, we use the Morlet wavelet transform to obtain a transformed signal that has better time and frequency localization and also attenuate noise components. The statistical decision theory is then applied to segment the components in the time-frequency domain. The test statistics or the features for isolating the components are the principal components of the wavelet transformed signal. This test statistics may be viewed as a mapping from the time domain to the signal plus noise subspace in the time-frequency domain. The crucial problem of determining the parameters governing the test statistic and the threshold is solved by using the principal component analysis of the signal. As the requirements for time domain and frequency domain segmentation are contradictory, a two stage segmentation scheme (time domain and frequency domain, not necessarily in that order) is then used to segment the signals.

6576-22, Session 3

Analysis of breast MRI data dased on (topographic) independent and tree-dependent component analysis

A. Saalbach, Univ. Bielefeld (Germany); O. Lange, Florida State Univ.; T. Nattkemper, Univ. Bielefeld (Germany); A. Meyer-Bäse, Florida State Univ.

In recent years, dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) has become a powerful complement to X-ray based mammography in breast cancer diagnosis and monitoring. In DCE-MRI the time related development of the signal intensity after the administration of contrast agent can provide valuable information about tissue characteristics at pixel level. The integration of this information constitutes an important step in the analysis of DCE-MRI data.

In this contribution we investigate the applicability of three different approaches from the field of independent component analysis (ICA) for feature extraction and image fusion in the context of DCE-MRI data. Next to FastICA, Tree-Dependent Component Analysis and Topographic ICA are applied to twelve clinical cases from breast cancer research with a histopathologically confirmed diagnosis. The outcome of all algorithms is quantitatively evaluated by means of Receiver Operating Characteristics (ROC) statistics. Additionally, the estimated components are discussed exemplarily and the corresponding data is visualized.

The study suggests that all of the employed algorithms show some potential for the purposes of lesion detection and subclassification and are rather robust with respect to their parameterization. However, with respect to ROC analysis Tree-Dependent Component Analysis tends to outperform all other algorithms as well as with regarding to the consistency of the results.

6576-23, Session 3

Exploratory analysis of functional MRI analysis using HSOM and HTMP

A. Saalbach, Univ. Bielefeld (Germany); O. Lange, A. Meyer-Bäse, Florida State Univ.

As a complement to model based approaches for the analysis of functional Magnetic Resonance Imaging (fMRI) data, methods of exploratory analysis offer interesting options. While unsupervised clustering techniques often allow for the detection of interesting patterns in the data, topographic mapping techniques such as the Self-Organizing Map (SOM) or the Topographic Mapping for Proximity Data (TMP) provide additionally a structured overview of the data.

In this contribution we investigate the applicability of two recently proposed variants of these algorithms which make use of concepts from non-Euclidean geometry. Compared to standard methods, both approaches provide more freedom for the representation of complex relationships in low-dimensional mappings while they offer a convenient interface for the visualization and exploration of large data sets.

Based on data from a fMRI experiment, visual data representations are generated and the employed techniques are quantitatively evaluated.

6576-120, Session 3

Multispectral MWIR image feature extraction using filters derived from independent component analysis

S. K. Chari, C. E. Halford, A. L. Robinson, E. L. Jacobs, Univ. of Memphis

This paper presents the use of independent component spatio-spectral filters (SSF) for multispectral infrared image segmentation. The SSFs are the reconstruction filters generated by applying independent component analysis to multispectral infrared images. It is known that these filters of natural visible color images show some form of color opponency similar to the neurons in the primate visual cortex. This study determines if any such spectral opponency exists in the SSFs derived from multispectral infrared images. SSFs of natural and man made materials in the mid wave infrared region are compared and contrasted. Two approaches are used to obtain feature vectors for image segmentation. In the first technique separate spatial energy vectors for each band are generated. While in the second method combined spatio-spectral energy vectors are generated using the opponency associated with the SSFs. When images are filtered with SSFs, the objects in the image tuned spectrally and spatially to that particular filter would respond with the highest energy output. These energy vectors are further processed and fed to a clustering algorithm for image segmentation. These SSFs learn their spectral opponency, spatial frequency and orientation characteristics from the data itself. The advantages of using such filters over gabor filters, discrete wavelet transforms and fractals for multispectral feature vector generation are studied.

6576-37, Poster Session

A taste of compressed sensing

R. A. DeVore, Univ. of South Carolina

No abstract available

6576-02, Session 5

Improved total variation algorithms for wavelet-based denoising

G. R. Easley, System Planning Corp. and Univ. of Maryland/College Park; F. Colonna, George Mason Univ.

Many improvements of wavelet-based restoration techniques suggest the use of the total variation (TV) algorithm. The concept of combining wavelet and total variation methods seems effective but the reasons for the success of this combination have been so far poorly understood. We propose a variation of the total variation method designed to avoid artifacts such as oil painting effects and is more suited than the standard TV techniques to be implemented with wavelet-based estimates. We then illustrate the effectiveness of this new TV-based method using some of the latest wavelet transforms such as contourlets and shearlets.

6576-04, Session 5

Wavelet analysis applied to smart structure carbon composite material: past achievements and future challenges

K. J. Jones, Rice Univ.

Objective. Nanoengneering is beginning to achieve new levels in Smart Structures with carbon composite materials embedded with Carbon Nano Tubes (CNT). This paper will examine past wavelet analysis applied to composite-embedded optical fibers and extend the approach to CNT sensor for Nanoengneering.

Background. With a carbon-fiber composite wing, Boeing is pushing the envelope of aviation design in its 787 jetliner. With composites, designers are allowed to tailor features such as subtle curvature variation all over the wing. They can produce the same or more tilt while reducing drag. Other advantages are reduced weight, resistance to corrosion and fatigue. Embedded CNT anemometers will provide the aircraft with a nano-smart skin.

What Will Be Achieved. Carbon Nano Tubes (CNT) have outstanding electrical and mechanical properties. It can be either metallic with conductivity of Silver or Gold, semiconductor or isolator of very large bandgap depending on how a thin layer or layers of carbon hexagon rolls into a tubular structure called chirality. They are extremely strong material, light weight, good thermal conductivity and chemical stability. Useful CNT devices are being reported: design of solar voltaic cells (Ou and Szu, 2006), nanometer-scale resonant cavities (R. O. Claus et al., 2005) and self-assembled nanostructured multilayer spectral filters (R. O. Claus et al. 2006).

Earlier carbon fiber composites relied on embedding sensors (MEMS or Fiber Bragg Gratings (FBG)) to detect either damage or pressure and temperature. The author applied wavelets both for edge detection (SPIE 3986-52) and crack detection (SPIE 4328-32) in composite embedded fiber optic sensors. The first paper analyzed the output of a diffraction grating, demonstating that wavelets could be applied to very fine dimensions. The same methods of wavelet analysis will be extended to Carbon Nano Tubes to achieve a similar dimensional level of resolution.

6576-07, Session 5

Video watermarking capacity in the DWT hierarchy

M. P. Mitrea, O. Dumitru, F. Prêteux, Institut National des Télécommunications (France)

Watermarking enforces property right for digital video: a mark is transparently embedded into original data. The true owner is identified by detecting this mark. The robust watermarking techniques allow the mark detection even when the protected video is attacked.

We advance a theoretical method to evaluate the maximum quantity of information which can be inserted into the 2D-DWT coefficient hierarchy, for prescribed transparency and robustness. Note that generally the better the transparency and robustness, the smaller the mark size.

This approach relies on the noisy channel modelling any watermarking technique: the mark is a sample from the information source while the original video and the attacks play the noise role. Within this mathematical framework, the maximal mark size is expressed by the channel capacity. In order to ensure the accuracy in capacity evaluation, our paper do not relay on any assumption concerning the noise model. Instead, it carries out an in-depth analysis on the statistical behaviour (stationarity and probability-density function) of the real life attacks (compressions, rotations, linear filtering, StirMark attack).

The experiments are carried out in cooperation with the SFR (Vodafone group) mobile service provider in France. They are performed on 10 low rate video sequences of 30 minutes each and compares among them three types of bi-orthogonal DWT, namely the (2,2), (4,4), and (9,7). The overall results (theoretical and experimental) are discussed not only for conventional watermarking applications, but for hidden channel, indexing and retrieval applications, as well. Perspectives are also open with respect to the MPEG standardisation.

6576-08, Session 5

Wavelet-based fusion approach using unique reconstruction approach

S. P. Kozaitis, M. Ouendeno, Florida Institute of Technology

We reconstructed fused cross-sensor image data in a unique fashion that attempts preserve sensor-unique characteristics. We use an inverse transform that is designed to simultaneously preserve the most desirable information characteristics from each image after fusion while minimizing reconstruction error. We compared different fusion algorithms, and wavelets based on smoothness. Using this approach could form the basis of an image fusion approach for a variety of applications.

6576-15, Session 5

Wavelet-based texture image classification using vector quantization

E. P. Lam, ThalesRaytheonSystems

Classification of image segments on textures can be helpful for target recognition. Sometimes target cueing is performed before target recognition. Textures are sometimes used to cue an image processor of a potential region of interest. In certain imaging sensors, such as those used in synthetic aperture radar, textures may be abundant. The textures may be caused by the object material or speckle noise. Even speckle noise can create the illusion of texture, which must be compensated in image pre-processing.

There are many approaches of texture classification. Some use Fourier-based methods while the recent approaches use a multiple channel approach. It was shown in recent works that using wavelet decomposition can perform classification using a two-channel subband coder. Instead of performing a dyadic wavelet decomposition in some image compression methods, a wavelet packet decomposition can be performed. The dyadic wavelet tree does not perform well with texture classification, because the decomposition approach emphasizes the lower spatial frequency components. Textures often have mid and high spatial frequency components that make the wavelet packet ideal for this.

In this paper, we will discuss how to perform texture classification but constrain the number of wavelet packet node decomposition. This allows the decomposition to stop at a finite time. If not constrained, the new approach may run indefinitely. The new approach performs a two-channel wavelet decomposition. Comparing the strength of each new subband with others at the same level of the wavelet packet determines when to stop further decomposition. This type of decomposition is performed recursively. Once the decompositions stop, the structure of the packet is stored in a data structure. Using the information from the data structure, dominating channels are extracted. These are defined as paths from the root of the packet to the leaf with the highest strengths. The list of dominating channels are used to train a learning vector quantization neural network.

A quadtree based segmentation approach can be employed before use of texture classification. The size of image chip extracted from segmentation can affect texture classification because image energy is affected by chip size. Therefore, it may not be possible to compare the feature vector with the known feature space vectors of textures from the database. Because of the nature of the feature vector extraction, it is possible for the feature vector of the unknown texture to be smaller in size, compared to the feature vector size of the database. The purpose of quadtree segmentation is to achieve homogeneity.

Using the wavelet decomposition approach, it is found that the all images have one common dominant channel. This dominant channel corresponds to the low frequency spatial frequencies. Because we are not interested in using the energy of the channels, the dominant channel is discarded during the feature extraction. The dominant channel is used for further wavelet decomposition, if needed. Since all images have this common dominant channel, it does not help in distinguishing between texture classes.

6576-44, Session 5

Next gen wavelets down-sampling preserving statistics

H. H. Szu, Office of Naval Research; L. Miao, The Univ. of Tennessee; P. Chanyagon, The World Bank (Thailand); M. Cader, The World Bank

No abstract available

6576-47, Session 5

Adaptive Rochio text classifier using wavelets

P. H. Carter, Naval Surface Warfare Ctr.

No abstract available

6576-34, Poster Session

Nanorobot assembly carbon nanotubes for mid-IR sensor

N. Xi, Michigan State Univ.

No abstract available

6576-45, Session 7

Nanotechnology at NSWC

F. Santiago, Naval Surface Warfare Ctr.

No abstract available

6576-46, Session 7

Future direction of nanometrology and nanomanufacture

K. W. Lyons, National Institute of Standards and Technology

No abstract available

6576-50, Session 7

Taiwan nanotechnology

M. Wu, Academia Sinica (Taiwan)

No abstract available

6576-35, Poster Session

Wellness engineering and wellness doctors as gate keepers of aging baby boomers

H. H. Szu, Office of Naval Research

No abstract available

6576-13, Session 9

Pavement crack evaluation with bidimensional empirical mode decomposition

A. Y. Ayenu-Prah, Jr., N. Attoh-Okine, Univ. of Delaware; S. Bhuiyan, The Univ. of Alabama/Huntsville

Crack evaluation is essential for effective classification of pavement cracks. Digital images of pavement cracks have been analyzed using techniques such as fuzzy set theory and neural networks. Bidimensional empirical mode decomposition (BEMD), a new image analysis method recently developed, can potentially be used for pavement crack evaluation. BEMD is an extension of the empirical mode decomposition (EMD), which can decompose non-linear and non-stationary signals into basis functions called intrinsic mode functions (IMF). IMFs are monocomponent functions that have well defined instantaneous frequencies. EMD is a sifting process that is non-parametric and data-driven; it does not depend on an a priori basis set. It is able to remove noise from signals without complicated convolution processes. BEMD decomposes an image into intrinsic mode surfaces (IMS), which are the two-dimensional analogs of IMFs. A synthetic image will be generated and analyzed with BEMD, before and after the introduction of noise that may simulate the existence of a crack. Results of the analysis can help in crack evaluation for pavement crack classification.

6576-31, Session 9

Passive unattended sensors

R. W. Van Dine, DKL International, Inc.

DKL is developing sensors to enhance the survivability of ground assets in an urban combat environment by providing unattended detection of human electromagnetic fields. This will provide the warfighter with a potent tool for force protection and asymmetric warfare countermeasures. The sensor detects changes in the charge pattern in the detection area. Specifically, it detects the change in “volts per meter” in the ultra-low-frequency (ULF) .2 to 10 Hz range.

When a person walks into the detection area, the person’s ULF electric field changes the charge pattern on the materials in the detection area. The field of the person couples weakly to the materials in the detection area. The person’s movement changes that capacitive charge coupling and creates a charge redistribution on the materials in the detection area. When the volts per meter pattern shift the circuit detects and displays the changing voltage pattern. If the person stands still the charges equalize and the voltage pattern stabilizes. With each step or slight movement the person creates another charge redistribution or shift in the voltage pattern. During periods when the charges are equalized (the person is not moving) the circuit no longer can detect the presence of that person. The system detects movement only in a totally passive manner.

6576-33, Session 9

Noninvasive methodology for wellness baseline profiling

D. W. Chung, Chung Yuan Christian Univ. (Taiwan); Y. S. Tasi, National Huwei Institute of Technology (Taiwan); S. Miaou, W. H. Chang, Chung Yuan Christian Univ. (Taiwan); Y. Chang, Chung Yuan Christian Univ.; S. Chen, Y. Hong, C. S. Chyang, Q. Chang, Chung Yuan Christian Univ. (Taiwan); H. Hsu, J. Hsu, W. Yao, M. Hsu, Ming-Shen Hospital (Taiwan); M. Chen, S. Lee, National Taiwan Univ. (Taiwan); C. Hsu, Consultant; L. Miao, The Univ. of Tennessee; K. A. Byrd, M. F. Chouikha, X. Gu, Howard Univ.; P. C. Wang, Howard Univ. Hospital; H. H. Szu, The George Washington Univ.

Braun wrote the first paper in the Hungarian in 1966 about enzyme studies of saliva in diabetics. Then, Mehrotra et al of the India Dental Association wrote about the correlation of salivary sugar and blood sugar with periodontal health and oral hygiene status among diabetics & non-diabetics in 1968. The idea of saliva may serve as a smoking minor image of blood in terms of immunoglobulin subclass for bactericidal effect (Ig G, Ig A, Ig M, etc.). In fact, NIH has considered it as an indicator for when it is used to measure the immune response of blood taken from infant. All of these variability’s will be quantified by the new proposal of a wellness baseline ensemble profile conducted at household.

6576-43, Session 9

EMD of real world data analysis

N. E. Huang, NASA Goddard Space Flight Ctr.

No abstract available

6576-10, Session 10

Smart Altera firmware for DSP with FPGAs

U. H. Meyer-Bäse, R. Perry, A. Meyer-Bäse, Florida State Univ.; A. Vera, M. Pattichis, The Univ. of New Mexico

Field-programmable gate arrays (FPGAs) are on the verge of revolutionizing digital signal processing. Many front-end digital signal processing (DSP) algorithms, such as FFTs, multi-channel filterbanks, or wavelets, to name just a few, previously built with ASICs or programmable digital signal processors, are now most often replaced by FPGAs.

Design of current DSP applications using state-of-the art multi-million gates devices requires a broad foundation of the engineering skills ranging from knowledge of hardware-efficient DSP algorithms to CAD design tools. The requirement of short time-to-market, however, requires to replace the traditional HDL based designs by a MatLab/Simulink-based design flow. This not only allows the over 1 million MatLab users to design FPGAs but also to by-pass the hardware design engineer and leads therefore to shorter development time.

We have evaluated the Altera/Simulink tool flow used for a University design environment and present design experience of a semester course at FAMU-FSU College of Engineering. We talk about required background knowledge, key target smart firmware for FPGAs and possible advanced designs, e.g. FFT and multirate filter banks and wavelets designed by students with only basic logic experience.

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6576-11, Session 10

FPGA wavelet processor design using language for instruction-set architectures (LISA)

U. H. Meyer-Bäse, Florida State Univ.; M. Witte, RWTH Aachen (Germany); S. Rao, K. Lenk, Florida State Univ.; H. Meyr, RWTH Aachen (Germany)

A fundamental change is taking place in the world of logic design. A new generation of design tools is empowering software developers to take their algorithmic expressions straight into hardware without having to learn traditional hardware design techniques. These tools and associated design methodologies are classified collectively as electronic system level (ESL) design, broadly referring to system design and verification methodologies that begin at a higher level of abstraction than the current mainstream register transfer level (RTL).

A microprocessor, a much more efficient way of using silicon than a direct hardware implementation of an algorithm, has become in recent years one of the most important IP blocks for FPGA vendors. Altera for instance reported that they sold 10,000 systems of the NIOS microprocessor development systems in the first 3 year alone. Xilinx reported a even larger number of “Downloads” of their MicroBlaze microprocessors.

The design of an microprocessor is a long, tedious, and error-prone task consisting of typically three design phases: architecture exploration, software design (assembler, linker, loader, profiler), architecture implementation (RTL generation for FPGA or ASIC) and verification. The Language for instruction-set architectures (LISA) allows to model a microprocessor not only from instruction-set but also from architecture description including pipelining behavior that allows a design and development tool consistency over all levels of the design.

To explore the capability of LISA processor design platform (LPDP) we present in this paper three microprocessor design that implement a 8/8 wavelet transform processor that is typically used in today’s FBI fingerprint compression database. We have designed a 3 pipelined 16 bit RISC processor (NanoBlaze), since Xilinx only offer 8 bit microcontroller (PicoBlaze) and 32-bit RISC microprocessor (MicroBlaze) but typical DSP object are more efficient handled by 16 bit processor. Although RISC is usually considered a “fast” processor due to design concept like constant instruction word size, deep pipelines and many general purpose register, it turns out that for DSP operation consume essential processing time in a RISC processor. In a second step we have used design principle from programmable digital signal processor (PDSP) to improve the throughput of the DWT processor. A multiply-accumulate operation along with indirect addressing operation were the key to achieve higher throughput. A further improvement is possible with today’s FPGA technology. Today’s FPGAs offer a large number of embedded array multipliers and it is now feasible to design a “true” vector processor (TVP). A multiplication of two vector can be done in just one clock cycle with our TVP, a complete scalar product in two clock cycles. Code profiling and FPGA synthesis results are provided that demonstrate the essential improvement that a TVP has compared with a traditional RISC or PDSP design.

6576-17, Session 10

Neural dynamic optimization for unmanned aerial vehicle trajectory design

P. Xu, A. Verma, Knowledge Based Systems, Inc.

Online aerial vehicle trajectory design and reshaping is desired for a class of autonomous aerial vehicles in order to achieve real time decision making and mission planning capability. An aerial vehicle can be modeled as a nonlinear multi-input-multi-output (MIMO) discrete system. The inputs include the control parameters and the current system states describing the vehicle spatial coordinates and vehicle velocity for each degree of freedom. The outputs are the new system states. Given a task, the goal of an ideal trajectory design system is to generate a series of control parameter inputs that satisfy the objectives of the task under various disturbances and model uncertainties.

Conventional approaches such as Dynamic Programming (DP) suffer from the nonlinearity of the MIMO system and the high-dimensionality of the system state space. In this paper, we apply a Neural Dynamic Optimization (NDO) based approach to overcome these difficulties. A NDO model consists of two modules. One module simulates the nonlinear MIMO system and the other module, a multilayer perceptron (MLP) neural network, generates the control parameters online. The inputs of the MLP are the time-variant states of the MIMO systems. The outputs of the MLP, the control parameters, will be used by the MIMO to generate new system states. By such a formulation, a NDO model can approximate the time-varying optimal feedback solution. In addition, the MLP can also receive an optional reference inputs to force the control parameters to follow them to achieve some desired goal. Our preliminary result on a simplified UAV model is promising. We are conducting research on applying the method on a real vehicle with more inputs.

6576-30, Session 10

3D map generation for biomimetic applications using a net work of multi-static radar sensors

S. L. Kadambe, Office of Naval Research

A novel technique based on tomography has been developed for 3D map generation using the received backscattering data from different radar sensors. In this talk this technique will be described and also results using real radar backscattered data will be provided. A description of how this 3D maps can be used for biomimetics will also be provided.

6576-40, Session 10

Analog smart sensors

D. W. Chung, Chung-Yuan Christian Univ. (Taiwan)

No abstract available

6576-18, Session 12

An FPGA-based rapid prototyping platform for wavelet-based coprocessors

G. A. Vera, The Univ. of New Mexico; U. H. Meyer-Bäse, Florida State Univ.; M. Pattichis, The Univ. of New Mexico

MatLab/Simulink-based design flows are being used by DSP designers to improve time-to-market of FPGA implementations. Commonly, digital signal processing cores are implemented to be integrated in an embedded

system as coprocessors. Existing CAD tools do not fully address the integration of a DSP coprocessor design into an embedded system design. This integration might proof to be time consuming and error prone. It also requires significant knowledge of embedded systems and computer architecture details from a DSP designer.

We present a prototyping platform that allows rapid integration of embedded systems with wavelet-based coprocessors. The platform comprises software and hardware modules that allow a DSP designer a painless integration of a coprocessor with a PPC-based embedded system. The platform is extensible to different hardware providers and it has a wide range of applications, from industrial to educational environments.

6576-27, Session 12

Autonomous UAV techniques

M. Hsu, The George Washington Univ.; H. H. Szu, Office of Naval Research

The UAVs (Unmanned Air Vehicles) are used worldwide in different civil applications, such as oil pipeline surveillance, precision farming, forest fire fighting (yearly), search and rescue, boarder patrol, etc. The related industries of UAVs can create billions of dollars per year. However, the road block of adopting UAVs is that it is against FAA (Federal Aviation Administration) ATC (Air Traffic Control) regulations. In this paper, we purpose the collage winding theorem and integrated with other current technologies, such as voice recognition, etc, to match the regulations of FAA ATC. The autonomous UAVs must have the abilities of seeing to avoid air collisions and hearing to follow the instructions of ATC.

6576-32, Session 12

Automatic target recognition on unidentified explosive ordnance

R. N. Madan, Office of Naval Research

No abstract available

6576-19, Session 11

Design of hybrid neuron elements for spatio-temporal algebraic integration and nonlinear transformation of time-pulse encoded optical signals

V. G. Krasilenko, Open International Univ. of Human Development (Ukraine); V. F. Bardachenko, Institute of Cybernetics (Ukraine); A. I. Nikolsky, A. A. Lazarev, Vinnitsa National Technical Univ. (Ukraine)

In the paper we show a necessity and actuality of creation of macroelement (matrix) base, neuromodule array of physical hardware models of neurons with flexibly programmable extended spectrum of functions and operations, and also with possibility to select required accuracy, type of nonlinear transformation and training.

Further we consider the results of design and simulation of hybrid neurons with multichannel spatio-temporal algebraic accumulation - integration of optical signals.

We consider aspects of realization of such base elements with time-pulse (in particular pulse-width modulation). We show advantages of the offered optoelectronic realization of neurons with such encoding for the management by non-linearity of transformation and for realization of the algebraic spatio-temporal weighed adding-integration. Such neurons integrators possessing circuit relative simplicity, can be provided with flexibility by intellectual properties: by possibility of their training, adaptation.

We show aspects of their realization on a structure which is realized by the phototransformers, including time-pulse, devices of selection-storage on the base of currents mirrors and comparators on CMOS-transistors, saw-tooth current generators and analog multiphase memory structures of static-dynamic type. Such devices has the technical parameters: consumable power - 100-500 uW, temporal time (the period of time-pulse variables) - 0.1-1ms, optical power of input signals - 0.2- 20 uW; total delays - 1us , the non-linearity of saw-tooth current - 1 %, the number of integral signals - from 2 to 10, time integrations (number of time periods of integration) - from 10 to 100 at accuracy level of 1% (or integration error).

We consider the possible modifications of neurons-integrators with the purpose of improvement of their uses properties and improvement of their technical parameters, separately on realization of algebraic integration of input signals with non-synchronized fronts.

6576-20, Session 11

Programmed relational optoelectronic time-pulse coded processors as element basis for sorting neuron networks

V. G. Krasilenko, Open International Univ. of Human Development (Ukraine); V. F. Bardachenko, Institute of Cybernetics (Ukraine); A. I. Nikolsky, A. A. Lazarev, Vinnitsa National Technical Univ. (Ukraine)

In the paper we show that the biologically motivated conception of the use of time-pulse encoding gives the row of advantages (single methodological basis, universality, simplicity of tuning, training and programming et al) at creation and designing of sensor systems with parallel input-output and processing, 2D structures of hybrid and neuro-fuzzy neurocomputers of next generations.

Further we show principles of construction of programmable relational optoelectronic time-pulse encoded processors, continuous logic, order logic and temporal waves processes, that lie in basis of the creation. We consider a structure, executing extraction of analog signal of the set grade (order), sorting of analog and time-pulse coded variables. We offer optoelectronic realization of such base relational elements of order logic, that consists of time-pulse coded phototransformers (pulse-width and pulse-phase modulators) with direct and complementary outputs, sorting network on logical elements and programmable commutations blocks. We make estimations of basic technical parameters of such base devices and processors on their basis by simulation and experimental research: power of optical input signals - 0.200-200 uW, processing time - ten microseconds, supply voltage - 1.5-10 V, consumption power - tens - hundreds of microwatts, extended functional possibilities, training possibilities. Further we discuss some aspects of possible rules and principles of training and programmable tuning on the required function, relational operation and realization of hardware blocks for modifications of such processors. We show as on the basis of such quasiuniversal hardware simple block and flexible in the programmable tuning of base structures of processors it is possible to create sorting machines, neuron networks and hybrid data-processing systems with the untraditional numerical systems and pictures operands.

6576-21, Session 11

A weighted quadratic asymptotic analysis of classifier design with extensions to finite-size training sets

G. J. Dobeck, Naval Surface Warfare Ctr.

An asymptotic theory is presented for the analysis of classifiers whose designs are based on optimizing a cost function that governs how well the classifier estimates class membership from a set of training feature vectors. This theory gives a fundamental understanding of how different cost functions favor certain subsets of the training data when approximating the position of decision boundaries in feature space. Thus one can quantify the limitations that the choice of a specific cost function imposes on classifier design. This work extends previous work that relates classifier design to approximations of the Bayesian a posteriori probability of class membership (e.g., “Any Reasonable Cost Function Can be Used for A Posteriori Probability Approximation by M. Saerens, et al, IEEE Transactions on NN, September 2002). The paper shows how different cost functions, in concert with the underlying joint class pdf, determine where class decision boundaries are positioned in feature space. For example, our analysis shows that mutual information criterion positions decision boundaries between dominate class modes of the joint class pdf, while the mean squared error criteria positions these boundaries where the conditional class probabilities are approximately equal. Therefore, depending on the classification problem and what training data is available, some cost functions will lead to a better classifier design than others. This leads to several implications that are discussed. Several other criteria are analyzed in the paper including the generic Lp norm for p greater than or equal to zero. In addition, a finite-version of the theory is presented that bridges the gap between asymptotic theory (where the assumption is that the number of training samples goes to infinitity) and strictly finite-size training sets.

6576-25, Session 11

Fault tolerant adaptive routing for heterogeneous networked embedded systems

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Continued advances in semiconductor technologies are enabling a growing number of compact physical devices to be imbued with computing and communications capabilities. As microprocessors continue to shrink, wireless radios are also becoming more powerful and compact. Heterogeneous networked embedded systems comprising a large number of sensing, computing, and communication devices are promising with unlimited applications. It also poses a host of challenges qualitatively different from traditional stand-alone embedded computers or mobile ad-hoc networks, because they will be more tightly integrated with their environments, more autonomous, and more constrained in resources. Since the wireless links could be unreliable and the processing nodes could be unavailable, fault tolerance becomes an important issue for networked embedded systems. In this paper, we address this issue by presenting a set of adaptive routing algorithms for execution of distributive computing tasks. A turn model based adaptive algorithm is adopted and modified for networked embedded systems. Turn model shows an acceptable level of fault tolerance with existence of disable nodes in the network. Furthermore, virtual channel technique is introduced to improve the fault tolerant capacity for data communications. For a large-scale data-intensive collaborative computing task, the simulation demonstrates that adaptive routing can significantly improves the fault tolerance capacity and accommodate the dynamically changing networked environment.

6576-28, Session 11

Hardware implementation of a neural vision system based on a neural network using integrated and fire neurons

M. González, H. Lamela, M. Jiménez, J. A. Gimeno, M. Ruiz-Llata, Univ. Carlos III de Madrid (Spain)

In the high level capacity of parallel processing which biological systems display, the connectivity which neurons possess is fundamental. Generally they use their action potential, or pulsations, to transmit the information between themselves, in this way increasing the robustness of the transmission. In the investigative work carried out on the description of the activity of a population of pulse coupled neurons, the order of connections in such systems is technologically unfeasible, due not only to space requirements but also to power dissipation [1].

In the study of different configurations determined by interconnections, simplifications have been demonstrated: 4/8 connections per neuron, (conditioning its activation or inhibition) [2] or 5/9, where 4/8 act as activators and the rest act as inhibitors under the action of a global element designed for this purpose [3]. In order to simulate the high level of connectivity, and inspired by the success of temporal multiplexing in communications and computational networks, many investigators have adopted this method to resolve the problems mentioned.

If one wants to carry out this method with success, it is necessary to describe the activity of a population of neurons with an ordered list of the spatial - temporal localization, where each coordinate specifies the occurrence of an event in a particular position, within a determined time. The same localization may appear various times; while one single time can only occur once. Nevertheless, if this acquisition is carried out in fixed time spaces, acquiring only the position, the time will be determined by itself. This real time representation is called Address-Event Representation (AER) [4].

The elements used to generate the events, also denominated integration and trigger, integrate the current, directly or by the use of a transimpedance element, in such a way that when a determined value is reached a trigger is produced in the system, producing not only digitalization of the input signal but also we can generate a signal which indicates that an event has occurred. Upon asking for access, it is necessary to restart the system using the recognizing of the event. This way we also implement a synchronous protocol called Handshake [1] [5].

We present our work, which was carried out to implement the hardware for a vision system based on integrated neurons and Fire using a optoelectronic processor developed within our group for image processing [6] and using a PIC18F252 microcontroller, allowing management of the events.

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6576-01, Session 13

Carrier signal design using constrained iterative spectral deconvolution

A. M. Amini, Southern Univ.

The radio communication use in recent years has increased significantly. This increase has created a crowded spectrum. To avoid interference and spectral effectiveness in this crowded medium one needs to design a waveform for modulation of data far from the interfering frequencies. One effective approach to identify the interfering frequencies is by sampling the environment by both the transmitter and the receiver. The spectrum of the sampled environment will provide the available portion that is clear for transmission. The effectiveness of this approach depends on an accurate estimation of the spectrum of the environment. In some applications, the transmitter and receiver can not afford to sample the environment over a long time for accurate estimation of the spectrum since it impacts the amount of time that is available to transmitter/receiver for communication. Thus, the environment is sampled over a short time. This sampling amounts to multiplication of the interfering signals by a narrow rectangle window. In the Fourier domain, this amounts to convolution of the Fourier Transform of the interfering signals by a wide Sinc function. The broadening effects of the convolution along with introduction of side lobes may seriously limit the available portion of the spectrum for generation of the carrier signal. In this paper, we propose to use the constrained iterative spectral deconvolution to remove these effects. We will show that one period of the interfering signal is all that is need to successfully remove all side effects resulting from short time domain sampling of the environment.

6576-03, Session 13

Technique of information hiding based on neural network

L. Xu, G. Tao, North China Institute of Science and Technology (China)

A neural network algorithm is proposed which can conceal different files effectively such as *.exe, *.com, *.doc, *.txt and self-defined file formats. First, the important contents of file are coded into a binary array. The total number of 0 and 1 is N. Second, to make the neural network learn the sample space, N pixel values and their closely relevant pixel values are randomly chosen from a color BMP format image and used to train the neural network, thus we get a group of network parameters and its outputs Y1. Each element of Y1 is increased 0 or 1 according to the zeros and ones from the array, the increased Y1 is called Y2. Third, using the transmitted parameters, a receiver can restore the neural network. Network outputs Y3 can also be obtained by simulating the restored neural network with the seed pixel values. Finally, the encrypted information can be decoded by Y2 and Y3.

The acquisition of parameters and Y1 is different when the neural network is trained each time, so the algorithm has the characteristic of one-time pad, which can enhance the correspondence security. Because the network colligates the chosen pixel values and their closely relevant pixel values, a cryptanalyst can not restore the network parameters and Y3 easily. Without the seed picture and the password, he does not know the encrypted data even if he knows the network parameters and Y2. If he only has the seed picture, he does not know the encrypted contents either, because there is no other information in the picture, which just is used to train the network.

Using the same algorithm, the fragile watermark can be embedded into Y1 simultaneously. Besides telling you whether Y2 or network parameters has been tampered, the fragile watermark could as well, reflect the distortion status in spatial domain of the tampered image. Therefore, the proposed method is of significance in practice.

6576-05, Session 13

Research on the technique of public watermarking system based on wavelet transform and neural network

L. Xu, G. Tao, North China Institute of Science and Technology (China)

A hybrid algorithm of wavelet transform and neural network is presented which solves the problems confronted in public watermarking system. First, to get the wavelet coefficients, db1 wavelet is used to decompose the selected image. Second, to ensure a better quality of the marked image, some wavelet coefficients and their closely relevant wavelet coefficients are randomly selected from the wavelet coefficients decomposed by the low pass filter and used to establish the relational model by using neural network. Third, a bit information of watermark is also enlarged by increasing the amounts of zeros or ones and then a bit of the results is embedded by adjusting the polarity between a chosen wavelet coefficient and the output value of the model. Finally, a new image with watermark information is reconstructed by using the modified wavelet coefficients and their relevant wavelet coefficients. On the other hand, the process of retrieving watermark is inverse according to the embedding process. The embedded watermark can also be retrieved by using the hybrid algorithm and the bits processed function without knowing the original image and watermark. Experimental results show that the proposed technique is very robust against some image processing operations and JPEG lossy compression. Meanwhile, the extracted watermark can be proved by the embedding method. Attribute to the neural network, the proposed method is also robust against attack of false authentication. Therefore, the hybrid algorithm can be used to protect the copyright of one important image.

6576-06, Session 13

Arrogance analysis of several typical pattern recognition classifiers

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Various kinds of classification methods have been developed. However, most of these classical methods, such as Back-Propagation (BP), Bayes method, Support Vector Machine(SVM), Self-Organizing Map (SOM) are arrogant.

A human is being arrogant when their expressed conviction in a decision overstates their actual experience in making similar decisions, even is a mistake. We say that he is arrogant if he frequently makes arrogant decisions. Likewise, some classical pattern classifiers represent the similar characteristic of arrogance. Given an input feature vector, we say a classifier is arrogant in its classification if its veracity is high yet its experience is low. Typically, for a new sample which is distinguishable from original training samples, traditional classifiers recognize it as one of the known targets. Clearly, arrogance in classification is an undesirable attribute.

Conversely, a classifier is non-arrogant in its classification if there is a reasonable balance between its veracity and its experience. Inquisitiveness is, in many ways, the opposite of arrogance. In nature, inquisitiveness is an eagerness for knowledge characterized by the drive to question, to seek a deeper understanding. The human capacity to doubt present beliefs allows us to acquire new experiences and to learn from our mistakes. Within the discrete world of computers, inquisitive pattern recognition is the constructive investigation and exploitation of conflict in information. Thus, we quantify this balance and discuss new techniques that will detect arrogance in a classifier.

Through analysis on arrogance of several classical pattern classifiers, Recursive Self-Organizing Mapping (RSOM) based inquisitive pattern recognition (IPR) framework is advanced, which will allow one to determine when a classifier is being arrogant. By compromising between the arrogance and inquisitiveness, the new classifier can autonomously learn new discriminative patterns. The feasibility and validity of the method has been proven by several tests on radar target recognition and multi-pose object recognition.

6576-12, Session 13

Intellectual property protection of IP cores through high-level watermarking

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Reuse-based design methodologies allow to assemble complex system using smaller components, reducing system design complexity. These strategies, based in the use of reusable modules or Intellectual Property (IP) cores, are enabling the optimization of company resources due to the reduced development time and costs. However, sharing IP cores poses significant security risks, one of the main being the intellectual property protection of those shared modules. Design reuse has led to the development of intellectual property protection techniques. It is in this context where watermarking techniques come to get these goal.

We propose a watermarking technique for IPP of FPGA bases systems. The aim is to protect the author rights of reusable IP cores by means of a digital signature that uniquely identifies both the original design and the design recipient. The proposed watermarking technique relies on a procedure that spreads the digital signature in cells of look-up tables at HDL design level, not increasing the area of the system. This signature is preserved through synthesis, placement and routing processes. The technique includes a procedure for signature extraction requiring minimal modifications to the system. Thus, it is possible to detect the ownership rights without interfering the normal operation of the system and providing high invulnerability. To illustrate the properties of the proposed watermarking technique, both protected and unprotected design examples are compared in terms of area and performance. The analysis of the results shows that the area increase is very low while throughput penalization is almost negligible.

6576-16, Session 13

Automatic target recognition method for phased antenna arrays with no passive training mode information

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In this paper, a new self-organizing neural system with Independent Component Analysis for automatic target recognition for phased antenna arrays is developed. The existing target recognition schemes with phased antenna arrays consists of passive mode which uses secondary information to estimate parameters which are then used in active detection mode. The environment often changes and performance suffers because of the mismatch between the active testing mode and passive training mode. Hence we pose the target recognition problem as a challenging blind detection and recognition problem and develop a self organizing neural system for the phased antenna array radar detection. The new system consist of Independent Component Analysis based self-organizing neural scheme. The task of signal extraction and separation is formulated as that of maximizing the objective function of the mutual information between certain variables of a neural system. We develop a techniques for adjusting the free parameters (synaptic weights) of the system so as to optimize this mutual information. An unsupervised learning algorithm based on independent component analysis is used where the objective of the learning algorithm is to minimize the Kullback-Leibler divergence between the probability density function of the output variables and their factorial distributions. This is then implemented using a gradient descent method where the adjustment parameters are appropriately applied to synaptic weights. We apply the scheme to automatic target recognition with phased antenna radar arrays to develop a system which does not need secondary information or passive training mode.

6576-49, Session 13

Implicit differential analysis for cortical models

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6577-01, Session 1

A hybrid 802.16/802.11 network architecture for a United States coastal area network

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This paper presents a concept for a United States Coastal Area Network (U-SCAN) that is comprised of IEEE 802.11, 802.16, and satellite communications technologies. The Office of Naval Research (ONR) on behalf of the National Oceanographic Partnership Program (NOPP) has tasked The Johns Hopkins University Applied Physics Laboratory (JHU/APL) to perform an architectural study into the establishment of a United States Coastal Area Network (U-SCAN). The goal of this study is to define a wireless network architecture that can be deployed to enable contiguous coastal area network coverage for scientific, commercial, and homeland security (e.g. Coast Guard) applications within the United States Exclusive Economic Zone (EEZ), in a manner that is flexible, manageable, and affordable. The JHU/APL study will ultimately provide recommendations to NOPP regarding potential network architectures and technologies that could provide the desired capability, with a particular focus on commercial (both existing and emerging) technologies. This paper presents the envisioned U-SCAN architecture, and presents the envisioned technical capabilities and shortcomings of the component candidate technologies.

6577-02, Session 1

Indoor location sensing using ZigBee tag

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ZigBee is a low-power, short-distance wireless standard that has great possibilities in applications from home automation to industrial control. ZigBee is also a wireless standard based on 802.15.4 that was developed to address the unique needs of most wireless sensing and control applications. Key benefits of the 802.15.4 and ZigBee standards include extended battery life over current wireless standards, mesh and star network topologies, cost effectiveness, and no line of sight worries.

In this paper we present an improvement approach of indoor location sensing using ZigBee technology. This is a location-support system using ZigBee tag for in-building, mobile, location-dependent applications. In our experiment, we place four ZigBee terminals at the four corners of a 10 m*10m square space, and then this 10 m*10m square area is divided to 10 * 10 small squares with 1m*1m each. We place a ZigBee reference tag to this square array every 1 m in sequentially. The average RSSI value delivered to the four ZigBee terminals from this ZigBee tag will be recorded as a reference vector. When a tracking tag put into this square area, comparing the RSSI value of tracking tag delivered to the four ZigBee terminals and the reference vector established for this area, we can estimate where the tracking tag location is.

The major advantage of this system is that it improves the overall precision of locating objects by utilizing array of reference tags and some mathematic algorithms. Although ZigBee is not designed for indoor location sensing, this algorithm can be used for indoor location sensing, and added to make ZigBee technologies competitive in this new and growing market.

6577-03, Session 1

Adaptive binary signature design of code division controlled-MAC in wireless sensor network

L. Wei, S. N. Batalama, D. A. Pados, Univ. at Buffalo; B. W. Suter, Air Force Research Lab.

Wireless sensor networks (WSN) are characterized by their architecture, severe energy constraints and asymmetric many-to-one data flows. In this paper, we consider the problem of signature waveform design of code division controlled-MAC in WSN. In contract to conventional randomly chosen orthogonal codes, an adaptive signature assignment strategy is developed under the maximum pre-detection SINR (signal to interference plus noise ratio) criterion. The proposed algorithm utilizes slowest descent cords of the optimization surface to move toward the optimum solution and exhibits polynomial computational complexity with respect to signature length. Numerical and simulation studies demonstrate the performance of the proposed method and offer comparisons with the conventional signature assignment scheme.

6577-04, Session 1

Location-based route self-recovery for mobile ad hoc networks

S. R. Medidi, J. Wang, Washington State Univ.

Mobile ad-hoc networks (MANET) consist of mobile computing devices which communicate with each other through multi-hop wireless channel without the assistance of fixed infrastructures. The inter-networking flexibility of MANET comes with the cost of frequent topology changes which bring the challenges for its routing protocol design. Source-initiated routing alleviates the need for periodic topology updates, but has the problems such as delay and broadcast storm.

Frequent source discovery incur significant overhead and delay, one approach to avoid this is by using route self-recovery techniques. It relies on the assumption that after a route to the destination node breaks, the new route cannot be significantly different than the most recently used route. Current route self-recovery techniques introduce additional overhead for broadcasting, updating link information, etc. In this paper, we propose a new source-initiated routing protocol combining route self-recovery and location-aided broadcast, which is adaptive to the dynamics in network topology and improves the routing overhead and delay. It avoids reinitiating the route discovery and uses selective re-broadcasting to find a short detour and replace the broken links for route maintenance.

Broadcast storm problem has been addressed at MAC layer to prevent unnecessary forwarding of duplicates while maintaining a good broadcast coverage. In contrast, our protocol addresses the broadcast storm problem by initiating route self-recovery phase at networking layer and can be used with any of these MAC layer broadcasting schemes to further improve its performance. Simulation results show improvements in various aspects such as system throughput, routing overhead, scalability, and usefulness.

6577-05, Session 1

Enhancing ad hoc routing with history-based route selection

S. R. Medidi, P. M. Cappetto, Washington State Univ.

Ad-hoc networks are fundamentally resource constrained in terms of battery, cost, and infrastructure, but are attractive for a wide variety of applications such as battlefield surveillance, environmental monitoring, and emergency response. Battery impoverished nodes may selfishly elect to not forward packets to conserve their energy. Selfish packet dropping degrades the performance of the network and results in increased retransmissions. Selecting routes with fewer misbehaving nodes decreases the chance of surreptitious packet drops.

The choice of protocols above and below the routing layer affects the design of the routing protocol. For example, systems that rely on detecting whether or not their neighbors forward packets can use link-layer acknowledgments found in protocols such as 802.11. Secure routing can also use upper layer information from the transport layer such as acknowledgments and timeouts. Our approach takes a more generic, layer-independent method that gathers evidence soley from the routing to provide improved performance in the presence of misbehaving nodes.

Our approach uses locally collected information to select routes with nodes having the best aggregate performance. The packet counts from both data and control packets are gathered from the routing layer to help identify nodes with good past performance. Nodes use routes with the best average node rating. Alternately, other route weighting schemes could easily be used. Simulation results using ns-2 simulator confirm that there is a definite reduction in the routing overhead.

Results indicate that the per-connection throughput has increased and the aggregate number of packet drops have been reduced.

6577-07, Session 2

Approximate MLE algorithm for source localization based on TDOA measurements

G. Gu, Louisiana State Univ.

Passive source localization has been an important research topic in the signal processing society. This paper considers source localization based on TDOA (time-difference of arrival) measurements that has been studied extensively in the literature. Despite the fact that the measurement noises are additive and Gaussian, such a source localization problem is nonlinear in nature and the exact MLE (maximum likelihood estimation) solution is difficult to compute.

In this paper we consider the same passive source localization problem using the same quasi-linear measurement equations. Different from the existing solution methods, the nonlinear term in the quasi-linear measurement equations is treated as a constraint which is in fact a quadratic constraint. A numerical procedure based on simultaneous diagonalization is developed to compute the weighted LS (LS) solution under the quadratic constraint. This new procedure is shown to be an approximate MLE solution under the assumption that the ratios of the distances between all but one sensor and the target to the noise variance in TDOA measurements are suitably large. The assumption is rather mild and is satisfied so long as the relative distances among all the sensors are suitably large and the noise variance is suitably small which hold in practice for localization based on TDOA measurements. Our results are fairly complete and complement the existing ones in the literature. The simulation results are worked out to illustrate the effectiveness of the proposed solution procedures that compare favorably with the existing results.

6577-08, Session 2

The constrained Kalman filtering and its application to tracking of ground moving target

G. Gu, Louisiana State Univ.

Passive source location is investigated based on measurements of TDOA (time-difference of arrival) and AOA (angle of arrival) in which the measurement noises are assumed to be uncorrelated and Gaussian distributed. It also assumes the known knowledge of the positions and velocities of all the UAV (unmaned aerial vehicle) sensors within the UAV sensor network. The research focus is estimation of the location and tracking of the GMT (ground moving target) that requires to estimate both position and velocity of the GMT at each sampled time within the given time horizon. The underlying localization and tracking problem is nonlinear in nature for which MMSE (minimum mean squared-error) is difficult to achieve. We aim to develop an approximate MMSE algorithm for the underlying localization and tracking problem based on TDOA and AOA measurements. Based on the pseudo-measurement model in the existing literature, a state-space model is derived that governs the motion of the GMT and the nonlinear term involved in this model is taken as a part of the state vector. It leads to a nonlinear constraint imposed on the state vector.

Randomization of the state vector suggests to replace the hard constraint by its expectation. We first derive a solution to a similar constrained MMSE problem that is used to extend the Kalman filtering to develop a linear recursive MMSE estimator subject to the nonlinear constraint as mentioned earlier which is termed as constrained Kalman filtering. A simulation example is carried out the case of two UAV sensors that demonstrate good localization and tracking results.

6577-09, Session 2

Direction finding of GPS receiver interference based on a hybrid RF-DSP approach

J. Wang, M. G. Amin, Villanova Univ.

GPS receivers are subject to jammers, which can assume different waveforms and locations. Jammers can compromise the GPS receiver performance and disallow it to acquire or track the signals. It is of interest to concurrently null and localize interferers. While nulling can be performed using adaptive techniques implementing LMS and based on knowledge of satellite locations, high resolution direction of arrival estimation can proceed using subspace and eigenstructure methods. Typically, interference mitigation is performed for each satellite independently using an adaptive spatial weight vector whose length is equal to the number of antennas. At convergence, these weight vectors themselves contain the interference bearing information, which can be extracted using subspace processing. In this paper, we obtain the interference angle of arrival by performing singular value decomposition to the adaptive weight matrix. This approach allows the adaptive jammer cancellation to be performed in RF and eliminates the need to separately formulate the data covariance matrix for angle of arrival estimation.

6577-10, Session 2

MIMO-based performance enhancements in wideband random noise radar using adaptive beamforming and spatially distributed antennas

W. Darsono, R. M. Narayanan, The Pennsylvania State Univ.

Wideband signals have been used in radar systems for high-resolution surveillance and imaging applications. The motivation for using a wideband noise signal is that it offers improved spectral efficiency, i.e., it permits multiple users to occupy and operate within the same frequency band with minimal cross-interference. Random noise radar has the inherent covert capability, i.e. the Low Probability of Intercept (LPI) and Low Probability of Detection (LPD). By employing a random noise signal in wideband radar, we aim to exploit and combine both advantages. The recently developed multiple-input multiple-output (MIMO) system is an architecture that employs multiple antennas at both transmitter and receiver sides to exploit diversity and multipath for improved system performance. In digital communications, MIMO systems have been shown to resolve the bottleneck of traffic capacity of the network, and at the same time to exploit the spatial diversity. This paper shows the performance enhancement of MIMO-based wideband noise radar system configuration as opposed to the single antenna radar system. The system will also enjoy the inherent advantages of using the other technologies, i.e., covert feature of random noise signal, and spectral efficiency of wideband radar system. There are two different antenna arrangements that can be proposed for such configuration. The first configuration is when the radar antennas are collocated. For this configuration, we will employ adaptive beamforming techniques in order to properly combine the different waveforms transmitted from different transmitters and gathered by the antenna receivers. It will be shown that the radar system will benefit from the transmitted signal recovery used to detect the target, and thus this will improve the signal to noise ratio (SNR) of the overall system. Another configuration is when the radar antennas are spatially distributed. In this configuration, we will show that the system will benefit of getting a better radar cross section (RCS) of the intended detected target. (This work is supported by Air Force Office of Scientific Research (AFOSR) through Contract # FA9550-06-1-0029.)

6577-11, Session 3

A fast algorithm for direction of arrival estimation in a multipath environment

M. Naraghi-Pour, N. Tayem, Louisiana State Univ.

In this paper, a new spectral direction of arrival (DOA) algorithm is proposed that can rapidly estimate the DOAs of non-coherent as well as coherent incident signals. The proposed method constructs a date model which is based on a Hermition Toeplitz matrix whose rank is always related to the DOA of incoming signals and cannot be effected if the incoming sources are non-coherent, partially correlated, or highly correlated (fully coherent). In addition, our algorithm reconstructs the data in a way that can extend the dimension of the noise space. Therefore, the signal and noise space can be estimated properly. When we compared the proposed method with the well-known classical subspace algorithms, such as MUSIC, Matrix Pencil (MP) and ESPRIT algorithm, the proposed method has several advantages. First, the proposed method does not require multiple snapshots but a single snapshot observation to estimate DOAs. Hence, it is attractive for real-time applications. Second, no forward/backward spatial smoothing for the covariance matrix is needed, whereas the MUSIC and ESPRIT methods require it, which increases the computational load and is time-consuming. Third, the proposed method can detect the coherent sources, whereas the well-known MUSIC and ESPRIT methods cannot. The simulation results verify that the proposed method gives more accurate estimation and superior performance than the ESPRIT algorithm.

6577-12, Session 3

Decoder-aided multidata detection of OFDM-CDMA waveforms on HF multipath/fading channels

J. W. Nieto, Harris Corp.

This paper will investigate the possible improvements in performance for OFDM-CDMA waveforms when a forward error correction decoder is used to assist in the demodulation of OFDM-CDMA. Several modulation schemes and multipath/fading channels will be investigated.

6577-13, Session 3

Utilizing space frequency COFDM on multipath fading channels

F. C. Kellerman, Harris Corp.

Previous work by the author has demonstrated the performance of COFDM with Differential Space-Frequency Modulation applied to a simulated HF radio frequency channel. The combination of those techniques provided a means to achieve a low-power and low-cost radio architecture but surprisingly did not result in a relatively acceptable bit error rate performance.

This paper will be a continuation of the initial work. In a more rigorous manner, the bounds of the problem will be addressed. Attempts to improve the system's performance will be documented. Better methods of channel estimation, interleaving, iterative decoding and possibly more attennas will be applied to the problem of digital communication through a fast fading multipath channel such as the high frequency radio spectrum.

6577-16, Session 4

A review of scale factors, fixed-point precision, soft decisions and hard decisions on the performance of the UMTS (3GPP) turbo codes

J. W. Nieto, Harris Corp.

This paper reviews the effects of scale factors, fixed-point precision, hard decisions and soft decision information on the performance of the turbo codes defined in the UMTS third-generation cellular systems standard. The modulations of interest for this paper will be BPSK and QPSK. In addition, a new scale factor estimation technique for BPSK which provides improved performance at low signal to noise ratios will be presented.

6577-17, Session 4

UMTS-based data link and data network for telemetry and time space position information (TSPI) applications

R. Sivasankaran, W. Ferzali, G. S. Rajappan, Mayflower Communications Company, Inc.; A. Khosrowabadi, Edwards Air Force Base

Telemetry and Time Space Position Information (TSPI) applications can be challenging for the wireless communication devices and the data communication infrastructure since the application environments can be as varied and extreme as UAVs, ballistic missiles, and tactical fighter aircraft with varying number of participants and varying data rate and quality of service requirements. The data link should be capable of data throughput of several Mbps, accommodate dozens of simultaneous users, provide high data accuracy, and work reliably over hundreds of nautical miles (nmi). The data network should be able to provide fast and secure access to multiple air interface protocols, and flexible and timely access to the end user. We present an integrated data link and network architecture system solution, developed by Mayflower for the Air Force, AFFTC, Edwards AFB, CA, based on third generation UMTS cellular standards. The data link, called COTS Affordable Data Link System (CADLS), accommodates high mobility user applications typical of tactical fighter aircraft. Multi-input multi-output (MIMO) enhancements to CADLS aims to achieve data rates of up to 20 Mbps, provide a range of 300-500 km, and work reliably for a variety of flight trajectories (e.g., high altitudes, broad ocean areas, and non line-of-sight flight scenarios), using small, secure wireless data transmission devices. The data network, called Telemetry/TSPI Data Network (TDN), uses enhancements such as a multi-tiered network protocol structure to provide flexible IP-based transport, work with multiple air interface protocols, accommodate test platform mobility, and integrate seamlessly with unified infrastructure such as Test and Training Enabling Architecture (TENA). The integrated CADLS/TDN system is at an advanced stage of prototype development. We present the integrated CADLS/TDN system architecture, its features and capabilities, and the laboratory prototype developed under the Air Force program.

6577-18, Session 4

Comparison of ultrawideband channel models estimated by model selection techniques and hypothesis testing

D. Choudhary, A. L. Robinson, Univ. of Memphis

In this paper we compare Ultrawideband (UWB) channel models obtained using model selection techniques and hypothesis testing. Unlike narrow band communication, the assumption of Rayleigh channel for UWB communications is not always valid due to the wide bandwidths. We first investigate the distribution of UWB channel tap magnitudes using model selection techniques such as Accumulative predictive error (APE), Akaike information criterion (AIC), and Bayesian information criterion (BIC). To our knowledge APE has not been applied before for channel modeling. The model selection techniques act as metrics to identify how close a candidate distribution is to the true unknown distribution. The channel models are also estimated using Kolmogorov-Smirov hypothesis testing. Rayleigh, Weibull, Lognormal and Rician distributions form the candidate distribution models. The distributions chosen by the above mentioned techniques are presented. The pros and cons associated with each technique for channel modeling are examined. Rake receiver performance for ultrawideband communication channels is also analyzed.

6577-19, Session 4

Performance of chirp slope keying with joint time-frequency detectors

E. J. Kaminsky Bourgeois, I. X. Incer, Univ. of New Orleans

This paper presents joint time-frequency (TF) receivers for Chirp Slope Keying (CSK). In CSK the slope of a chirp is used to convey the digital information. In its simplest form, a down-chirp represents a zero while an up-chirp represents a one. The TF receiver first computes a joint time-frequency transform and then uses the Radon transform to determine the slope of the instantaneous frequency over several signaling intervals. Monte Carlo simulations are used to demonstrate the performance improvement of the receivers over traditional correlation receivers. We also show that a considerable improvement in performance, in terms of Probability of error vs. SNR, is achieved over other digital modulation schemes in channels with various deleterious effects.

6577-20, Session 4

Anti-collusion fingerprinting scheme based on error correction ability of nonlinear combinatorial code

W. Huang, I. M. Panahi, The Univ. of Texas at Dallas

Digital fingerprinting is an available method that can identify the customer or owner of the digital media (image, video, etc) and protect the copyright of the content providers. Fingerprinting system embeds a unique fingerprint, which is the identity of the owner, into each individual copy of the original content. The monitor can detect the original user of the legal copies and track the usage of the copyrighted media content and analyze the spread of the content. The most serious problem to fingerprinting is how to resist the effective attack—collusion. Collusion is to use some different marked copies of the same original content and generate a new version from which the detector can't regain the correct fingerprint. In this paper we use combinatorial theory and construct nonlinear DBBD (Differential Balanced Block Design) code as fingerprint for digital media. The code is collusion-secure and has the capability of error correction which is beneficial to the robustness of the fingerprint. We also present a scheme for combining this collusion-secure fingerprinting code with a multi-resolution wavelet based watermarking mechanism. We use wavelet-watermarking techniques to embed and extract the fingerprints, and then use our detection scheme and the error correction ability of the DBBD code to find the pirates. Experiments show good performance of the scheme.

6577-21, Session 4

RFID electronic seal and system using the RFID electronic seal

S. Shih, Cheng-Shiu Univ. (Taiwan)

To fulfill the demand of logistics, the goods after being manufactured are put into the supply chain. The most important information to both the supplier and the customer is the location of the goods in the supply chain management. Current cargo tracking systems use an IC (integrated circuit) card and GPS (global positioning system) or mobile phone system to monitor the location of the cargo truck, providing the cargo owner with the information of the number of the license plate of the cargo truck, the code number of the cargo container, the current location of the cargo truck, etc. It is, however, impossible to know whether the cargo container is opened and/or the cargo in the cargo container is stolen or switched, nor to prevent such events.

RFID (radio frequency identification) electronic seals are proposed to solve the above problems. A typical electronic seal has a structure similar to a combination lock to seal the rear door of a cargo truck, allowing the owner of the cargo to acquire the required information. The owner will notice in real time after unauthorized breakage of the RFID electronic seal. In this work, we present a low-cost and reliable RFID electronic seal that provides evidence once broken by an unauthorized person. Another objective of the present invention is to provide a reliable RFID electronic seal for sealing a cargo container or for tightening other goods. We also present a reliable tracking system using an RFID electronic seal so that the owner of a cargo or goods can be aware of the position of the cargo or goods carrier and status of the cargo or goods as well as breakage of the RIFD electronic seal in real time.

6577-14, Session 5

Sensor networks and network sensibility

M. Li, Univ. of Waterloo (Canada); H. Lin, J. A. Rushing, S. J. Graves, The Univ. of Alabama/Huntsville

Networks with densely distributed inexpensive microsensors are becoming a reality for monitoring and tracking objects of interest over a very large geographical area in both military and civilian applications. The sensibility of a sensor network depends strongly on how well the region is covered by the sensors and how much and how accurate the information each individual sensor can provide. In case of the primitive sensor networks where each sensor can only provide limited information not sufficient to locate the target, sensor network density of larger than two is needed. Taking into account the low fidelity of the sensors, this number gets larger in order to provide the desired accuracy and robustness against sensor failures. The question of how densely the sensors should be distributed is crucial in designing and deploying large scale sensor networks. In this paper, the problem of how many randomly distributed sensors are needed over a region is addressed analytically with the incompressibility method rather than the traditional probabilistic approach. Under the truly (Kolmogorov) random distribution, the upper and lower bounds of the numbers of sensors needed to guarantee 100% that every location of the region of interest can be sensed by at least k sensors are formulated and proved, and verified with experimental simulations. Here, k is a predefined value based on the characteristics of sensors and the requirement of network delectability.

6577-15, Session 5

A simple hill-climbing technique to place sensors in a polygonal area for increased intrution detection in the presence of a cognizant intruder

S. U. Khan, The Univ. of Texas/Arlington

Skillfully placing miniature sensors in a specified area of interest is a good way to sense intrution. Numerous studies have been conducted that discuss optimized sensor placements; however, they suffer from the following drawbacks: 1) Placements are performed in a rectangular or a square shaped area. 2) There is no oracle by which one can evaluate the intruder's strategy. One needs to address the sensor placement problem such that: 1) It is not limited to rectangular or square shaped areas, since in reality one can never gurantee that the area of interest would always be of such a shape; 2) It should include the intruder's strategy (whatever that may be), so that one can implement a counter strategy for it.

A simple hill-climbing algorithm is proposed for the placement of senors in a two-dimentional, enclosed, polygonal, planer area, so as to maximize intrution detection in the presence of a cognizant intruder.

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6578-01, Session 1

Tactical service oriented architecture (TSOA) over wireless communications

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This paper reports on the results of testing General Dynamics' Tactical Service Oriented Architecture (TSOA) over wireless communications during flight tests run at the Air Force's Airborne Networking CRADA. The wireless, tactical domain presents a number of challenges. In particular, details of efficiency, reliability, and interoperability are a concern in this TSOA solution.

Provided within this paper is discourse on why these details are relevent and how the approach taken addresses these details in a wireless, tactical domain. Also shown is how this approach differs from a traditional enterprise Service Oriented Architecture (SOA). Finally there is a discussion of the results of the testing, as well as what steps can be taken in the future and what challenges must be overcome.

6578-02, Session 1

Testbed for large volume surveillance through distributed fusion and resource management

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DRDC Valcartier has initiated - through a PRECARN partnership project - the development of an advanced simulation testbed for the purpose of evaluating the effectiveness of Network Enabled Operations (NEOps) in a coastal large volume surveillance situation. The main topics studied are distributed information fusion architectures and dynamic resources and networks configuration management. This article presents the requirements, design and first implementation builds of the testbed, and reports on some selected preliminary results. The testbed allows to model distributed nodes performing information fusion, dynamic resource management planning and scheduling, as well as configuration management, given multiple constraints on the resources and their communications networks. Two situations are being simulated: cooperative and non-cooperative target search. A cooperative surface target behaves in ways to be detected (e.g., rescued), while an elusive target attempts to avoid detection. The simulation consists of a networked set of surveillance assets including aircraft (UAVs, helicopters, maritime patrol aircrafts), ships, fixed sensors, ground stations and satellites. These assets have scanning radar, electro-optical, infrared and imaging radar capabilities. Since full data sharing over most real world links is not feasible, own-platform data fusion must be simulated to evaluate implementation and performance of distributed information fusion. A special emphasis is put on higher-level fusion concepts using knowledge-based rules, with level 1 fusion already providing tracks. Surveillance platform behavior is also simulated in order to evaluate different dynamic resource management algorithms. Additionally, communication networks are modeled to simulate different information exchange concepts. The testbed allows the evaluation of a range of control strategies from independent platform search, through various levels of platform collaboration, up to a centralized control of search platforms. The testbed is being implemented by MDA Inc., Actenum Inc., Simon Fraser University and the University of Calgary.

6578-03, Session 1

An evaluation of case-based classification to support automated web service discovery and brokering

E. G. Warner, R. V. Ladner, F. Petry, Naval Research Lab.

In this paper we evaluate the use of case-based classification to resolve a number of questions related to information sharing in the context of an Integrated Web Services Brokering System (IWB). We are developing the IWB to provide automated synchronization with internet/intranet Web Services data providers for client applications. Our approach is intended to support automated discovery of relevant Web Services, automated mediation of client requests and automated transformation of requests and corresponding responses.

There has been much interest in the use of ontologies such as OWL-S to support Web Services discovery. This approach usually involves a web service's deployment of an ontology that semantically describes the service. The ontology is intended to provide a means for prospective clients to identify whether the service's capabilities match the client's requirements. In contrast to this approach, we use case-based classification as a means of automating the IWB's recognition of relevant services and operations. Case-based classification retrieves and reuses decisions based on training data. We use sample Web Service Description Language (WSDL) files and schema from actual web services as training data in our approach and do not require the service to pre-deploy an OWL-S ontology. We present our evaluation of this approach and performance ratings in the context of meteorological and oceanographic (MetOc) Web Services as it relates to the IWB.

6578-04, Session 1

Enabling dynamic interoperability with multiple COI systems

E. J. Martens, A. Armbruster, D. E. Corman, Boeing Military Aircraft and Missile Systems Group

A range of Community of Interest (COI) Infospheres and systems are being independently developed and deployed by separate elements of U. S. forces and potential coalition partners. Because future operations will increasingly rely on seamless exchange of information between coalition partners, it is critical that all tactical and command elements be able to dynamically interact with these diverse systems. Solving this issue requires that each network element (platform, commander, war-fighter, etc.) be able to span, dynamically join and leave different COI systems as operational requirements dictate.

The COI Interoperability Agent (CIA) is the centerpiece of our solution. The Boeing Company in conjunction with the Air Force Research Laboratory has developed the CIA concept as a part of "Enabling Command and Tactical Element Dynamic Interoperability with Multiple COI Systems", which will be demonstrated in December 2006. It will enable each battle space entity to join, interact with, and leave multiple COIs. Each CIA consists of a common core containing the Information Router, COI Initiator (COIN) factory, and Platform Initiator (PIN) factory components along with one or more platform modules and COI modules. Bi-directional information flow is directed by the Information Router. The COIN enables dynamic connection to a COI. A COIN consists of two parts: 1) a Java Jar file containing the COI Module code establishing a COI connection and 2) a data component that configures the COI Module. The CIA uses the COIN factory to load and configure new COI Modules. The PIN factory fills a similar role for Platform Modules. The Platform Module contains code to link to a specific tactical entity. The CIA concept provides a path for the warfighter to dynamically connect to multiple COIs without a priori knowledge of COIs that will be needed.

6578-05, Session 1

An investigative analysis of information assurance issues associated with the GIG's P&P architecture

B. S. Farroha, R. Cole, Johns Hopkins Applied Physics Lab.; D. Farroha, Defense Intelligence Agency

The Global Information Grid (GIG) is a collection of systems, programs and initiatives aimed at building a secure network and set of information capabilities modeled after the Internet. The GIG is expected to facilitate DoD's transformation by allowing warfighters, policy makers, and support personnel to engage in rapid decision making. The roadmap is designed to take advantage of converged services of voice, data, video,

and imagery over common data links. The vision is to have commanders identify threats more effectively, make informed decisions, and respond with greater precision and lethality. The information advantage gained through the GIG and network-centric warfare (NCW) allows a warfighting force to achieve dramatically improved information positions, in the form of common operational pictures that provide the basis for shared situational awareness and knowledge, and a resulting increase in combat power.

The GIG Precedence and Preemption (P&P) requirements stem from the need to utilize scarce resources at critical times in the most effective way in support of national security, the intelligence community and the war-fighter. Information Assurance (IA) enables all information and data to be available end-to-end to support any mission without delay in accordance to the sensitivity of the task. Together, P&P and IA ensure data availability integrity, authentication, confidentiality, and non-repudiation.

This study addresses and analyzes the QoS and P & P requirements and architecture for the GIG. Threat scenarios are presented and used to evaluate the reference architectures. The goal of the study is to assess the Information Assurance concerns associated with implementing Precedence and Preemption within the GIG and to guarantee an acceptable minimum level of security and protection for DoD networks.

6578-06, Session 1

Embedded instrumentation systems architecture

N. A. Visnevski, P. C. Sanza, GE Global Research

Military systems in the new century are becoming increasingly complex, network centric, and information intensive. Existing ad-hoc test and evaluation (T&E) approaches are facing increasing challenges to cope with these complexities. This paper describes the operational concept of the Embedded Instrumentation Systems Architecture (EISA) that is being developed for Test and Evaluation (T&E) applications and is intended to address many of the current T&E challenges. The architecture addresses such future T&E requirements as interoperability, flexibility, and non-intrusiveness. These are the ultimate requirements that support continuous T&E objectives that are essential for defense transformation and network-centric warfare principles.

In this paper, we demonstrate that these objectives can be met by decoupling the Embedded Instrumentation (EI) system into an an-board and an off-board component. An on-board component is responsible for sampling, pre-processing, buffering, and transmitting data to the off-board component. The latter is responsible for aggregating, post-processing, and storing test data as well as providing access to the data via a clearly defined interface including such aspects as security, user authentication and access control.

The power of the EISA architecture approach is in its inherent ability to support virtual instrumentation as well as enabling interoperability with such important T&E systems as Integrated Network-Enhanced Telemetry (iNET), Test and Training Enabling Architecture (TENA) and other relevant Department of Defense initiatives.

6578-07, Session 1

Widely distributed C4ISR

D. A. Goughnour, M. J. Salonish, S. D. Allen, ElanTech, Inc.

Advances in networking and communications make the dream of a highly connected mobile war fighter, persistent networked sensors, and distributed command and control a reality. However, being able to communicate is only the first part of the problem. The ability to easily communicate with a wide variety of highly distributed sensors and systems presents significant new problems that need to be addressed. First, an application must discover what services are available and establish communications with the desired services. Secondly, time synchronization across all of the networked systems is critical to correctly correlating the information into a coherent picture. In addition, maintaining data consistency in a highly distributed environment is an extremely challenging problem. Given the amount of data available clients must be able to subscribe to specific data in order to avoid information/system overload. Finally the information must be presented to the user in a form and on a platform well suited to the task at hand. All of these problems, and many more, must be solved in order to deliver a truly effective net-centric C4ISR system.

A software architecture will be presented that attempts to solve the issues described above. The architecture inherently includes many features designed to address these issues. In addition, the user can select data from a wide variety of services, both local and remote and control how it is accessed, processed, and displayed. A detailed analysis of each of these techniques and how it impacts the effectiveness of the system will be discussed.

6578-08, Session 1

Methodology for assessing technologies to improve or compress the kill chain

D. K. Bowley, C. Standford, S. James, Defence Science and Technology Organisation (Australia)

Offensive Support (OS) modelling has generally not been implemented within a closed simulation in such a way that its contribution to the overall mission performance can be captured, measured and integrated . However the issue of realistically measuring OS performance becomes more critical as new technologies are proposed to improve or compress the kill chain, particularly in the context of complex environments. A study is being conducted to determine and implement an explicit kill chain in CASTFOREM such that it can be configured to use a variety of components and its impact on performance can be measured and compared. To assess the kill chain six Measures of Performance have been adopted from the Royal Australian Air Force. These are Timeliness, Appropriateness, Precision, Discrimination, Orchestration and Survivability, referred to as TAPDOS. These MoP will allow the study to align with accepted standards of OS usage in the Australian joint fires environment, to facilitate the use of Sunbject Matter Experts to support the study and promulgate performance results. The outcome of the study will be an enhanced CASTFOREM simulation capable of identifying and reporting specific kill chain events and measures associated with the target performance demands, system performance availability, system selection and performance delivered.

6578-09, Session 2

Evaluating technologies for tactical information management in net-centric systems

D. C. Schmidt, Vanderbilt Univ.

Future DoD operations will run in net-centric systems characterized by thousands of platforms, sensors, decision nodes, actuators, and operators connected through heterogeneous networks to exploit information superiority and achieve mission objectives. The networks, operating systems, middleware, and applications that populate this environment offer many configuration points for adjusting their resource requirements and the quality of service (QoS) they deliver. For example, the Global Information Grid (GIG) is intended to organize and coordinate this technology space to provide DoD planners and warfighters with the right data to the right place at the right time across enterprise operational systems and battlefield tactical systems. The enterprise portion of the GIG relies on commercial Web Services standards, however, that do not yet address the real-time QoS requirements of DoD tactical information management.

To build and evolve tactical information management systems, it is necessary to develop standards-based QoS-enabled publish/subscribe (pub/sub) platforms that enable participants to publish information they have and subscribe to information they need in timely manner. Since there is little evaluation of the ability of these platforms to meet the performance needs of tactical information management, this paper provides two contributions: (1) it describes common architectures for the OMG Data Distribution Service (DDS), which is a standard QoS-enabled pub/sub platform and (2) it evaluates implementations of these architectures to compare their performance with each other and with other pub/sub middleware. Our results show that DDS implementations perform significantly better than non-DDS alternatives and are well-suited for certain classes of data-critical tactical information management.

6578-10, Session 2

Dynamic policy enforcement in JBI information management services with the KAoS policy and domain services

J. Donnelly, J. Madden, ISX Corp.; J. M. Bradshaw, A. Uszok, Institute for Human and Machine Cognition

Policy descriptions are increasingly being used to express rules and constraints for software systems and enforced dynamically by policy management systems. In this paper, we describe the application of one such policy management system, KAoS, to the control of distributed information management services defined by the Air Force Research Laboratory's Joint Battlespace Infosphere (JBI) program. Our research has defined the policy ontologies necessary to describe the desired limits on the behavior of the participants in the system, both human and software, with one set of well-defined policies. At the same time, we have implemented the policy decision points (PDPs) and policy enforcement points (PEPs) necessary to implement distributed interpretation and enforcement of those policies. As a result, a single set of tools for the definition, analysis, control, and monitoring of policy can be used to implement access control, service configuration, service delivery prioritization, and control of simple software agents known as fuselets.

6578-11, Session 2

A QoS management system for dynamically interoperating net-centric systems

J. P. Loyall, J. Ye, P. Sharma, R. E. Schantz, BBN Technologies

Effective network-centric warfare requires information exchange with suitable quality of service (QoS) to meet the warfighter's needs. Information delivered too late or with the wrong resolution, form, or precision can be insufficient for the user to perform his role in a warfighting scenario. One of the key characteristics of net-centric warfare environments, as instantiated by the Global Information Grid (GIG), is dynamic reconfiguration and interoperability, in which Communities of Interest (COIs) can be formed and reformed dynamically to respond to real-time threats and unfolding situations. There is a need for a QoS management capability that can support the dynamic interoperability and real-time requirements of net-centric warfare. In order to be effective, this QoS management capability must manage the production, delivery, and consumption of information within available resources, mediate competing demands for resources, and adjust to dynamic conditions. In this paper, we describe the architecture for a QoS Management Service (QMS) that works alongside Information Management Systems (IMSs) in dynamic COIs. The QMS provides QoS management (including resource management and quality of information management) in dynamically changing, mission driven environments for interoperating assets within a COI and for assets and resources shared between COIs. The QMS provides mechanisms for QoS policy specification, QoS enforcement and monitoring, dynamic resource allocation, and application adaptation in dynamic COIs. It is based on a layered architecture that maps mission requirements to QoS policies and enforcement. We describe the QMS architecture, prototype implementation, demonstration, and evaluation. Based on these experiences, we also discuss future research directions.

6578-12, Session 2

AIMS taking on roles to support information dominance

P. J. Ceccio, Northrop Grumman Corp.

Military solutions to enable information sharing are being developed that will fundamentally change future concepts of operation. The development of sophisticated approaches to managing this information is a key element to reliably disseminate valued information to the tactical edge. This paper will describe the merging of the Air Force Research Labs (AFRL) Joint Battlespace Infosphere Reference Implementation (JBI/RI) and the Northrop Grumman Advanced Information Architecture (AIA(tm)) to support these tactical edge users. The newly formed product is called the Advanced Information Management System (AIMS).

The resulting technology, rooted in a service oriented approach, provides a managed information dissemination approach through the use of publish, subscribe, and query services. Information can be collected and shared among Communities of Interest (COI) without specific involvement from the tactical users.

Persistence (via archiving to repositories), is a new capability added to the existing AIA(tm). Extreme care is taken to effective manage the information within this dynamic environment. For example, Information resulting from queries and subscriptions is cached to mitigate potential bandwidth challenges at critical location within the system.

AIMS improves security by allowing the establishment of roles for retrieval/publishing of information. The access to information is controlled not only at the message level but also by specified elements within the metadata tags.

Lastly, the fortification of AIMS with Web Services allows for a highly cohesive loosely coupled design. Use of a Universal Description, Definition, and Integration (UDDI) describes and registers services in the architecture. The UDDI allows implementations outside of AIMS (3rd party) to invoke any of the registered services for use within their own applications.

6578-13, Session 2

Managing information sharing in tactical environments

J. P. Hanna, V. T. Combs, Air Force Research Lab.

In the battlefield environments, new tactical radios that support wireless Internet Protocol (IP) are being developed. Interim solutions to enable IP over existing tactical links are in the process of being deployed. Ubiquitous IP-based interconnectivity will fundamentally change the way that our current soldiers and systems share data. The expected proliferation of tactical sensor assets and non-traditional ISR assets will bring unprecedented volumes of data to the battlefield. Sophisticated approaches to managing this data, rapidly transforming it into actionable information, and reliably disseminating it to the war fighter, are the current foci of our research. This paper will present an in-house research project, named, Hydra, that is developing information management approaches targeted at addressing a specific set of challenges expected to be encountered in tactical deployment. We begin by describing the architecture of Hydra and the service oriented model that it provides. Then, we discuss the initial build of Hydra, code-named Dino, which addresses end-to-end publication and subscription of Managed Information Objects (MIOs) over intermittent or otherwise disrupted communications infrastructures. Two different deployment approaches for Dino are contrasted and performance metrics are presented and discussed. Next, results of initial testing on TCP/IP networks over 2.4GHz (802.11) and 900MHz modems are presented. Finally, we describe the research objectives of the next planned build, code-named Bamm-Bamm, and its expected capabilities. We close the paper with a broader perspective for the future research goals of Hydra and briefly discuss our vision of Tactical Information Dominance.

6578-14, Session 2

iFUSE: a development environment for composable, easy-to-assemble information transforms

R. A. Joyce, Architecture Technology Corp.-New York

A crucial component of a net-centric information management system is a set of simple programs or scripts — fuselets — that effect small transformations on available data. Individual fuselets can perform tasks such as filtering, aggregation, monitoring, format conversion, and simple image manipulation. The global effect of a collection of cooperating fuselets is to add value to the system: to transform data into knowledge. Fuselets are also adept at bridging heterogeneous

systems, providing consumers the data they need in the format they require — not necessarily the format that was convenient for the original data producer. ATC-NY has created an extensible fuselet development environment, iFUSE, that provides the support fuselet developers need in order to create and discover fuselets, avoid design and efficiency pitfalls, and ensure the appropriate factorization of fuselet code. For the individual fuselet, iFUSE lets the user focus on the information being transformed, not the code needed to implement the transformation. iFUSE also helps the designer understand the environment in which the fuselet operates, automatically detecting potential data flow problems and providing visualization tools such as "fuselet slicing," which allows fuselet authors and infosphere maintainers to assess the effects of additions and changes in context. In this talk, we review the accomplishments and lessons learned from the recently-completed iFUSE research and development effort and present promising future directions for fuselet research.

6578-15, Session 2

Semantic mediation and transformation services

J. R. Milligan, Air Force Research Lab.

Semantic interoperability is becoming an increasingly important problem as user communities seek to interact over and across information spaces such as those that ride on the Global Information Grid (GIG). Semantic interoperability can be defined as the ability of two (or more) systems (services) to exchange data on the basis of an agreed vocabulary (ontology) that guarantees the same interpretation (semantics or meaning) of notions (concepts and their interrelationships) for the users of the interoperating systems. Semantically-aware cross-domain information and service mediation capabilities are needed to improve interactions between Communities of Interest (COIs) and the applications that service them. One goal is to augment systems and services with flexible information transformation capabilities that are dynamically responsive to changing end-user needs without imposing major impacts to existing and legacy systems. These capabilities produce quality information that is of value to the context of the end-user through information assessment, correlation, aggregation, and other mediation services. This leads to an improvement in the efficiency and effectiveness of decision-makers by transforming a sea of data into actionable information. Another goal is to provide agile mediation services between applications and services to promote device-level interoperability between operational and tactical information producers and consumers. This leads to information exchange that may be transparent to people but critical to the success of processes and workflows needed to accomplish the mission of joint, coalition, and multi-agency operations. Semantic representations of individuals, systems, services, processes, domains, and organizations and the relationships between them are foundational to agile information transformations that enable dynamic mediation services and interoperability. Planned and current areas of investigation include pedigree management, transformation logic production and execution environments, mediation service workflow orchestration, and ontological contextualization of information. This paper describes on-going and future areas of research being conducted by the Air Force Research Laboratory located in Rome, NY.

6578-16, Session 2

Pedigree management and assessment in a net-centric information management environment

M. M. Gioioso, D. McCullough, C. Marceau, R. A. Joyce, Architecture Technology Corp.-New York

Modern Defense strategy and execution is increasingly net-centric and distributed, allowing more information to be made available in a timely manner. In this environment, the commander or warfighter must distinguish decision-quality information from potentially inaccurate, or even conflicting, pieces of information collected from multiple sources. If the decision-maker had access to information about the sources of the information as quickly and easily as to the information itself, he could make quick and informed decisions based on the available resources.

The Pedigree Management and Assessment Framework (PMAF) enables the publisher of information to record standard pedigree, such as information about the source, manner of collection, and the chain of modification of that information as it passed through other processing or assessment. In addition, the publisher can define and include other related information relevant to quality assessment, such as domain-specific information about sensor accuracy or organizational structure of agencies. PMAF stores this potentially enormous amount of information in a volume-efficient manner and presents the information to the user in an intuitive graphical format, together with PMAF-generated assessments that allow the user to quickly estimate information quality. PMAF has been created for a net-centric information management system; it can access pedigree information across communities-of-interest and across network boundaries and will be implemented in a Web Services environment. Currently, we have demonstrated volume-efficiency, extensibility of pedigree content, and the ability to reach across different protocols to gather information to support quality decisions.

6578-17, Session 2

Composition modeling framework (CMF)

G. R. Staskevich, J. R. Milligan, Air Force Research Lab.

In 1999, the Committee to Assess the Policies and Practices of the Department of Energy (DOE) characterized stovepipe systems as "systems procured and developed to solve a specific problem, characterized by a limited focus and functionality, and containing data that cannot be easily shared with other systems." Traditionally, software systems weren't built with interoperability in mind primarily because there was no immediate need for different systems to talk to each other. The introduction of ARPANET in the late 1960's marked the beginning of the Internet as we know it today, and over the evolution of information technology since then, organizations and people have an increasing desire to use information in ways not possible thirty years ago. Since people often use the Internet to get and share information, it stands to reason that they might also desire the software applications that they use in their daily activities to get and share information over the network with the software applications of the other people they work with. Just as communication over the network would not be possible without adherence to common networking protocols and standards, we suggest that the dynamic sharing of information between software applications on behalf of the people working together and using them will not be possible until standards-based information sharing protocols and methods are established for Communities of Interest (COIs). For our purposes, we define a COI as the collection of people (and systems) that are concerned with the exchange of information (and data) to achieve a common goal. To help enable dynamic information sharing between one software application and another without hard-coding specific brittle interfaces, it is our proposition that the envisioned information sharing protocols will need to be based (in part) on the ability to describe and encode machine-readable representations of the meaning of the data that needs to be exchanged and translated between the applications that serve one or more COIs. This article will describe a method we apply using current internet and semantic web technologies (including XML , XML Schema , and OWL) in a prototype developed for the semi-automated generation of semantic models of COI information spaces. Providing a semantic understanding of COI information spaces to software applications through use of such models is the next logical step in trying to meet the ultimate challenge of making extinct the stovepipe systems that are still in such rich abundance today. Specifically presented is a Composition Modeling Framework (CMF) and prototype implementation that demonstrates the CMF method to capture the structure, meaning and abstract implementation of the underlying information space that services a COI, providing a basis for dynamic interoperability between software applications which are designed or augmented to use semantic protocols.

6578-18, Session 3

CUGSS communications

G. L. Duckworth, Defense Advanced Research Projects Agency

No abstract available

6578-19, Session 3

Methods for calculating the probability of detection and target location error of unattended ground sensors

K. W. Brendley, Artis LLC; G. A. Klager, U.S. Army Night Vision & Electronic Sensors Directorate

In U.S. Army's ATD, Network Sensors for the Future Force, ample data were generated regarding the detection and target location capabilities of the MDUGS unattended ground sensor. Analysis approaches for reducing these data along with the results are presented. For calculating probability of detection, the line of bearing data were grouped into bins based on a threshold comparison and modeled using logit and probit methods. For calculating target location error, track error data were assumed to fit a Rayleigh distribution. The goodness of fit of this assumption and other statitical measures are reported.

6578-20, Session 3

A novel framework for command and control of networked sensor systems

G. Chen, Intelligent Automation Inc.; J. B. Cruz, Jr., The Ohio State Univ.; Z. Tian, Michigan Technological Univ.; D. Shen, Intelligent Automation Inc.; E. P. Blasch, P. Khanh, Air Force Research Lab.

In this paper, we propose a highly innovative advanced command and control framework for Networked Sensor Systems. The primary goal is to enable and enhance threat detection, validation and mitigation for future battlespace and battlespace situational awareness operations by graphical game theory and advanced knowledge infrastructures for information fusion. To achieve this goal, we will develop a framework that consists of three closely coupled systems: 1) An advanced Information Manager automates the processing and integration of information from disparate sources to produce an integrated object state for use by a multi-hypothesis track grouping capability that identifies groups of cooperating objects which are performing common tasks. Tracking information quality & completeness enables the capture of a more complete understanding of the situational awareness in its' tactical context. 2). An innovative Knowledge Generation Engine automates the contextual reasoning and inference construction by spawning intelligent agents to obtain available intelligence data from a variety of information sources (e.g., intelligence data), which is then fused with each groups' kinematic and composition information to infer its Course of Action (CoA) and alerts the analyst if hostile activities are identified with high probability. 3). An Autonomous Sensor Manager uses these CoAs to optimally task available sensor assets to minimize cost of operation and decision response time. The automation provided by our framework will enhance the situation awareness in a battlepsace environment, significantly compress decision time lines, reduce manpower requirements, and increase mission effectiveness to achieve superiority.

6578-22, Session 4

Interference division multiple access communications

L. R. Brothers, Defense Advanced Research Projects Agency

No abstract available

6578-23, Session 4

Paradigm shifts in wireless networking

J. C. Ramming, Defense Advanced Research Projects Agency

No abstract available

6578-24, Session 4

Throughput of 802.11g wireless devices in ad hoc mode

B. B. Luu, R. L. Hardy, Army Research Lab.

The U.S. Army Research Laboratory has used IEEE 802.11g standard wireless LANs for implementation in mobile ad hoc networks (MANET). One common problem with the use of 802.11g wireless devices is maintaining a high operational throughput over distances. In this paper, we will assess the throughput performance of four 802.11g wireless network interface cards (NIC) performing in ad-hoc mode and in an outdoor environment. This assessment is based on characteristics of NICs, such as chipset, amplification, and antenna diversity over various operating distances. The assessment showed that antenna diversity for outdoor environment has no throughput improvement, more amplification does not always improve data rates, and Broadcom wireless NIC has the best performance at the farthest distance.

6578-25, Session 4

The airborne network definition project: a network architecture effort for future battlefield networks that enable network-centric warfare

B. Ganguly, S. Finn, J. McLamb, W. Bynoe, L. Veytser, I. Pedan, S. A. Davidson, MIT Lincoln Lab.

The concept of Network-Centric Warfare (NCW) has gained wide acceptance as a transformational effort within the Department of Defense. The Airborne Network Definition (AND) project is a research effort aimed at defining and proving a highly capable battlefield network architecture, enabling seamless data sharing between elements. The network is designed to be mission-defined and seeks to enhance warfighting capabilities by providing new and improved pathways to share data.

One of the key components in the goal of achieving NCW capability is the development of the Small Combat Network (SCN) architecture. Roughly speaking, an SCN os the network infrastructure deployed in a single battle unit, and its associated connections to backbone infrastructure. The SCN should:

-Provide highly connected data pathways between the SCN members for tactical data exchange. -Be mission oriented, and designed for the combat environment. -Be self-contained and not dependent on the Global Information Grid (GIG), but should provide connectivity to the GIG when available/needed. -Be a transitional step toward IP-converged reliable battlefield connectivity, while still leveraging legacy systems.

Our goal is to develop an end-to-end network architecture, with a specific focus on developing an effective SCN architecture. The architecture provides reliable connectivity, topology, routing and control algorithms for achieving the network design.

The architecture must network surface, air and space segments, which variously contain fighting platforms, fighting support platforms, command and control infrastructure, and telecommunication infrastructure. The key technical contribution of the AND effort is overcoming the heterogeneity of the communicating entities inside the theater.

This paper presents the SCN architecture we are developing, and highlights its features and key design choices. We describe an example of an operation that the proposed SCN architecture supports, and how the network is instantiated inside the scenario. We show simulation results in terms of Measures of Performance (MOPs) and Measures of Effectiveness (MOEs) of actual warfighting applications. Our results show that the proposed architecture supports key data sharing in this operation that tangibly enhance warfighting capabilities. Finally, we outline future phases of the AND project and a transition plan for transfer of the technology into actual battle systems.

6578-26, Session 4

Live-flight demonstration of agent technology for connecting the tactical edge to the global information grid

E. J. Martens, D. E. Corman, Boeing Military Aircraft and Missile Systems Group

The Boeing Company in conjunction with the Air Force Research Laboratory (AFRL) have recently completed and flight demonstrated agent-based technology that, along with an advanced Information Management System (IMS), enables tactical platforms such as the F-15 to connect to and interoperate with other Global Information Grid (GIG) systems. The "Improving War-Fighting Effectiveness through Integration of a Tactical Strike Fighter with the Global Information Grid" or GIG Client program was under-taken to carryout the DOD goal of GIG-enabling weapon systems. The technology was demonstrated through live-flight test flights using the Boeing Company's F-15E aircraft flying on two test flights in early February 2006.

Through the developed GIG Client technology, a live-flight F-15E aircraft was connected with the GIG via its fielded Link-16 network and an off-board agent called the Platform Adaptor. During the flight, the aircrew received information from GIG sources on Blue Force tracks, Unmanned Air Vehicle (UAV) position, route, type, and other UAV mission data, and imagery data from Intelligence and UAV sources. F-15E status information such as position, speed, weapons status, fuel, and targeting data was published to GIG for use by prototype Combined Air Operations Center (CAOC) applications. Through this managed exchange of information, the GIG Client program demonstrated the utility of increasing tactical platform awareness for prosecuting missions relevant to today's battlefield and the potential of the GIG to support collaboration between Command and Control (C2) and manned and unmanned assets

6578-27, Session 4

Demonstration of high-data-rate wavelength division multiplexed transmission over a 150 km free space optical link

D. W. Young, J. E. Sluz, J. C. Juarez, M. B. Airola, R. M. Sova, H. Hurt III, Johns Hopkins Applied Physics Lab.; M. J. Northcott, J. Phillips, A. McClaren, D. Driver, J. E. Graves, D. D. Abelson, AOptix Technologies, Inc.; J. J. Foshee, Air Force Research Lab.

This paper describes the system configuration and data transmission performance of a wavelength division multiplexed (WDM) 150 km free space optical (FSO) link between Maui (Haleakala) and Hawaii (Mauna Loa). The FSO terminals were designed and developed by AOptix Technologies, Inc.; the optical transmission equipment was designed and developed by JHU/APL. Over a 5 day period, multiple configurations including single channel 2.5 Gb/s transmission, single channel 10 Gb/s, and four 10 Gb/s channels (aggregate data rate of 40 Gb/s) were demonstrated. Links at data rates from 10 to 40 Gb/s were run in excess of 3 contiguous hours - data on the received power, frame synchronization loss, and bit error rate were recorded.

This paper will report on the data transfer performance (bit error rates, frame synchronization issues) of this link over a 5 day period. A micropulse lidar was run concurrently, and on a parallel path with the FSO link, recording data on scattering loss and visibility. Comparisons between the state of the link due to weather and the data transfer performance will be described.

6578-28, Session 4

Hawaii 150km FSO 40 Gbps communications link demonstration

M. J. Northcott, AOptix Technologies, Inc.; J. J. Foshee, Air Force Research Lab.; D. D. Abelson, J. E. Graves, J. Phillips, A. McClaren, AOptix Technologies, Inc.; D. W. Young, R. M. Sova, J. E. Sluz, J. C. Juarez, M. B. Airola, Johns Hopkins Applied Physics Lab.

AOptix Technologies Inc., under contract to the USAF/AFRL, successfully demonstrated a Free Space Optics (FSO) communication link between the Hawaiian mountaintops of Mauna Loa and Haleakala, separated by approximately 150km. The AOptix FSO link provided the equivalent of an end to end 40 Gbps "virtual" Single Mode Fiber connection at a fraction of the cost of actual fiber and without the need to use Optical to Electro to Optical (OEO) conversion. The eyesafe terminals used AOptix adaptive optics technology to minimize the effects of atmospheric turbulence and efficiently coupled laser light between the platforms, maximizing data throughput and link reliability. AOptix was teamed with JHU/APL to accomplish the successful link demonstration. JHU/APL was responsible for the optical communications modems and related data collection.

The demonstration measured real atmospheric effects and link characteristics over the long distance to support advanced simulation studies that will be used to define the technology required for both long-range fixed and mobile air-to-air laser communication applications.

The paper will discuss the technology used to perform the FSO Communications Link Demonstration; including measured atmospheric conditions experienced during the tests and will also present performance data collected during testing.

6578-29, Session 4

A framework for assessing and predicting network loads and performance for network centric operations and warfare

E. E. Santos, Virginia Polytechnic Institute and State Univ.

While much work in NCO/NCW has focused on developing the components based on information sharing and cross awareness (e.g. conceptual models for co-operability and the common operating picture (COP)), the lynchpin is a robust network infrastructure. However, little is known about the overall effectiveness and performance of NCO/NCW networks in general. Determining how robust or stable an existing infrastructure (network) will be and to pinpoint weaknesses or faultiness is an important and critical concern, especially since these networks need to be able to be employed in an adaptive and dynamic environment. Determining if an existing NCO/NCW network infrastructure is indeed robust and reliable is a major undertaking due to the inherently large-scale and complex nature of interaction. Employing theoretical models which can be used to analyze and predict performance (e.g. scalability, reliability, etc) is particularly important in order to design a realistically deployable network.

As such, in this paper we will present the design of a rigorous theoretical framework to assess and predict the effectiveness and performance of networks and their loads for deployment in Network Centric Operations (NCO) and Network Centric Warfare (NCW). The framework is imbued with the ability to pinpoint bottlenecks and suggest corrections and modifications leading to more effective and deployable networks. The framework is decomposable in order to allow for flexibility in description, prediction and analysis. The key components include:

A. Network Representation Component (NRC),

B. Performance Measures Component (PMC),

C. Performance Tool Suite Component (PTSC), and

D. Submodel Interaction Component (SIC).

6578-30, Session 4

Synchronization techniques for wireless multi-radar covert communication networks

S. C. Surender, R. M. Narayanan, The Pennsylvania State Univ.

To support network centric operations for battlespace surveillance, communication technologies are heavily dependent on effective synchronization mechanisms. We consider multiple separately located radar system nodes that configure a covert communication channel between the nodes using random noise signals. Such radars form an effective network-centric system that has intrinsic properties such as low probability of intercept (LPI) and low probability of detection (LPD), along with its data dissemination capabilities. The idea of using frequency-notched noise spectra combined with embedded OFDM

data symbols as a communications signal between noise radars has already been demonstrated. However, its performance is severely limited due to the fact that this noise-data signal is affected by frequency-offsets and timing offsets. The receiver in such systems depends heavily on the IDFT window for detecting the OFDM symbols embedded in the noise waveform. Synchronization errors bring unwanted noise into this window in the form of ISI, ICI, etc. It therefore becomes crucial that these errors are corrected before decoding the incoming signal. In this paper, we propose unique packet detection and timing estimation techniques for the noise-data signal used for communications between the random noise radars. These techniques are unique in the sense that they are not applied to traditional OFDM signals, but to OFDM symbols embedded within ultrawideband (UWB) noise. Another aspect of this technique is that does not use training symbols, pilots, or repeated symbols for synchronization. Without any preprocessing required in the transmitter, the correlation property of band-limited white noise is used to achieve the desired results. The prominent advantage envisioned is the development of a more reliable and covert communication system, allowing effective data dissemination in our network-centric applications.

6578-31, Session 4

Passive RF tags for radar channel communications using frequency-notched noise waveforms

K. D. Kim, R. M. Narayanan, The Pennsylvania State Univ.

In military operations, especially in the battlefield, information about the warfighter's situation and surroundings is very important in deciding the next steps of tactical operations. However, owing to its unique situation, communications ability is very limited and is greatly compromised if the warfighter transmits any kind of signal. Therefore, the passive RF tag, similar to those used in RFIDs, is an attractive solution to provide limited communications and signaling in a concealed manner. A new technique to induce covertness in the RF tag channel with noise waveforms for radar communications is under investigation. The proposed solution uses noise waveforms for covertness because they have low probability-of-detection (LPD) and low probability-of-intercept (LPI) properties. The radar system transmits band-limited noise signals and the RF tag on the warfighter's vehicle retransmits a modified noise-like waveform back towards the radar using a pre-arranged circuit structure. The noise-like waveform is a frequency-notched version of the received radar waveform. The probability density function (PDF) of the notched waveform is not very different from that of the original noise waveform if the amount of notch is 10% of the entire band. The actual location of the notch frequency conveys a specific message. When the radar receives the signal from the tag, it correlates the received signal from tags with the expected signal response for specific messages and finds the proper tag locations depending on the results. To provide battlefield situation information, warfighters modify the tags to induce the frequency notches. For example, if they are in a dangerous situation they may send Tag-A signal asking for reinforcement, and if they want to convey that they are in a position to maintain their current operations, they may send Tag-B signal, etc. As a result, the distant radar can achieve situational awareness and do necessary actions. Although such communications through radar channels is limited in scope, it achieves covertness while providing information about several critical battlefield situations.

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6578-32, Session 4

A network-centric robust resource allocation strategy for unmanned systems: stability analysis

K. Khorasani, Concordia Univ. (Canada)

It is widely believed that communications will be the critical technical factor in designing large scale unmanned networks consisting of a large number of heterogeneous nodes that may be configured in ad-hoc fashions and incorporating intricate architectures. In fact, one of the challenges to this field is to recognize the entire network as a heterogenous collection of physical and information systems with complicated interconnections and interactions. Using high data rates that are essential for their real-time interactive command and control systems, these networks require the utilization of optimal integration of local feedback loops into a scheduling and resource allocation systems. This integration becomes particularly problematic in the presence of latencies and delays.

Given that dynamics of a network of unmanned systems could easily become unstable and unmanageable depending on the interconnections between their nodes, in this paper we study how stability of the resulting time-delayed dependent controlled network can be compromised based on configuration changes. We also formally investigate and study the necessary conditions on our proposed robust resource allocation strategies to be able to cope with these interconnections and time-delays in an optimal fashion.

Our time-delayed dependent network consists of three nodes that can be configured into different architectures. To model our traffic and network we use a fluid flow model that is of low order and simpler than a detailed Markovian queueing probabilistic models. Using the sliding mode-based variable structure control (SM-VSC) techniques that enjoy robustness capabilities, we design on the basis of an inaccurate/uncertain model our proposed robust nonlinear feedback-based control approaches. The results presented in this paper are analyzed analytically to guarantee for different configurations the stability of our known/unknown time-delayed dependent network of unmanned systems.

6578-33, Session 4

Node compromise attacks and network connectivity

K. S. Chan, F. Fekri, Georgia Institute of Technology

Net-centric warfare requires widespread, highly reliable communications even in the face of adversarial influences. Maintaining connectivity among network entities is vital towards mission readiness and execution. We examine required communications range of nodes in a wireless sensor network. Several parameters of these networks are studied in terms of how they influence overall network connectivity such as key predistribution schemes and node compromise attacks. Communications in wireless sensor networks is important due to the limited resources available in these situations. In many battlespace situations for networks of unmanned ground sensor nodes, communication range is limited by resources, hardware ability and unpredictable terrain. Additionally, networks attempt to minimize the transmission power of each node to conserve power, as the radio is oftentimes the largest drain on available energy resources. Furthermore, such networks are vulnerable to physical node compromise and attack by an adversary and destroy connectivity in these situations. What is studied here is overall network connectivity and its relationship to key predistribution schemes and node compromise attacks. In networking situations with an adversarial presence, it may be possible to continue to mission objectives properly with the remaining uncompromised network resources with some reconfiguring of network parameters. We derive a single expression to determine required communication radius for wireless sensor networks to include these situations.

6578-34, Session 5

The DARPA urban challenge

N. A. Whitaker, Defense Advanced Research Projects Agency

No abstract available

6578-35, Session 5

Multiplatform information-based sensor management: an inverted UAV demonstration

C. M. Kreucher, J. W. Wegrzyn, M. Beauvais, R. Conti, General Dynamics Advanced Information Systems

This paper describes an experimental demonstration of a distributed, decentralized, low communication sensor management algorithm. Earlier work has described the mathematics surrounding the method,

which includes a novel combination of particle filtering for predictive density estimation and information theory for maximizing information flow. While the utility can be seen via Monte Carlo simulations, a demonstration using real hardware is required to actually verify the real-world utility of the method. In this paper, we describe an inverted Unmanned Aerial Vehicle (UAV) test-bed that has been developed by General Dynamics Advanced Information Systems (GDAIS) Michigan Research and Development Center (MRDC) to facilitate and promote the development and conversion of the research algorithm into an operational, field-able system. Using a modular design with wheeled robots as surrogates to UAVs, many of the development and control issues associated with platforms that must remain airborne are deferred to experts in avionics and flight control.

6578-36, Session 5

Collaborative unmanned vehicle engagement in adversarial missions

J. Reimann, G. Vachtsevanos, Georgia Institute of Technology; J. Ge, L. Tang, A. Liberson, Impact Technologies; H. Chang, U.S. Army Research Office

In future urban warfare scenarios, the expectations placed on unmanned vehicles in terms of autonomy, reliability and cooperation will be significantly increased. This paper introduces an innovative solution to the multiplayer differential pursuit-evasion game problem, in which multiple pursuing unmanned vehicles attempt to intercept several evading targets in minimum time. To reduce the complexity of the multiplayer game, it is decomposed into several simple two-player games. Each player is modeled using simple vehicle dynamics to limit the complexity of the two-player games, and each game is solved efficiently using the fast marching method. Based on the set of two-player game solutions, collaboration between the pursuers is reintroduced by assigning each pursuer the task of either containing or intercepting a target. In addition to reducing the overall complexity of the differential pursuit-evasion game, the decomposition approach also allows for rapid online replanning thereby enabling the pursuers to adapt rapidly to possible changes in the game parameters. Several different multiplayer scenarios are simulated to illustrate the effectiveness of the differential game approach.

6578-37, Session 5

Agent-based multiplatform control, collaboration, and target hand-off

N. P. Coleman, U.S. Army Armament Research, Development and Engineering Ctr.; J. Robbins, B. Tirabassi, Technical Solutions, Inc.

Deploying a world wide force that is strategically responsive and dominant at every point on the spectrum of conflict involves the cooperative system development and use of advanced technologies that yield revolutionary capabilities to support the war-fighters needs. This presentation describes an agent based control architecture and prototype implementation developed by ARDEC that enables command and control of multiple unmanned platforms and associated mission packages for collaborative target hand-off/engagement. Current prototypes provide the ability to remotely locate, track and predict the movement of enemy targets on the battlefield using a variety of sensor systems hosted on multiple, non-homogeneous SUAVs and UGVs.

These technologies, including integrated mission package/platform control, agent collaboration, asset employment, target tracking, geo-location, target monitoring and prediction, path planning and target hand-off capabilities, have been developed and integrated as API based component plug-ins into the unique multi-modal interface Multi-Platform Controller. These capabilities provide an enhanced Situational Awareness, while greatly increasing the Soldiers lethality and survivability for improve mission success. Component technologies have been developed by several different companies using the ARDEC sponsored and developed Weapons System Operating Environment (WSOE) Software Development Kit (SDK) for Decision Aids as a software service for easy inclusion by lead system integrators into future Army systems.

Field tests have successfully demonstrated the Multi-Platform Controller deploying and commanding multiple ground and aerial robotic platforms. Live video captured from Unmanned Aerial Vehicles (UAVs) is displayed on the MPC for target tracking and monitoring tasks. Applications developed using the SDK provide Gap Identification, Path Prediction and Planning, and Geo-location services on the targeted tracks. The execution of plans on these tracks are accomplished by converting them to Joint Architecture for Unmanned Systems (JAUS) and NATO 4586 command streams for execution by both ground and air assets and sent to and from the Soldiers man-wearable computer via tactical internet in Variable Message Format (VMF) protocol as required to employ the asset.

6578-38, Session 5

Formation control in multiplayer pursuit evasion game with superior evaders

X. Wang, The Ohio State Univ.; G. Chen, Intelligent Automation Inc.; J. B. Cruz, Jr., The Ohio State Univ.; H. Chang, U.S. Army Research Office; E. Blasch, Air Force Research Lab.

In this paper, we consider a multi-pursuer multi-evader pursuit evasion game where some evaders' maximal speeds are higher than those of all pursuers. We call such evaders as "superior evaders" to emphasize the fact that they have comparatively more advantageous control resources. In multi-player pursuit evasion game, hierarchical framework is applied widely in order to decompose the original complicated multi-player game into multiple small scale games, i.e. one-pursuer one-evader games and multi-pursuer single-evader games. The latter is especially required for superior evaders. Although usually only suboptimal results are obtained, the resulting decentralized approaches are favored by researchers from the point view of communication aspect for practical applications. For the autonomous systems of pursuers in multi-pursuer single-superior-evader games, how to exploit the cooperation between pursuers so that the superior evader can be captured successfully in the shortest time is the main problem. Based on our previous work, for a multi-pursuer single-superior-evader game on a plane, we first study the number of pursuers necessary for the capture. Regarding each player as a mass point, a moving planar coordinate system is fixed on the evader. Then formation control is used for pursuers in their pursuit strategies so as to 1) avoid collision between pursuers; 2) reduce the distance between each pursuer and the evader over the evolution of the game; 3) keep the pursuers' formation shape invariant relative to the evader during the pursuit process and enclose the superior evader within the union of each pursuer's capture domain at the end of the game.

6578-39, Session 5

Collaborative multitarget tracking using networked robotic vehicles

S. Biswas, S. Gupta, F. Yu, Michigan State Univ.

This paper will present a collaborative target tracking framework, in which joint networking and tracking mechanisms are developed for tracking multiple mobile targets using a team of networked micro robotic vehicles. Applications of such a framework would include multi-agent intrusion detection, network-centric asset coordination for intruder tracking, and other collaborative weapon engagement scenarios. The key idea of the developed framework is to design wireless vehicular network protocols that are customized for collaborative multi-target tracking applications. The paper will comprise of the following components. First, the architectural details of a Swarm Capable Autonomous Vehicle (SCAV) system that is used as the mobile platform in our target tracking application will be presented. The SCAV system (http://www.egr.msu.edu/~sbiswas/Research_n/SCAV.htm) has been developed in our laboratory, and its functionalities include self-localization at centimeter resolution within an in-laboratory reference coordinate system, autonomous navigation using an Extended Kalman Filter, collision avoidance using infra-red obstruction sensing, and inter-vehicle wireless networking using a variety of Mobile Ad Hoc routing protocols. The second component of the paper will be a formalization of the multi-target tracking problem using collaborative mobile agents.

Third, a set of inter-vehicular network routing protocols will be developed for enabling the collaborative tracking framework. Fourth, a heuristics based tracking solution framework that leverages the underlying wireless network protocols in a cross-layer fashion, will be developed. Next, the performance of the proposed network protocols and the tracking framework will be evaluated using a simulator as well as a laboratory testbed of a fleet of SCAV vehicles. Finally, a detailed system characterization of the framework along with network performance sensitivity analysis will be carried out.

6578-40, Session 5

Hunter standoff killer team (HSKT) ground and flight results

B. M. Moreland, U.S. Army Research, Development and Engineering Command

Since the inception of powered flight, manned aerial vehicles have been a force multiplier on the battlefield. With the emergence of new technology, the structure of the military battlefield is changing. One such technology, Unmanned Aerial Vehicles (UAVs) has emerged as a valuable asset for today's war fighter. UAVs have traditionally been operated by ground control stations, yet minimum research has been targeted towards MAV / UAV connectivity. Airborne Manned Unmanned System Technology Baseline (AMUST-Baseline) was a concept that demonstrated the battlefield synergy gained by Manned and Unmanned Vehicle teaming. AMUST-Baseline allowed an Apache Longbow's (AH-64D) co-pilot gunner (CPG) to have Level IV, control of a Hunter fixed wing UAV. Level IV control of a UAV includes flight control, payload control, and direct data receipt. With the success of AMUST-Baseline, AATD, Lockheed Martin, and the Boeing Company are working towards enhanced Manned and Unmanned connectivity, through a technology investment agreement. This effort named Airborne Manned Unmanned System Technology Demonstration (AMUST-D) will focus on the connectivity between two manned platforms, Apache Longbow (AH-64D) and Command and Control (C2) Blackhawk, and Hunter UAV. It will allow robust communication from the UAV to each platform through Tactical Common Data Link (TCDL). AMUST-D will use decision aiding technology developed under the Rotorcraft Pilots Associate (RPA) Advanced Technology Demonstration (ATD) to assist in control of the Hunter UAV, as well as assist the pilot in regularly performed duties. Through the use of decision aiding and UAV control, the pilot and commander will be better informed of potential threats, thus increasing his situational awareness. The potential benefits of improved situational awareness are increased pilot survivability, increased lethality, and increased operational effectiveness and efficiency.

Two products are being developed under the AMUST-D program, the Warfighters Associate (WA) which will be integrated onto the Apache Longbow, and the Mobile Commanders Associate (MCA) which will be integrated onto the A2C2S. In this paper we will discuss what WA and MCA provides to the warfighter, and the results from the HSKT ground and flight test.

6578-41, Session 7

UrbanScape

B. S. Leininger, Defense Advanced Research Projects Agency

No abstract available

6578-42, Session 7

Leveraging neuroscience for geospatial intelligence

A. A. Kruse, Defense Advanced Research Projects Agency

No abstract available

6578-43, Session 7

Geospatial challenges in a net centric environment: actionable information technology, design, and implementation

M. R. Hieb, M. J. Pullen, George Mason Univ.; M. W. Powers, H. Yu, U.S. Army Engineer Research and Development Ctr.

Terrain and weather effects represent fundamental battlefield information supporting situation awareness and the decision-making processes for net-centric operations. Realization of the promised potential of net-centric operations is challenging with respect to these effects, since these effects can both enhance or constrain force tactics and behaviors, platform performance (ground and air), system performance (e.g. sensors) and the soldier. We define four issues in this area as viewed from the perspective of the geospatial community. First, the size of geospatial data and information products enabling Battle Command processes can be quite large requiring sensitivity to the frequency of network use, the packet size of products and distributed data and information provisioning. Secondly, computational requirements for geo-processing and analysis in the creation of actionable geospatial information and the computational burden impact strategies for net-centric geospatial solutions. Third the tenants of Metcalf's Law influence the design of information products for a net-centric Battle Command Environment. Finally, interoperability between force elements (nodes) must address not only syntactic consistency, but consistency of both a lexical and semantic representation if we are to realize shared, coherent awareness. This paper presents a systemic approach for successful resolution of these challenges.

6578-44, Session 7

Airborne data to actionable intelligence in minutes

M. Phipps, P. P. Hed, M. Meister, General Dynamics Advanced Information Systems

No abstract available

6578-45, Session 7

Orchestrating and optimizing multisource ISR

M. Limcaco, General Dynamics Advanced Information Systems

No abstract available

6578-46, Session 7

Spatio-temporalreasoning of urban environs for C2 planning and execution

M. L. Collins, U.S. Army

US troops have proven their dominance over opposing forces from standoff ranges. Enemy tactics now take conflicts into urban areas. Complex urban terrain, defined by its concentration of humanity with accompanying buildings and infrastructure, diminishes the technological superiority of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems. Simultaneously, urban terrain is a force multiplier for insurgents who exploit the “cultural camouflage” that provides them cover and concealment until the battlespace is shaped to their advantage. The complexity and dynamic nature of this environment generates unprecedented demands for preparedness and operational agility at all echelons.

Missions can transition between humanitarian assistance, stability and support, or armed combat instantaneously. The demand for timely, accurate and precise Actionable Geospatial Intelligence is at a premium. Yet the increase in both volume and frequency of such intelligence in its raw forms could actually hamper decision-makers as they try to assimilate myriad information feeds. Extending this to a network-centric force, one quickly realizes that a distributed common

tactical picture could overly tax secure communications bandwidth. To succeed, innovative enterprise solutions for data representation, management and dissemination must be developed and implemented.

The Urban Reasoning and Battlespace ANalysis (URBAN)* Army Technology Objective (ATO) is focused on building spatio-temporal analytics to support tactical scale decisions across the spectrum of military missions in urban environs. URBAN is attempting to fuse the disciplines of terrain analysis, knowledge management and temporal modeling to aid the understanding of the dynamic influences and interaction of culture, geography, weather and infrastructure for the purposes of mission planning as well as mission Command and Control (C2).

* URBAN has been combined with 3 other ATOs to form the Network Enabled Command & Control (NEC2) ATO.

6578-47, Session 8

GIS approaches for geographic dynamics understanding and event prediction

M. Yuan, Univ. of Oklahoma

This paper reviews key GIS approaches to geographic dynamics understanding and event prediction, and the review will synthesize recent developments and critical issues that hamper effective spatiotemporal reasoning. Geographic domains exhibit diverse dynamics across multiple spatiotemporal scales. Such diverse and complex geographic dynamics challenges means to connect relevant information and infer the underlined processes. Central to the paper is the idea that forms in space and time offer clues to the underlined geographic processes and events. Connections of forms and patterns captured by spatiotemporal data to the responsible processes and events serve as the conceptual and methodological foundations for geographic dynamics understanding and event prediction.

Reviews in the paper will investigate how geospatial forms and patterns may suggest the underlined processes and events. Statistical methods have long been established to examine if a point distribution should be categorized as random, clustered, or dispersed. When a point distribution is determined not random, the distribution is then assumed to be resulted from certain geographic events or processes. However, theoretical bases for random distributions of lines or polygons are not yet available, and statistical bases are lacking to evaluate linear or polygonal patterns against random distributions. Nevertheless, alternative methods are being developed to connect geospatial distributions of lines or polygons to geographic processes and events, especially in tracking, climate, and hydrology. The review, syntheses, and critics in the paper will draw new insights into theoretical and methodological foundations for the study of geographic dynamics understanding and event prediction.

6578-48, Session 8

Incorporating uncertainty with geospatial forecasts for terror events

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Having the ability to accurately forecast potential terrorist events is of utmost importance to intelligence analysts and military planners performing counter-measures for the global war on terror. Forecasts not accounting for uncertainty in their input measurements may mislead planners into allocating security resources-personnel and sensors-to protect lower-value targets. We have been developing spatial, threat-event forecasting techniques for urban environments operating by extracting correlation signatures from associations made between historical events and geospatial information sources. Our focus is to improve the forecasting techniques (estimating likeliest locations a terrorist would target) by incorporating numerical uncertainty and data error associated with the geospatial and historical information. We consider a range of factors contributing data variations (e.g., type of weapon, geometry of impact region for historical event, data distribution, measurement and observation error, etc.) accounting for uncertainty. We discuss the variation-contributing factors, impacts they have on forecasts, and show the results from tests of a few of the factors. Preliminary results when analyzing variation of the position of reported historical event locations show numerical uncertainty with values ranging up to 100 m has a negligible effect on the forecasts; however, values exceeding 1 km may have significant impact by translocation of “threat hotspots” up to several blocks away. We conclude by speculating results for the untested “contributing” factors.

6578-49, Session 8

EcoSentinel: a spatially explicit model for prediction of outbreaks of the Siberian moth in Siberia and the Russian Far East

M. C. Saunders, B. J. Miller, M. McFadden, The Heron Group LLC

EcoSentinel is a proprietary software application that uses a knowledge base (i.e. a formalized articulation of logic in a form usable by suitable computer software). The knowledge base can process geographically positioned data into maps of predicted outcomes of the problem articulated in the model. These maps are suitable for use in all geographic information systems (GIS). EcoSentinel/SM, The Siberian Moth Outbreak Prediction Model, is a knowledge base that captures the equations and logic of Dr. Yuri Kondakov’s research on defoliation and outbreak prediction of Siberian Moth. This model consists of two predictive models: a defoliation prediction model based on Siberian Moth larvae observations, and a potential outbreak prediction model based on measured changes in Siberian Moth adult populations and reproductive coefficients. Point-collected input data are processed into suitable two dimensional geographically referenced form using a spatial statistical process called Kriging. The knowledge base analyses these Kriged data and processes the data into maps. Outputs from EcoSentinel and The Siberian Moth Model are raster-based electronic maps. Users can select the output form and file format when exporting the maps.

6578-50, Session 8

Detecting space-time cancer clusters using residential histories

J. R. Meliker, BioMedware, Inc.; G. M. Jacquez, BioMedware, Inc. and Univ. of Michigan

Methods for analyzing geographic clusters of disease typically ignore the space-time variability inherent in epidemiologic datasets, do not adequately account for known risk factors (e.g., smoking and education) or covariates (e.g., age, gender, and race), and do not permit investigation of the latency window between exposure and disease. Our research group recently developed Q-statistics for evaluating space-time clustering in cancer case-control studies with residential histories, computed using TerraSeer’s STISTM software. This technique relies on time-dependent nearest neighbor relationships to examine clustering at any moment in the life-course of the residential histories of cases relative to that of controls. In addition, in place of the widely used null hypothesis of spatial randomness, each individual’s probability of being a case is instead based on his/her risk factors and covariates. Case-control clusters will be presented using residential histories of 220 bladder cancer cases and 440 controls in Michigan. In preliminary analyses of this dataset, smoking, age, gender, race and education were sufficient to explain the majority of the clustering of residential histories of the cases. Clusters of unexplained risk, however, were identified surrounding the business address histories of 10 industries that emit known or suspected bladder cancer carcinogens. The clustering of 5 of these industries began in the 1970’s and persisted through the 1990’s. This systematic approach for evaluating space-time clustering has the potential to generate novel hypotheses about environmental risk factors. These methods may be extended to detect differences in space-time patterns of any two groups of people, making them valuable for security intelligence and surveillance operations.

6578-52, Session 9

GEOINT for MDA

C. Andreasen, C. Read, National Geospatial-Intelligence Agency

No abstract available

6578-53, Session 9

Challenges of maritime domain awareness and global maritime intelligence integration

T. Breidenstein, National Intelligence Agency

No abstract available

6578-54, Session 9

Maritime domain awareness network

M. Andress, Office of Naval Intelligence

No abstract available

6578-56, Session 9

Comprehensive maritime awareness (CMA)

C. Dwyer, Naval Research Lab.

No abstract available

6578-57, Session 9

Software solutions for ship tracking and harbor surveillance

U. C. Benz, Definiens Imaging GmbH (Germany); A. Hsu, D. W. Hugo, National Geospatial-Intelligence Agency

No abstract available

6578-58, Session 9

Automated detection of objects inside scanning sonar data

J. M. Irvine, S. A. Israel, S. M. Bergeron, Science Applications International Corp.

No abstract available

6578-59, Session 9

Change detection and intelligence preparation of the environment in support of maritime domain awareness

R. E. Betsch, Naval Oceanographic Office

No abstract available

6578-60, Session 9

SeeCoast: persistent surveillance and automated scene understanding for ports and coastal areas

B. Rhodes, A. M. Waxman, M. Seibert, N. A. Bomberger, T. M. Freyman, W. Kreamer, L. Kirschner, A. C. L'Italien, W. Mungovan, C. Stauffer, L. Stolzar, BAE Systems Advanced Information Technologies

No abstract available

6578-62, Session 9

Determinants for global cargo analysis tools

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No abstract available

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6579-01, Session 1

Recent advances in multiview distributed video coding

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Video surveillance systems are becoming omnipresent nowadays, due to high criminality and terrorist threats. Large surveillance systems are deployed in strategic places such as airports, public transportation and downtown. Thanks to the improve performance and reducing cost of cameras, a trend towards dense networks of cameras is expected. The wireless camera sensor network is one example of such as system, which consists of a large number of nodes that are densely deployed, each node being an independent, low-power, smart device with sensing, processing and wireless communication capabilities.

Hereafter, we consider a network of multiple cameras which are capturing overlapped images from the same scene with different viewing positions, referred to as multi-view. Because many vision-based techniques can benefit from multi-view, such as object recognition, event detection, target tracking and view interpolation, multi-view image and video processing has attracted increasing attention recently. The range of applications for multi-view systems is very wide and covers different areas such as homeland security and military, but also environment monitoring and healthcare

On the other hand, the amount of data captured in multi-view imaging is often tremendous. This makes data reduction a key issue. If the cameras were allowed to communicate with each other, it would be easy to exploit this correlation in full and transmit only the necessary information to the receiver. However, such collaboration is usually not feasible since it would require a complex inter-node communication system that would be power consuming. Furthermore, due to the strong correlation between images acquired by different cameras, multi-view data reduction has its own characteristic that differs significantly from traditional image/video compression. It is therefore necessary to develop compression algorithms that are able to exploit this correlation without requiring any cooperation amongst the cameras. As a result, an increasing amount of work on multi-view sampling and compression has been proposed in recent years.

MPEG is conducting work in 3D Audio-Video (3DAV) for Multi-view Video Coding (MVC). It is based on the recent Advanced Video Coding (AVC) standard. MVC performs block-based predictive coding across the cameras in addition to predictive coding along the time axis of each camera, hence achieving high compression efficiency. However, the encoder requires high computational power to perform predictive coding. In addition, it calls for communication between the cameras, which is not feasible in practice.

Distributed source coding (DSC) is a new coding paradigm based on two Information Theory theorems: Slepian-Wolf and Wyner-Ziv. Theoretically, it states that the optimal rate achieved when performing joint encoding and decoding of two or more correlated sources can be reached by doing separate encoding and joint decoding. In other words, a single decoder is used to perform joint decoding exploiting the statistical dependencies. Based on DSC, a new video coding paradigm, referred to as distributed video coding (DVC) is defined. In a practical scenario such as a network of surveillance cameras, DVC allows for low power / low complexity cameras as well as no communication between the cameras, which are major advantages.

In multi-view DVC, side information can be generated either by temporal extrapolation within a camera sequence, or by inter-view extrapolation from the side cameras. In this paper, we discuss some recent advances in multi-view DVC. In particular, we consider the problem of view prediction across cameras and fusion strategy to optimally combine temporal and inter-view side information. Results are presented in terms of coding efficiency as well as complexity.

6579-02, Session 1

Memory-efficient contour-based region-of-interest coding of arbitrarily large images

N. G. Sadaka, Arizona State Univ.; G. P. Abousleman, General Dynamics C4 Systems; L. J. Karam, Arizona State Univ.

In this paper, we present a memory-efficient, contour-based, region-of-interest (ROI) algorithm designed for ultra-low-bit-rate compression of very large images. The proposed technique is integrated into a user-interactive wavelet-based image coding system in which multiple ROIs of any shape and size can be selected and coded efficiently. The coding technique compresses regions of interest and background information independently by allocating more bits to selected targets and fewer bits to the background data. This allows the user to transmit large images at very low bandwidths with lossy/lossless ROI coding, while preserving the background content to a certain level for contextual purposes. Extremely large images (e.g., 65000 X 65000 pixels) with multiple large ROIs can be coded with minimal memory usage by using intelligent ROI tiling techniques. The foreground information at the encoder/decoder is independently extracted for each tile without adding extra ROI side information to the bit stream. The arbitrary ROI contour is down sampled and differential chain coded (DCC) for efficient transmission. ROI wavelet masks for each tile are generated and processed independently to handle any size image and any shape/size of overlapping ROIs. The resulting system dramatically reduces the data storage and transmission bandwidth requirements for large digital images with multiple ROIs.

6579-03, Session 1

Real-time super-resolution-enhanced ultra-low-bit-rate video coding

W. Chien, Arizona State Univ.; G. P. Abousleman, General Dynamics C4 Systems; L. J. Karam, Arizona State Univ.

This paper presents a software-only, real-time video coder/decoder (codec) with super-resolution-based enhancement for ultra-low-bit-rate compression. The codec incorporates a modified JPEG2000 core and interframe predictive coding, and can operate with network bandwidths of less than 1 kbits/second. Highly compressed video exhibits severe coding artifacts that degrade visual quality. To lower the level of noise and retain the sharpness of the video frames, we build on our previous work in super-resolution-based video enhancement and provide new extensions so that it can be employed in real-time video coding systems. The adopted super-resolution-based enhancement uses a constrained set of motion vectors that is computed from the original (uncompressed) video at the encoder. Artificial motion is also added to the difference frame to maximize the enhancement performance. The encoder can transmit either the full set of motion vectors or the constrained set of motion vectors depending upon the available bandwidth. At the decoder, each pixel of the decoded frame is assigned to a motion vector from the constrained motion vector set. L2-norm minimization super-resolution is then applied to the decoded frame set (previous frame, current frame, and next frame). A selective super-resolution scheme is proposed in order to prevent ghosting which, otherwise, would result from the adopted super-resolution enhancement scheme when the motion estimation fails to find appropriate motion vectors. Results using the proposed system demonstrate significant improvement in the visual quality of the coded video sequences.

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6579-04, Session 1

Signal compression via coordinate logic transforms

E. E. Danahy, K. A. Panetta, Tufts Univ.; S. S. Agaian, The Univ. of Texas at San Antonio

While the number of mobile devices in use is steadily increasing, so is the demand for more complex multimedia content. With this comes an additional need for advanced signal processing techniques to quickly, efficiently, and accurately manipulate the data. One area where this is most evident is in signal compression, where the necessity for reducing the size of signals being streamed and presented is essential to adequate playback. However, as the quality of the devices also rises (larger screens, higher resolution audio, faster playback), the quality of the stored or transmitted data can't suffer due to compression, as any errors and sacrifices become more apparent to the end user.

Coordinate logic (CL) filters are a method for applying basic logic operations to signals, and have been used in several image processing areas from edge detection to noise filtering. Presented here is an alternate method for calculating the CL filters through the use of logical transforms, eliminating the need for the logic operations. Termed coordinate logic (CL) transforms, they presents the possibility of a simpler hardware implementation, as algorithmic parallelism is present that can be exploited through application specific circuits. This paper uses CL transforms to introduce a new method for signal compression, leading to a reduction in bandwidth and therefore the possibility of higher throughput during transmission. Applicable to a wide range of signal types for all types of applications, compression via CL transforms is demonstrated on several binary and grayscale digital images. The results, compared with JPEG (a commonly used compression algorithm), show that this technique is able to achieve competitive levels of compression coupled with a limited introduction of errors, both desired aspects for the use of multimedia in mobile devices.

6579-05, Session 1

A predictive-transform (PT) sidelobe canceller for adaptive radar systems

E. H. Feria, College of Staten Island/CUNY

A novel predictive-transform (PT) sidelobe canceller is advanced to significantly alleviate dimensionality issues associated with sample matrix inverse (SMI) techniques that are used for adaptive radar systems. The technique is illustrated with knowledge-aided airborne moving target indicator (AMTI) radar subjected to severely taxing environmental disturbances. The signal to interference plus noise ratio (SINR) radar performance and complexity of the techniques compare quite well with that of other techniques such as multistage Wiener filtering, three bin Doppler and three pulse ADPCA.

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6579-06, Session 2

A prompt information retrieval system on handheld devices

Y. Huang, W. Yen, S. Lin, Tatung Univ. (Taiwan)

In this paper, we propose a prompt information retrieval system which aims to construct a mobility-learning activity under the up-to-date wireless technology. The system consists of a Tablet PC and PDAs with wireless networking capabilities. The PDA is equipped with a friendly retrieval interface and a good learning environment. In our system, users only need to click the buttons or input the keywords to retrieve bird information. Besides, users can discuss or share their information and knowledge via the wireless network. Our system saves bird information in four categories including "Introduction," "Images," "Sound," "Streaming Media," and "Ecological Memo". The integral knowledge helps users understand more about birds. Data mining and fuzzy association rules are applied to recommend users those birds they may be interested in. A streaming server on the Tablet PC is built to provide the streaming media for PDA users. By this way, PDA users can enjoy the multimedia from Tablet PC in real time without downloading completely. Finally, the system is a perfect tool for outdoor teaching and can be easily extended to provide navigation and touring services for national parks or museums.

6579-07, Session 2

Enhanced network management method for random IMS application servers

S. Kim, SAMSUNG Electronics Co., Ltd. (South Korea)

Enhanced network management is a model which is a combination of service and security systems in IMS environment. This system deals with a multi-channel queueing system and is designed for reliability and availability of IMS (Internet Multimedia Subsystem) application server. The security system in this research deals with a complex reliability system that consists of main unreliable servers, backups and repair facilities to repair the broken servers. Even though the results in this research are applied in IMS environments, the methods can be also applied to human resources, manufacturing processes and military operations. The tractable results are used for demonstration in the framework of optimization problems.

6579-08, Session 2

Detecting and isolating malicious nodes in wireless ad hoc networks

F. Li, S. A. Jassim, Univ. of Buckingham (United Kingdom)

Malicious nodes can seriously damage wireless ad hoc networks as a result of different actions such as packet dropping, [1]. Secure routes are defined as the shortest path to the destination-host while every node on the route is trusted even if not known. In this paper we shall review existing techniques for secure routing and propose to complement the route finding with creditability scores. Each node saves a credit-score list for its immediate neighbors. Each node monitors its neighbors and stores information about their behavior. Credits are reviewed and updated regularly. The level of trust in any route will be based on the credits associated with the neighbors belonging to the discovered route. Malicious nodes will have significantly lower credit scores than other nodes, due to packet dropping behavior, and can be avoided when looking for the best route.

We shall evaluate the performance of the proposed scheme by modifying our simulation system so that each node has a "credit list" of its neighbors which are updated according to the neighbors' behaviors. Secure route-finding algorithms will be based on the proposed mechanism. We shall conduct a series of simulations with and without the proposed scheme and compare the results.

[1] Fanzhi Li, Xiyu Shi & Sabah Jassim, "The Effects of Malicious Nodes on Performance of Mobile Ad Hoc Networks", Proceedings of SPIE 6250, May 2006

6579-10, Session 2

A sobering look at topology constraints in network sensor systems

G. J. Lenihan, Endevco Corp.

Although network sensor data acquisition, in the purest sense, is nothing more than remote telemetry data gathering; it has become more sophisticated by the desire for Plug and Play operation, as well as more sophisticated signal processing, less wires, denser packaging, and less power consumption.

Employing fewer wires has always been the desire of the industrial process control community, but has become an even greater mission of the air frame avionics community, since it reduces weight and inspection costs. The addition of Plug and Play facilitates ease of system integration, both at the user and supplier side.

The real challenge in the developing a network sensor system is the ability of it to perform near, or virtual real-time signal processing of many channels over a very tightly coupled physical topology, such as multi-drop or multi-cast; whereby the number of copper twisted pair are at a minimum.

This paper will highlight the challenges, as well as present system solutions for meeting the challenges of providing a compact network sensor that performs cogent data handling of sensor acquisition data with minimal wire.

6579-34, Session 2

Impact on routers performance to classify and condition real-time interactive multimedia traffic based on its PHB

S. Alsharif, Univ. of South Alabama

This paper presents a new method which enhances the quality-of-service (QoS) and hence the response time and queuing delay of real-time interactive multimedia over the Internet. A service class based on differentiated services mechanism has been developed. Evaluation of response time under different traffic conditions has been conducted via simulation. Specifically, the impact on routers performance at the boundary of a DS-enabled domain was evaluated using OPNET and the results are presented. Since audio and video traffic have different needs, priority schemes for different types of interactive multimedia traffic have been studied to provide control and predictable service, and therefore, better quality of service.

6579-11, Session 3

Switching theory-based steganographic system for JPEG images

R. C. Cherukuri, S. S. Agaian, The Univ. of Texas at San Antonio

Steganography is an art of hiding the very presence of communication by embedding message into harmless digital media. Hence, it can be technically referred as the means of secret communication. A steganographic should posses the following properties: a) good visual & statistical imperceptibility for the security of hidden communication b) sufficient payload for ensuring that a large quantity of data can be conveyed. Joint Photographic Experts Group (JPEG) is lossy compression, which means that the reconstructed image is very nearly the same as the original but not the exact duplicate

In this article, we present a new algorithm using the switching theory for hiding the secured information into a given JPEG-compressed images. In brief, the algorithm identifies the smooth, texture, edge block based for the relation between the between the “DC coefficient” and “AC coefficients”. This helps in analyzing the statistical nature of each block thus minimizing the distortion and enhancing the security of the embedded information. The embedding mechanism is switched based on the block’s statistical characteristics. Thus, the proposed system offers high capacity while simultaneously withstanding visual and statistical attacks.

The comparisons with the existing embedding algorithms such F5 and Model Steganographic algorithms are presented in terms of the maximum embeddable data and corresponding embedding efficiency. And robust of the proposed system in terms of RMS error and security issues with reference to existing stego detection algorithms will be presented.

6579-12, Session 3

New quantization matrices-based JPEG steganography

Y. O. Yildiz, K. A. Panetta, Tufts Univ.; S. S. Agaian, The Univ. of Texas at San Antonio

Modern steganography is a secure communication of information by embedding a secret-message within a “cover” digital multimedia without any perceptual distortion of the cover media, so the presence of the hidden message is indiscernible. Modern steganography has drawn broad interest in the past decade. The availability of various steganographic algorithms, together with existing digital multimedia and Internet, has made covert/secure communications a reality in this digital age. JPEG images are popular cover media due to their visual resilience to steganographic intrusion and JPEG’s wide-spread use. Recently, several transform based steganographic methods for data hiding in JPEG have been developed:

* J-Steg (1993, With maximum capacity of 13% and with embedding efficiency of 2),

* F5 (A.Westfeld, 2001, With maximum capacity of 13% and with embedding efficiency of 1.5),

* Outguess (N.Provos, 2001 With maximum capacity of 6% and with embedding efficiency of 1).

* Model Based Steganography (P.Sallee, 2001 With maximum capacity of 13% and with embedding efficiency of greater than 2).

This paper presents a JPEG steganographic algorithm using new quantization matrices. The goal of this study is to add additional security to a JPEG embedding algorithm while increasing secret message hiding capacity and make the detection of steganographic intrusion harder. The algorithm has been implemented in Matlab and shall be transformed to Symbian OS. Preliminary experimental results

* Offer better performance than well-known JPEG embedding algorithms like F5 and Model Based Steganography.

* Demonstrate that this method using different types of JPEG images is immune to statistical attacks.

6579-14, Session 3

A mesh-based robust digital watermarking technique against geometric attacks

Y. Huang, W. Yen, Y. Chen, Tatung Univ. (Taiwan)

One of the great challenges of the existing watermarking methods is their limited resistance to the extensive geometric attacks. Geometric attacks can be decomposed into two classes: global distortion such as rotations and translations and local distortion such as the StirMark attack. We have found that the weakness of multiple watermark embedding methods that were initially designed to resist geometric attacks is the inability to withstand the combination of geometric attacks. In this paper, the watermark is used in the gray-scale authentication image. We propose a robust image watermarking scheme that can withstand the geometric attacks by using local tri-mesh feature points. Our proposed method can re-synchronize the attacked images and is independent of the embedding and authentication process. The geometric invariant scheme is combined with the complementary modulation embedding strategy to enhance the resistance of geometric attacks. The experimental results verify that the proposed scheme is effective for geometric attacks.

6579-15, Session 3

Steganography anomaly detection using simple one-class classification

B. M. Rodriguez II, G. L. Peterson, Air Force Institute of Technology; S. S. Agaian, The Univ. of Texas at San Antonio

There are several security issues tied to multi-media when implementing the various applications in the cellular phone and wireless industry. One primary concern is the potential ease of implementing a steganography system. Traditionally, the only mechanism to embed information into a media file has been with a desktop computer. But, as the cellular phone and wireless industry matures, it becomes much simpler for the same techniques to be performed using a cell phone. In this paper two methods are compared that classify cell phone images as either an anomaly or clean, where a clean image is one in which no alterations have been made and an anomalous image is one in which information has been hidden within the image. An image in which information has been hidden is known as a stego image. The main concern in detecting steganographic content with machine learning using cell phone images or otherwise is that training targets specific embedding procedures to determine if the method has been used to generate a stego image. This leads to a possible flaw in the system when the learned model of stego is faced with a new stego method which doesn’t match the existing model. The proposed solution to this problem is to develop systems that detect steganography as anomalies, making the embedding method irrelevant in detection. The classification methods being compared are self organizing map (SOM) and Parzen-windows used for anomaly detection of steganographic content.

6579-16, Session 4

Data hiding based on Fibonacci-Haar transform

F. Battisti, Univ. degli Studi di Roma Tre (Italy); K. O. Egiazarian, Tampere Univ. of Technology (Finland); M. Carli, A. Neri, Univ. degli Studi di Roma Tre (Italy)

In this work, we propose a wavelet domain watermarking system based on the Fibonacci numbers. The generalized Fibonacci p-sequence is defined by A.P. Stakhov. Fibonacci 1-numbers are: 1, 1, 3, 5, 8, 13, 21, ..., that is the classical Fibonacci sequence. Using the Fibonacci p-sequence, it is possible to define a new transform domain, having a structure similar to the Haar wavelet decomposition with asymmetries in the subbands. Eskicioglu proposed a robust watermarking method based on SVD. In this contribution, we present the results obtained adopting that SVD method. The main feature of this algorithm is the possibility to embed four different marks or four versions of the same mark at the same time. The strength of each mark is "tuned" to the particular subband and to the l-sequence. Without knowing the actual value of the l parameter, it is not possible to determine the decomposition used, adding a further level of security to the system. For each l, a new decomposition is available; we are investigating the possibility to relate the values of l to the content of the image, to maximize the embedding capacity of the system while preserving the invisibility of the mark. The perceptual aspect of the proposed watermarking scheme have been considered and measured by evaluating both the PSNR and the WPSNR. To test the robustness of the embedding procedure, the watermarked image has been modified with different attacks and mark has been extracted. The main contributions of this approach are the use of the FHT for hiding purposes, the flexibility in data hiding capacity, l-th key-dependent secrecy of the used transform, and its robustness against the most commons attacks.

6579-17, Session 4

A chaotic cipher Mmohocc and its security analysis

X. Zhang, The Graduate Ctr./CUNY; L. Shu, Sichuan Univ. (China); K. Tang, The Graduate Ctr./CUNY

In this paper we introduce a new chaotic stream cipher Mmohocc which utilizes the fundamental chaos characteristics. The designs of its major components are discussed. The cryptographic properties of period, auto- and cross-correlations, and the mixture of Markov processes and spatiotemporal effects are investigated. The cipher is resistant to the related-key-IV attacks, Time/Memory/Data tradeoff attacks, algebraic attacks, and chosen-text attacks. The keystreams successfully passed two batteries of statistical tests and the encryption speed is comparable with RC4 and CTR-AES. We suggest that this cipher will be suitable for wireless and multimedia communication scenarios.

6579-19, Session 4

Reversible data hiding by exploiting structure information in block transform domain

H. Cai, S. S. Agaian, The Univ. of Texas at San Antonio

Traditional data hiding schemes tend to permanently distort the cover media while the hidden information is extracted. Despite minor or invisible in some circumstances, the distortion in the cover media cannot be allowed in a variety of important applications, such as military uses, medical diagnosis, law enforcement and remote sensing. Reversible or lossless data hiding methods have been developed to alleviate this problem by preserving the original information. The current reversible data hiding algorithms are developed in the spatial domain and transform domain using wavelet and the DCT. The limits of these methods exist, for example, they cannot achieve low distortion for high capacity embedding information. It is intriguing to develop new algorithms which can combine the advantages of spatial and transform domains.

In this paper, we present a novel reversible data hiding technique which utilizes the features of DCT and wavelet transforms to achieve low distortion and high capacity of information hiding. Our test data achieved 0-0.5 bpp embedding size for the grayscale images of 512x512x8 and the PSNR is higher than 50dB. In the presented algorithm, the wavelet multilevel structure and the corresponding DCT positions are chosen as the coefficients to embed the hidden information. This algorithm can be readily extended to JPEG/JPEG2000 format images. While the proposed reversible data hiding algorithm is applied to the still images, it is straightforward to be implemented to MPEG images.

6579-20, Session 5

Biometric authentication system with watermarking-based signatures protection

P. Campisi, E. Maiorana, A. Neri, Univ. degli Studi Roma Tre (Italy)

In the last few years we have witnessed a constant increase of the utilization of biometrics-based authentication systems due to several inherent advantages they offer over classic methods. However, in a biometric system the issue of data security and integrity is extremely critical. Encryption and watermarking are among the possible countermeasures to attacks. While encryption does not provide security anymore when the data are decrypted, watermarking can be used to secure and authenticate unencrypted data. Watermarking based securitization approaches involve embedding biometric information into the host data, which can be even biometric data. Some approaches embedding fingerprints into host images, face features into fingerprints, iris features into faces, have already been proposed. We propose a signature-based biometric system, using watermarking to keep secret some signature features in a signature image. A signature is intrinsically different from other commonly used biometric data. Being a behavioural biometric, it possesses dynamic properties as well as statistical characteristics, unlike fingerprints and faces, which can not be derived from a still signature image. The proposed method aims at embedding and keeping hidden the dynamic features and the overall statistical description, belonging to the user or to a certification authority, in a static representation of a signature, and using them for authentication. The used watermarking technique is tailored to images with sharpened edges, just like a signature picture, to obtain a robust method able to hide relevant data while keeping the original structure of the host figure, thus leading to low visibility of the embedded signal.

6579-21, Session 5

The problems of using ROC curve as the sole criteria in positive biometrics identification

Y. Du, C. S. Belcher, Indiana Univ.-Purdue Univ. Indianapolis; C. Chang, Univ. of Maryland/Baltimore County

Receiver operating characteristic (ROC) curve is popular used in biometrics identification. It a plot of the false acceptance rate v.s. false rejection rate. It is an objective measure of accuracy. Positive biometrics identification is one-to-many verification. ROC curve has been served as a "golden" criteria in measuring the accuracy of biometrics system for positive biometrics identification. However, in this paper, we will analyze the problems of using ROC curve as the solely criteria in positive biometrics identification. Such as the sample size will determine the effectiveness of the ROC curve. From the view of detection and estimation theory, ROC curve only took concerns of system variance, and would not be able to detect the system bias, which could result the big problem in accuracy. We will use iris recognition as an example. At the end, we will discuss the solution to solve these problems.

6579-22, Session 5

Wavelet-based face detection for face recognition

N. Al-Jawad, S. A. Jassim, Univ. of Buckingham (United Kingdom)

Wavelet transforms (WT) are widely accepted as an essential tool for image processing and analysis. Image and video compression, image watermarking, content-base image retrieval, face recognition, texture analysis, and image feature extraction are all but few examples. It provides an alternative tool for short time analysis of quasi-stationary

signals, such as speech and image signals, in contrast to the traditional short-time Fourier transform. The Discrete Wavelet Transform (DWT) is a special case of the WT which provides a compact representation of a signal in the time and frequency domain. In particular, wavelet transforms are capable of representing smooth patterns as well anomalies (e.g. edges and sharp corners) in images. In this presentation, we are focusing using wavelet transforms for facial feature detection.

There are a number of different wavelet image decomposition schemes. The most commonly used scheme is the pyramid scheme, which we have adopted. At a resolution depth of k, the pyramidal scheme decomposes an image I into 3k+1 frequency subbands (LLk, HLk, LHk, HHk,..., HL1, LH1, HH1). the lowest-pass subband LLk representing the k - level resolution approximation of the image I, while the other high frequency subbands highlight the significant image features at different scales. While the distribution of the LL coefficients is an approximation of that of the original image pixels, the coefficients in each of the other subbands have a Laplacian (also called generalised Gaussian) distribution. In this paper we shall propose a facial projection profile that exploits the statistical properties and parameters of the non-LL subbands to be used to locate and detect faces in images/videos. We shall present test results to measure the performance of these techniques using benchmarked audio-visual images/video.

6579-23, Session 5

Secure access control to hidden data by biometric features

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In this paper a data hiding system, driven by biometric data, is proposed. Data hiding is a technique commonly used to protect the copy right of digital information, by hiding some data (the mark) into the object to be protected (the cover data). To be effective, the embedding procedure should not be noticeable and should resist to the attacks aiming to remove the mark. One of the main vulnerabilities of the existing embedding systems is the public knowledge of the embedding domain. Fridrich has proposed a key-dependent basis function scheme to increase the overall security of the watermarking applications. Obviously, the secrecy of the key and the modality of its generation, are the core points of this augmented-security watermarking system. In this work, we propose the use of biometric data to generate the secret key. These values determine the particular basis functions that will be used to decompose the image. In particular, the Tree Structured Haar transform, based on non uniform sampling of the time interval splitting, has been chosen as transform domain. Among all the biometric techniques, for this experiment we have selected the fingerprint. A fingerprint is made of a series of ridges and furrows on the surface of the finger. The uniqueness of a fingerprint can be determined by the pattern of ridges and furrows as well as the minutiae points. Minutiae points are local ridge characteristics that occur at either a ridge bifurcation or a ridge ending. A subset of minutiae is used to generate the key.

6579-24, Session 5

Log-polar-based framework for mobile vehicle tracking with road follower

P. Melnyk, R. A. Messner, Univ. of New Hampshire

A new computationally efficient framework for vehicle tracking on a mobile platform is proposed. The principal component of the framework is the log-polar transformation applied to video frames captured from a standard camera. The log-polar transformation provides two major benefits to real-time vehicle tracking from a vehicle moving along a single or multi-lane road. First, it significantly reduces the amount of data required to be processed since it collapses the original Cartesian video frames into log-polar images with much smaller dimensions. Second, the log-polar transformation is capable of mitigating perspective distortion due to its scale invariance property. This second aspect is of interest for vehicle tracking because the target vehicle appearance is preserved for all distances from the observer (camera). This works however only if the center of log-polar transformation is coincident with the vanishing point of perspective view. Therefore, a road following algorithm is proposed to keep the center of log-polar transform on the vanishing point at every video frame compensating for the carrying vehicle movements. Since the algorithm is intended to be used in the mobile embedded devices, it is developed to achieve both mathematical simplicity and algorithmic efficiency while avoiding computationally expensive mathematical functions. The use of trigonometric and exponential functions is minimized comparing to the log-Hough transform traditionally used in log-polar space. This new algorithm focuses on straight radial line fragments, thus shifting its mathematical engine to the linear equations' domain.

6579-25, Session 6

Human visual-system-based image enhancement

E. J. Wharton, K. A. Panetta, Tufts Univ.; S. S. Agaian, The Univ. of Texas at San Antonio

Many current techniques for image enhancement perform poorly when the image contains regions of improper illumination or are over/under exposed.

This paper presents a method of image enhancement using an adaptive thresholding method based on the human visual system. We utilize a number of different enhancement algorithms applied selectively to the different regions of an image to achieve a better overall enhancement than applying a single technique globally. The presented method is useful for images that contain various regions of improper illumination. It is also practical for correcting shadows. This thresholding system allows various enhancement algorithms to be used on different sections of the image based on the local visual characteristics. It further allows the parameters to be tuned differently for the specific regions, giving a more visually pleasing output image.

We demonstrate the algorithm and present results for several high quality images as well as lower quality images such as those captured using a cell phone camera. We then compare and contrast our method to other state-of-the-art enhancement algorithms.

6579-26, Session 6

Wavelet library for constrained devices

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Wavelet transforms are becoming an essential tool of image/video processing and analysis. This paper is concerned with core wavelet-base image processing/analysis tasks that are suitable for implementation on constrained devices and or demanding conditions, such as mobile phones or other similar devices. These devices have in most cases limited memory and no support for floating-point calculations plus the fact that they should provide a real-time response.

Different applications benefit more from different wavelet transforms, different decomposition schemes, even different subbands. Yet the demands are the same in terms of speed and efficiency. Taking into account the different combinations of several computing environments and context demands we designed and developed a wavelet library called "Heat Wave" which is based on using the lifting scheme to create integer wavelet coefficients within fixed bit length range.

We will focus on two different requirement conditions and test the performance of the Heat Wave library. The first condition was where a fast biometric verification model was required and the second condition relates to video compression where memory is severely limited. Further more each condition we shall present test results for the performance of the various wavelets in the Heat Wave library in terms of speed of processing and efficiency ratios. In the case biometrics, efficiency ratios are based on verification accuracy and compression rates.

6579-27, Session 6

Efficient ROI recognition-based CBIR for large database with parallel distributed RSOM

S. Xia, X. Lv, J. Liu, W. Hu, National Univ. of Defense Technology (China)

We humans describe an image by extracting subjective concepts like sky, clouds, fowers, cars, etc. This however cannot be done by a contemporary CBIR system, where instead the image is interpreted in the form of primitive features. These low level features are computed from pixels or patches. There is a gap between these low-level representations and the high-level concepts, popularly known as the semantic gap. In order to bridge this gap, we propose a novel region based indexing and retrieval scheme.

First thousands of images are segmented into a galaxy of meaningful ROI's, called image-primitive. Thereafter, all image-primitives are standardized as image-key-words. Each image primitive, with its low level feature vector being extracted, is combined with one or more basic semantic concepts. Then a Rescursive SOM(RSOM) tree , a special kind of hierarchical cluster tree and composed of multi-SOM nets, can be supervisingly trained. In such an RSOM tree, the feature vector of each image-primitive is recognized as one or more results, namely the semantic concepts, meanwhile they are separately associated with one or multi- image documents. Finally, because an RSOM tree incorporates the cluster representation into the index structure, it provides a practical solution to index clustered data sets and supports the retrieval of nearest-neighbors effectively and efficiently without having to linearly search a high-dimensional large database of ROI-features. Consequently, all images are converted to text documents containing multi-keywords, so they are further indexed and retrieved using modifed elastic bucket tries.

As a complementarity, considering the properties of a large and dynamic database, and the structure characteristics of the RSOM tree, an incremental RSOM tree-based distributed parallel clustering and recognizing algorithm was advanced.

The performance of the proposed scheme has been tested on large image database.

6579-28, Session 6

Interactive and adaptive image segmentation algorithm for CBIR

X. Lv, S. Xia, National Univ. of Defense Technology (China)

Image segmentation is critical for content-based image retrieval(CBIR). When an image is automatically segmented with traditional region-growing method, a satisfactory performance is usually not guaranteed. Since humans are the ultimate users of most CBIR systems, it is important to obtain segmentations that can be used to organize image contents semantically, according to categories that are meaningful to humans. As a state of the art, it is very difficult to reach this goal automatically. Since we humans can quickly capture the information of an image, this can be a kind of very reliable prior information. By utilizing this in a human-machine interactive way, a new approach that is based on low-level features for color and texture, is proposed. It combines knowledge of human perception in order to segment natural scenes into perceptually/semantically uniform regions.

The proposed approach is based on two types of spatially adaptive low-level features. The first describes the local color composition in terms of spatially adaptive dominant colors, and the second describes the spatial characteristics of the grayscale component of the texture. In the procedure of segmentation, the morphological operator dilation is used to fill inner small holes in segmented object regions and morphological erosion to remove some wrong or unuseful edges, the image enhancing technique is also used to enhance the homogeneity of a single object region and the gap between two adjacent object regions in visual feature. Together with as less human operations as possible, the proposed algorithm used to obtain robust, accurate segmentations. The resulting segmentations convey semantic information that can be used for CBIR. The performance of the proposed algorithms is demonstrated in the domain of photographic images.

6579-13, Poster Session

Fourier phase domain steganography: phase bin encoding via interpolation

E. L. Rivas, S. S. Agaian, The Univ. of Texas at San Antonio

The art of writing in cipher, or steganography, has been used for centuries in various media including in written form and, more recently, in audio and image electrical signals. Most of the existing modern steganographic methods can be classified into two major classes, time domain and transform domain techniques. Any steganographic technique must achieve a balance between the following three primary constraints:

1) Perceptibility of the secret message within the carrier

2) Robustness to host perturbation or distortion

3) Message bandwidth or density

One of the most broadly covered techniques is that of the Least Significant Bit, or bit-plane, encoding. While this technique allows a high message bandwidth and randomizes the signal to appear as noise, thereby decreasing perceptibility, it can also be very sensitive to attacks.

In this paper, we present a new steganographic technique for hiding secured data into the phase coefficients in the transform domain. In brief, the cover is converted to the Fourier domain and the target phase bin is replaced by a value which itself is the linear interpolation of the two neighboring bins. Then a phase shift is added to or subtracted from the interpolated value. The motivation of this process is to minimize the error induced by bin manipulation while maintaining a system that is robust to distortion due to audio compression and noise. Comparison of error rates due to noise and audio compression is made with a similar technique, relative phase encoding.

6579-30, Poster Session

A robust digital watermarking scheme by use of integral imaging technique

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A novel integral imaging-based 3-D digital watermarking scheme is presented. In the proposed method, an elemental image array(EIA) obtained by recording the rays coming from a 3-D object through a pinhole array in the integral imaging system is employed as a new 3-D watermark. This EIA composes of a number of small elemental images having their own perspectives of a 3-D object, and from this recorded EIA various depth-dependent 3-D object images can be reconstructed by using the computational integral imaging reconstruction(CIIR) algorithm. This 3-D property of the EIA watermark can make available a robust reconstruction of the watermark image even though there are some data losses in the embedded watermark by attacks. To show the robustness of the proposed scheme against attacks, some experiments are carried out and its results are discussed.

6579-31, Poster Session

OFDM securitization by phase carrier random offset

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In recent years, ultra-wideband technology has attracted an always increasing interest both from the academic community and industry. The UWB radio is characterized as a signalling technique with ultra-wide signal bandwidth and restricted spectral power density. While Impulse Radio UWB (IR-UWB) is obtained by the transmission of ultra-short impulses, Multi Band UWB (MB-UWB) is based on Orthogonal Frequency Division Multiplexing (OFDM) technology.

In this paper we propose an OFDM UWB system with a physical layer built-in security management algorithm. In brief, M of the N used OFDM frequencies, are used to transmit the data, while the remaining N-M sub-bands carry the data encrypted-hash version. An L-PSK (Phase Shift Keyng) modulation is adopted on each career.

The m-th data-constellation, $1 \leq m \leq M$, changes its starting phase phi_m every symbol time T while all the encrypted-hash constellations have theta_m=0 M+1≤m≤N. The phase-hopping sequence {phi_1, phi_2, ..., phi_m} for the k-th symbol period, is decided by the encrypted-hash bit transmitted during the (k-1)-th time T. Thus the data during the first period T must be transmitted without any hopping-sequence.

The encrypted-hash MD2 (128 bit Message Digest) algorithm works like a FEC (Forward Error Correction), and at the same time provides a robust data protection. Moreover, since the constellation keys change very rapidly, they are also difficultly detectable by a hypothetic attacker.

Simulations results verify the superior performance of the proposed approach, also in terms of BER, due to the encrypted hash, with respect to a standard PSK-OFDM system.

6579-32, Poster Session

Quantify similarity with measurement of enhancement by entropy

E. A. Silva, K. A. Panetta, Tufts Univ.; S. S. Agaian, The Univ. of Texas at San Antonio

In this paper we show that a modified version of the measurement of enhancement by entropy (EME) can be used as an image similarity measure, and thus an image quality measure. Until now, EME has generally been used to measure the level of enhancement obtained using a given enhancement algorithm and enhancement parameter. The similarity-EME (SEME) is based on the EME for enhancement. Image similarity assessment is closely related to image quality assessment in that quality is based on the apparent differences between the degraded image in question and the original, unmodified image. Automated evaluation of image compression systems relies on accurate quality measurement. The importance of high quality compression systems increases as the applications for such systems increase, e.g. in medical imaging. Current algorithms for measuring similarity include mean squared error (MSE), peak signal-to-noise ratio (PSNR), and structural similarity (SSIM). We will compare SEME to existing measures over a set of images judged by humans.

6579-33, Poster Session

The evolution of ambient learning and ambient learning in a mobile world

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During the last years a lot of new technologies for distance and e-learning have been developed. Several new terms and notions have been created: d-learning, e-learning, m-learning, ubiquitous learning, ambient learning, ... The aim of this paper is to give an overview of these developments and analyse the terms carefully. Furthermore, an overview of the new developments and the new paradigms in e-learning that result in future ambient learning in a mobile world is given.